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Ecological and Economic Analyses of Marine Ecosystems in The Bird's Head Seascape, Papua, Indonesia: II

**ECOLOGICAL AND ECONOMIC ANALYSES OF
MARINE ECOSYSTEMS IN THE BIRD'S HEAD
SEASCAPE, PAPUA, INDONESIA: II**

*edited by
Megan Bailey and Tony J. Pitcher*

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DIRECTOR'S FOREWORD

This report being a sequel to '*Ecological and Economic Analyses of Marine Ecosystems in the Bird's Head Seascape, Papua, Indonesia I*' (2007), the first question we should ask is what the original report was, in terms of sequence. We do know that it was not a prequel: this clearly was '*Historical Ecology of the Raja Ampat Archipelago, Papua Province, Indonesia*', i.e., FCRR 14(7), published in 2006.

Thus, a new name (technically a retronym) is needed for the original which spawns the sequel(s). My suggestion is 'urquel', from 'ur', i.e., 'first' or 'original' in German, and Quell(e), a source, also in German, which should satisfy philologists, Germanophiles and cerevisaphiles.

Now to the sequel. The nice thing about models is once you have them they become attractors for more and better data. This is the case here: an ecosystem model has been generated for the marine part of Raja Ampat, in spite of this being one of the most remote regions of the world, as elaborated upon in the ...urquel.

Now, having this model, it has become possible for the authors of the four papers in this report to generate another round of hypotheses that they can test and scenarios that they can run – again: all of this in an area that a few years ago was supposed to be devoid of data and not amenable to study using ecosystem modeling. This is fantastic.

I am also pleased that the questions and scenarios that are run are not exclusively biological ones, i.e., 'what would happen to predators and prey if species x were fished more heavily'. Rather economic questions are being posed of the management implications of various scenarios, which are obviously the ones that will appeal the most to policy-makers.

EXECUTIVE SUMMARY

In an era of declining fish stocks and habitat degradation, ecosystem-based management (EBM) is considered an alternative approach to promote the sustainability of marine resource use. The regency government in Raja Ampat, Papua, Indonesia, is considering implementing an EBM approach to marine management in their area. Raja Ampat is part of the Bird's Head Functional Seascape (BHS), an area of high marine biodiversity. Under a grant from the David and Lucile Packard Foundation, Conservation International (CI), The Nature Conservancy (TNC), World Wildlife Fund (WWF), the State University of Papua (UNIPA) and researchers from the Fisheries Centre at the University of British Columbia (UBC) have come together to assist in the EBM initiative for the BHS, and specifically for Raja Ampat. This research report presents materials prepared by the Fisheries Ecosystems Restoration Research group (FERR) and the Fisheries Economics Research Unit (FERU) at the Fisheries Centre at UBC, and is the third research report to be published from this project¹.

The first paper highlights new ecosystem-based modelling developed by the FERR group using Ecopath with Ecosim (EwE) software, a quantitative tool used to simulate ecosystem interactions. A preliminary working model was published in an earlier research report (see footnote below), but several improvements are documented here, including local data from stomach sampling and reef health monitoring surveys, as well as a new diet algorithm and estimates of the total Raja Ampat fish catch including illegal, unreported and unregulated components (IUU). A new departure in this project has been the discussion, acquisition and use of extensive local data required by the modellers from field sampling and interviews carried out by the field teams. The final EwE model, tuned to this local data, has been used to examine a series of realistic EBM policy scenarios suggested by the project partners and stakeholders in Indonesia. As part of the quantitative management advice that may underpin the implementation of EBM in Raja Ampat, the detailed results are presented here and in six manuscripts that have been accepted, submitted, or are in preparation for peer-reviewed journals (see Appendix E).

The second paper in this report presents two small studies undertaken by FERU members as part of the BHS economic sub-project. The first study compares the value of Raja Ampat's main economic sectors through time by applying two different methods of discounting: conventional and intergenerational. This simple analysis demonstrates that under conventional discounting, management choices favouring marine conservation may not seem cost-effective due to short-term costs. The second study in this paper presents the outcomes of a discussion on possible development options in Raja Ampat. The interview was intended to highlight the interaction among different economic sectors in Raja Ampat, in hopes of eventually contributing to a quantitative model linking sectors.

The third paper in this report presents a game-theoretic model supporting the implementation of EBM by examining the possible incentives that could be used to shift fisher effort away from destructive fishing gears in Raja Ampat. There is virtually no monitoring and enforcement currently in place in Raja Ampat, and fishers worry that the use of cyanide and explosives to catch grouper and snapper may be negatively affecting reef health and fish populations. The elimination of blast fishing could bring economic benefit to the area, but the high profitability of the cyanide fishery appears to be a barrier to economic benefits through the elimination of the gear.

The fourth section of this report evaluates the expected progress from the successful implementation of the BHS EBM project. The authors contend that a considerable improvement in management might be expected in Raja Ampat as a result of the EBM work.

The final contribution in this report describes a new modelling tool called EcoLocator for use with EwE that displays the biomass distribution of species at highly spatial resolution. EcoLocator was developed specifically for the Bird's Head EBM project, but is generalized for use with any EwE model.



Megan Bailey and Tony Pitcher
Vancouver, Canada, May 2008

¹ The first two contributions were: Palomares, M.L.D., Heymans, J.J., 2006. Historical Ecology of the Raja Ampat Archipelago, Papua Province, Indonesia. Fisheries Centre Research Reports 14(7): 64 pp., and Pitcher, T.J., Ainsworth, C.A., Bailey, M. (Eds.), 2007. Ecological and Economic Analyses of Marine Ecosystems in the Bird's Head Seascape, Papua, Indonesia: I. Fisheries Centre Research Reports 15(5): 184 pp.

CHAPTER 1

ECOSYSTEM SIMULATION MODELS OF RAJA AMPAT, INDONESIA, IN SUPPORT OF
ECOSYSTEM-BASED FISHERIES MANAGEMENT¹

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ABSTRACT

This report describes synoptic ecosystem models employing the Ecopath with Ecosim (EwE) framework for the Raja Ampat archipelago in Eastern Indonesia and we provide examples of their use in support of ecosystem-based fisheries management (EBFM). This is the final technical report for the Bird's Head Seascape Ecosystem-Based Management project (BHS EBM) from the Fisheries Ecosystems Restoration Research (FERR) group at the UBC Fisheries Centre. The project is a David and Lucile Packard Foundation-funded initiative jointly among The Nature Conservancy (TNC), Conservation International (CI), World Wildlife Fund (WWF) and other partners in Indonesia, with two UBC Fisheries Centre teams providing modelling (FERR) and economics (FERU) support since its inception in 2005. This document supports a number of peer-reviewed publications, in press, submitted and in preparation, which answer specific EBFM research questions posed by scientific partners in Indonesia.

By integrating project data gathered in the field by CI and TNC, we improve on the preliminary models described in 2007 in earlier reports. Locally-gathered information has been used to tune model parameters: this includes present biomass (from dive transects), fisheries (from overflight data), fishery catches (from resource surveys), fish diets (gut content analysis), local ecological knowledge about fisheries and habitats from interviews of artisanal and commercial fishing operators (from participatory rural appraisal and resource use surveys). In two cases (fish diets and fishers' perceptions of biomass change) field surveys requested by the modelling group have been successfully carried out by TNC/CI teams; this is probably the first time in the world that those constructing ecosystem models have had the opportunity to interact with field teams in this way. We present the methodology used to process this field data into a form useable by the EwE models, and we present the parameterization and dynamic functioning of the models in a form for review. Model description in this report includes the balancing of the static Ecopath model, and tuning of the dynamic Ecosim model to time series catch estimates utilizing a novel assessment of illegal and unreported catch (previously reported), relative biomass estimates from fisheries data, and primary production trends. We also present an equilibrium analysis to demonstrate the current exploitation status of stocks in Raja Ampat. The full project team provided a final check on the models and identified EBFM scenarios for investigation at a workshop in Bali, June 2007.

EBFM scenarios investigated with the models at the request of the project team are the likely ecosystem effects of: changes in the anchovy fishery after complete cessation, under limited quota, and under increased fishing; restricting the commercial exploitation of groupers; excluding all net fisheries for reef fish; blast fishing increased or kept at the status quo; increases in the tuna fishery; and Hawksbill turtles restored to former abundance. We also examine how an increase in fishing may affect the local ecology and economy, and attempt to examine what the unexploited ecosystem of Raja Ampat might have looked like. We conclude with a summary of forthcoming peer-reviewed articles, and suggestions for future ecosystem research in support of EBFM in the Bird's Head Seascape.

¹ Cite as: Ainsworth, C.H., Varkey, D.A., and Pitcher, T.J., 2008 Ecosystem simulation models of Raja Ampat, Indonesia, in support of ecosystem-based fisheries management. Pages 3-124 in Bailey, M., Pitcher, T.J. (Eds.) *Ecological and Economic Analyses of Marine Ecosystems in the Bird's Head Seascape, Papua, Indonesia: II*. Fisheries Centre Research Reports 16(1): 186 pp.

INTRODUCTION

OVERVIEW

This is the final technical report prepared for the Bird's Head Seascape Ecosystem-Based Management (BHS EBM) project by the Fisheries and Ecosystems Restoration Research (FERR) group at the Fisheries Centre, University of British Columbia. This document builds on the first technical report (Ainsworth et al. 2007), which provided preliminary Ecosim models for Raja Ampat and demonstrations of model behaviour. Here we finalize five EwE and Ecospace models of the Raja Ampat archipelago in Papua, Indonesia including present-day models for Kofiau Island, SE Misool Island and the Dampier Strait, together with models for Raja Ampat in 1990 and 2005. The models have been revised to include additional data and findings emerging from field studies in the BHS EBM project by partners in Indonesia (The Nature Conservancy (TNC), Conservation International (CI) and World Wildlife Fund (WWF)). Here, we present the methods used to process field data into a form usable by the models, and we present the final models' parameterization and dynamic functioning in a form for review. This technical report will support other peer-reviewed contributions investigating questions of importance to ecosystem-based fisheries management (EBFM) in Raja Ampat and other coral reef ecosystems of the world.

THE RAJA AMPAT ISLANDS

The physical system

The Raja Ampat (RA) archipelago extends over 45,000 km² and consists of approximately 610 islands including the 'four kings', Batanta, Misool, Salawati and Waigeo (COREMAP, 2005). Erdmann and Pet (2002) provide an overview of the major oceanographic features occurring in the Raja Ampat archipelago, while Firman and Azhar (2006) provide a detailed description of the geology, physical oceanography, coastal biology and resource use patterns in Raja Ampat (including mining, forestry and fishing sectors). Aerial photographs produced by the BHS EBM project are available online at www.rajaampat.org or on DVD². The area encompasses a variety of marine habitats, including some of the most biodiverse coral reef areas on Earth (Donnelly et al., 2003; McKenna et al., 2002a). It is estimated that RA possesses over 75% of the world's known coral species (Halim and Mous, 2006).

Fisheries

Skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*) and Spanish mackerel (*Scomberomorus commerson*) are pursued in commercial pole and line, trolling and purse seine fisheries. These constitute the majority of commercial catch, but export fisheries exist for high value reef fish products like groupers, snappers and Napoleon wrasse. Indonesia is known to have suffered a rapid depletion in recent decades of near-shore fish stocks and coral reef animals, especially sharks, turtles, tunas and reef-associated fish (Tomascik et al., 1997). Some of the depletions can be attributed to the sharp increases in price received for export products between 2000 and 2002, which was the result of the Asian economic crisis and the consequent strengthening of foreign currencies, particularly the US dollar, with respect to the Indonesian Rupiah³.

By assembling available fisheries statistics, Ainsworth et al. (2007) were able to confirm that there has been a marked decline over the last 15 years in the catch-per-unit-effort (CPUE) in many targeted stocks. Despite the well-known inadequacies of CPUE data as an index of relative abundance (e.g., Beverton and Holt, 1957; Gulland, 1974; Hilborn and Walters, 1992), the especially sharp decline since 1990 allows us to make two conclusions regarding the current status of exploited marine resources in Raja Ampat. The first conclusion is that some targeted stocks have likely declined; the second conclusion is that stocks were, until at least the 1990s, in a very lightly exploited state. Only a lightly exploited ecosystem would be capable of such a drastic reduction in the catch rate, in the neighbourhood of an order of magnitude since 1990 for many species, barring any massive increase in fishing effort over that period.

² Contact: Joanne Wilson, TNC CTC. Jl Pengembak 2, Sanur, Bali, Indonesia joanne_wilson@tnc.org.

³ Christovel Rotinsulu. CI. Jl.Gunung Arfak.45. Sorong, Papua, Indonesia, personal communication.

A new EBFM initiative

Challenges to management of coral reefs in Raja Ampat, and elsewhere, now centre on the serious issues of overexploitation (Pandolfi et al., 2003), destructive fishing practices like cyanide fishing and blast fishing (Erdmann and Pet-Soede, 1996; Pet-Soede and Erdmann, 1998), land-based pollution (McCulloch et al., 2003; Kaczmarek et al., 2005), climate change (Hughes et al., 2003; Harvell et al., 2002) and outbreaks of corallivores such as the crown of thorns starfish (*Acanthaster planci*), a frequent source of mass mortality in corals (Chesher, 1969). However, the Raja Ampat Regency government has shown initiative to protect the marine environment and serve as many as 24,000 commercial and artisanal fishers who rely on it (Dohar and Anggraeni, 2007). For example, a decree by the Bupati (Regent) in 2003 declared Raja Ampat to be a Maritime Regency and helped to establish a new network of marine reserves in 2006 covering more than 650,000 hectares of sea area and 44% of reef area. The fisheries office (Departemen Kelautan dan Perikanan, DKP) has further pledged to declare as much as 30% of the marine area protected in the Regency, exceeding the national goal of 20%⁴.

To facilitate the adoption of an EBFM strategy, The Nature Conservancy (TNC), Conservation International (CI), World Wildlife Fund (WWF) and the Fisheries Centre at the University of British Columbia (UBC) entered into comprehensive program of study with the goals of increasing the body of scientific knowledge in Raja Ampat and providing scientific advice to management bodies. The project is rare in that elements of the field sampling have been designed especially to support the ecosystem modelling, and there has been a strong, continuous interaction between modellers and field researchers. The contribution made in this report provides a foundation for the continued analysis of trophic dynamics in Raja Ampat through a dynamic model. The models have been constructed to be applicable to a variety of research questions, and can be readily updated as new information becomes available.

TROPHODYNAMIC MODELLING

The trophodynamic (food web) Ecopath with Ecosim (EwE) models used in this study are constructed at various spatial scales to investigate scientific research questions of interest to EBFM, and especially to answer specific questions fielded by investigators in the BHS EBM project, the Raja Ampat Regency fisheries bureau, and other knowledgeable academics. The Raja Ampat model encompasses the greatest area, and includes the 'four kings' (the islands Batanta, Misool, Salawati and Waigeo) as well as shelf and oceanic in-flow areas. It accounts for only a fraction of the total area for the Bird's Head Seascape but we chose to focus our attention on this area because most of the scientific studies conducted for the BHS EBM project are centred here, with the main exception of the turtle nesting habitat study conducted by WWF in Cenderwasih Bay and nearby regions. Also, we assume that the data repositories in Sorong will reflect the recorded fishery activities of the immediate Raja Ampat area most strongly, even though many of the data we received are aggregated by area. Finally, the expertise held by project members and scientific partners relates most strongly to the area of Raja Ampat.

Scientific questions regarding the interrelation of functional groups and fisheries are investigated using the large Raja Ampat model in order to obtain a synoptic view of ecosystem functioning and the impact of management scenarios on industry, while models of smaller areas comprising Kofiau Island, Southeast Misool Island and the Dampier Strait (hereafter called the sub-area models) are used to investigate particular research questions requiring a degree of spatial resolution or site specificity. The sub-area models allow us to make useful predictions with respect to the outcomes of spatial management options, not limited to the placement and configuration of no-take areas and fishery restricted zones such as in marine protected areas (MPAs).

BHS EBM PROJECT DATA INTEGRATION

Much of the data integrated here into the EwE models comes from the diverse studies in the BHS EBM project. These include reef health monitoring biomass and coral coverage estimates from SCUBA and

⁴ Becky Rahawarin. Kepala Dinas Perikanan dan Kelautan, Raja Ampat. Jl. A. Yani, Kuda laut, Sorong, Papua, personal communication.

snorkelling diving transects, local ecological knowledge and fisheries knowledge from interviews of artisanal and commercial fishing operators, fisheries statistics and other data from various literature sources collected by project members and UBC researchers (Table 1.1.). The methods section provides a more detailed record of BHS EBM data sources and data processing methodology. Additional sources of information from published studies and databases provided a foundation for the models in Ainsworth et al. (2007). BHS EBM project outputs that could not be integrated into the models are discussed along with options for future study in the discussion section.

Table 1.1 BHS EBM project data used in the EwE models.

BHS EBM Output	By	Use	Reference
<i>Quantitative data</i>			
Reef health monitoring	TNC, CI	Ecopath parameterization; biomass and coral coverage (all models)	Kofiau results: (A. Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. Email: amuljadi@tnc.org. Unpublished data) SE Misool results: (M. Syakir. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. Email: msyakir@tnc.org. Unpublished data) Waigeo results (not used) (M. Erdi Lazuardi. CI. Jl Arfak No. 45. Sorong, Papua, Indonesia 98413. Email: erdi@conservation.or.id. Unpublished data) Protocol: Mous and Muljadi (2005); Pratomo and Setiawan (2006).
Local ecological knowledge interviews	CI	Bzero calculations for Ecosim. Article in preparation (shifting baselines), Time series biomass for Ecosim	Data collection: C. Rotinsulu. CI. Jl.Gunung Arfak.45.Sorong, Papua, Indonesia. Email: chris@conservation.or.id. Unpublished data. Data processing using fuzzy logic: Ainsworth et al. (2008) Protocol: Ainsworth et al. (2007; Appendix C1)
Resource use survey	TNC	Illegal, unreported and unregulated (IUU) catch (Varkey et al., in prep.) Catch estimation for Raja Ampat	A. Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. Email: amuljadi@tnc.org. Unpublished data. This report.
Fish gut content analysis	CI	Ecopath diet matrix	Data collection: C. Rotinsulu. CI. Jl.Gunung Arfak.45.Sorong, Papua, Indonesia. Email: chris@conservation.or.id. Unpublished data. Data processing: This manuscript. Protocol: Ainsworth et al. (2007; Appendix C2)
Coastal rural appraisal	TNC, CI	Catch data used in Ecopath catch matrix. Fishing areas used to set Ecospace habitat types.	J. Wilson. TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia, 80228. Email: joanne_wilson@tnc.org
Participatory rural appraisal	TNC, CI	Human population density to set sub-area model catch ratios	C. Rotinsulu. CI. Jl.Gunung Arfak.45.Sorong, Papua, Indonesia. Email: chris@conservation.or.id. Unpublished data.
Socioeconomic valuation report	CI	Ecopath commodity price and fishing cost matrices.	Dohar and Anggraeni (2007)
Socioeconomic evaluation of anchovy fishery	UBC	Ecopath catch matrix	Bailey et al. (2008)
Coastal rural appraisal 2004	TNC	Ecopath catch matrix; Ecospace habitats; human population density to set sub-area model catch ratios	Anon. (2004); Protocol: Mous (2005)

Table 1.1 cont.

<i>Qualitative data</i>			
MARXAN analysis	TNC	MPA testing locations for Ecospace	M. Barmawi. TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia, 80228. Unpublished data. Contact: joanne_wilson@tnc.org.
Aerial photography	TNC	Ecospace habitat	Barmawi, 2006.; Online interactive map: www.rajaampat.org; DVD photographs (M. Barmawi. TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia, 80228. Unpublished data. Contact: joanne_wilson@tnc.org).
CI Resource atlas for the Regency of Raja Ampat	CI	Ecospace habitat	Firman and Azhar (2006)
Perception monitoring	TNC	Supporting literature	Halim and Mous (2006) Protocol: Halim et al. (2005)
Historical ecology	UBC	Supporting literature	Palomares and Heymans (2006)
<i>Previous work</i>			
REA report 2002	TNC	Ecopath biomass	Donnelly et al. (2003)
Rapid Assessment 2002	CI	Ecopath biomass	McKenna et al. (2002)

MATERIALS AND METHODS

ECOPATH WITH ECOSIM

To understand the impact that fisheries have in the coral reef ecosystem of Raja Ampat, we have used the Ecopath with Ecosim (EwE) suite of modelling tools. Although ecosystem models such as EwE offer no panacea, they can provide a new perspective on stock dynamics and can be used to explore unintuitive interactions that may have strong effects on the functioning and resilience of the ecosystem. EwE can be used to examine predator-prey feeding interactions, foraging behaviour, several types of fisheries impacts and abiotic effects such as climate. Although EwE models have been made for areas all over the world (Christensen and Walters, 2005), the models may be a most useful tool to EBM in a highly interconnected marine ecosystem such as a coral reef, where complex trophic interactions can be expected to have a significant and compounding effect on stocks. In fact, Ecopath was invented first to represent a coral reef ecosystem (Polovina, 1984). The presence of mixed fisheries in coral reef ecosystems also makes it impossible to manage stocks effectively as discrete entities, but managing stocks on the basis of multi-species functional groups (i.e., groups of species with similar life history characteristics and trophic niches) is a suitable alternative.

Ecopath (Polovina 1984, Christensen and Pauly 1992) operates like a thermodynamic accounting system. It tracks the biomass or energy flow rates in and out of functional groups for one instant in time as instantaneous fluxes. Mass balance is maintained in functional groups according to Equation 2.1.

$$B_i \cdot (P/B)_i = Y_i + \sum_{j=1}^n B_j \cdot (Q/B)_j \cdot DC_{ij} + E_i + BA_i + B_i (P/B)_i \cdot (1 - EE_i) \quad (2.1)$$

where,

B_i and B_j are biomasses of prey (i) and predator (j), respectively;

P/B_i is the production/biomass ratio;

Y_i is the total fishery catch rate of group (i);

Q/B_j is the consumption/biomass ratio;

DC_{ij} is the fraction of prey (i) in the average diet of predator (j);

E_i is the net migration rate (emigration – immigration);

BA_i is the biomass accumulation rate for group (i);

EE_i is the ecotrophic efficiency; the fraction of group mortality explained in the model, while consumption (Q) for a predator group is calculated as in Eq. 2.2.

$$B \cdot (Q/B) = B \cdot (P/B) + (1 - GS) \cdot Q - (1 - TM) \cdot P + B(Q/B) \cdot GS \quad (2.2)$$

where GS is the proportion of food unassimilated; and TM is the trophic mode expressing the degree of heterotrophy (0 and 1 represent autotrophs and heterotrophs, respectively and intermediate values represent facultative consumers).

Ecopath solves a set of n simultaneous linear equations of the form in Eq. 2.1, where n represents the number of functional groups in the model. The program therefore serves as a framework on which to place piecemeal information about the ecosystem and judge the compatibility of the available biological information under the constraints imposed by the thermodynamic requirements of both predator and prey. Through the assumption of mass balance, we can infer the unknown properties of the ecosystem based on the available data, which is extremely helpful in a data limited study area like Eastern Indonesia.

Ecosim (Walters et al. 1997) adds temporal dynamics, describing the biomass or energy flux between compartments through coupled differential equations derived from Eq. 2.1. The set of differential equations is solved using the Adams-Bashford integration technique. Biomass dynamics are described by Eq. 2.3.

$$\frac{dB_i}{dt} = g_i \sum_{j=1}^n f(B_j, B_i) - \sum_{j=1}^n f(B_i, B_j) + I_i - (M_i + F_i + e_i) \cdot B_i \quad (2.3)$$

Where,

dB_i/dt represents biomass growth rate of group (i) during the interval dt ;

g_i represents the net growth efficiency (production/consumption ratio);

I_i is the immigration rate;

M_i and F_i are natural and fishing mortality rates of group (i), respectively;

e_i is emigration rate; and

$f(B_j, B_i)$ is a function used to predict consumption rates of predator (j) on prey (i) according to the assumptions of foraging arena theory (Walters and Juanes 1993; Walters and Korman, 1999; Walters and Martell, 2004).

A recent multistanza routine (Christensen and Walters, 2004) is used with Ecosim in the Raja Ampat models to impose an equilibrium age structure across age categories for some functional groups (Ainsworth et al., 2007).

BHS EBM PROJECT DATA INTEGRATION

We use the Raja Ampat model for the present day as a master version; we adapt it for the sub-area models of Kofiau Island, Southeast Misool Island and the Dampier Strait. In this report, we refer to the present-day Raja Ampat model as representing the year 2005. However most data points in the model originate from the years between 2002 and 2007.

Reef health monitoring

Scientific output from the BHS EBM project is used to revise the EwE parameters of Ainsworth et al. (2007). Where possible, reef health monitoring data is used to set the biomass of fish functional groups directly. Recent biomass data is obtained from reef health monitoring studies around the Kofiau and Boo Island groups⁵ and Misool Island⁶. Reef health monitoring has been recently completed for Waigeo by field partners in CI (Sorong). Unfortunately, sampling only began in the fall of 2007 and so was unavailable at the time of this work⁷. The reef health monitoring protocol is available for Kofiau sites in

⁵ A. Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. E-mail: amuljadi@tnc.org. Unpublished data.

⁶ M. Syakir. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. E-mail: msaykir@tnc.org. Unpublished data.

⁷ Contact: M. Erdi Lazuardi. CI. Jl Arfak No. 45. Sorong, Papua, Indonesia 98413. E-mail: erdi@conservation.or.id

Pratomo and Setiawan (2006) and Misool sites in Mous and Muljadi (2005). Samoily (1997) provides additional discussion on the biases and challenges of coral reef stock assessment using transect measurements.

Reef health monitoring studies conducted snorkeling and SCUBA transects in monitoring sites selected by a stratified random approach after the methodology of Jolly and Hampton (1990) (see Mous and Muljadi, 2005). Transect sites in Kofiau and Waigeo were selected randomly with replacement from among a population of sites that occur at 3 km intervals along the coast line. One-third of the sites were selected for examination. This is an intensive sampling regime compared to previous TNC efforts in Komodo National Park (Mous and Muljadi, 2005). A similar protocol was designed by TNC staff for Waigeo Island; sampling was conducted by CI staff in this area. Five dive transects were conducted at each site monitored. Herbivorous fish are counted at 4 and 8 m depth. For herbivores > 40 cm tail length (TL), the family is also recorded as surgeonfish (Acanthuridae), rabbitfish (Siganidae) or parrotfish (Scaridae). Piscivorous fish are counted at 12 m depth. The divers searched for 8 piscivore families, but representatives from only 5 were recorded in Kofiau: Carangidae, Serranidae, Lutjanidae, Scobridae and Sphyraenidae. Also recorded was the percent cover for hard coral (live), hard coral (dead), hard coral (bleached), soft coral, macro-algae and 'other' substrates. The number of crown of thorn starfish and turtles observed was noted.

Herbivorous fish

Abundance counts for herbivorous reef fish are converted to biomass density estimates by calculating the total body weight of observed individuals using length-weight (L/W) relationships and dividing the biomass by the area scanned in the transect. Since herbivorous fish data were recorded at the family level, we use family-specific L/W parameters from Fishbase (FB); they represent the average value of Raja Ampat model species in each herbivorous family. Family growth parameters are in Appendix Table D.4.1. The dives are timed at 4 minutes each. The reef health monitoring protocol in Mous and Muljadi (2005) calls for the diver to swim slowly. We assume that 100 m is covered in one transect, although this distance will vary with current speed⁸. Also, the snorkeling transects (at 4 m depth, counting small herbivores) will cover more distance on average than the SCUBA transects (>4 m counting large herbivores and piscivores). This may cause us to overestimate the biomass of small herbivores, but we assume the bias is negligible. For herbivorous fish species, divers count the fish occurring to a distance of 5 m on either side of the transect line. Total area scanned is then 1000 m² per transect.

Average individual weights from mean lengths were determined using Equation 2.4.

$$W = aL^b \quad (2.4)$$

where a and b are species growth parameters found respectively in the 'a' and 'b' fields of the FishBase (FB) PopGrowth table (selected at the species level), L is total fish length (TL) from sampling in cm and W is body weight in g. Small herbivorous fish were recorded by TNC divers into two size categories, 12.5 cm and 30 cm. The proportion of these individuals was recorded (in percentage) as belonging to the families Scaridae, Acanthidae or Siganidae. These two size categories refer to the median body length⁹, therefore we assume it is equal to the average body length of fish recorded as required by Equation 2.4. Larger herbivorous fish were recorded individually into one of the following size categories (50, 70, 90 or 120 cm); similarly, we assume that these categories represent average body length. Biomass density at Kofiau and Misool dive sites is calculated as the total observed biomass divided by the area scanned.

Piscivorous fish

Biomass calculations for piscivorous fish at Kofiau and Misool Islands are calculated based on the reef health monitoring surveys. Body lengths recorded in transect studies were converted to body weights using the L/W conversion in Eq. 2.4 with species-specific L/W parameters from FB. The L/W coefficient,

⁸ Peter Mous. COREMAP II. Jl. Tebet Raya No. 91, Jakarta, Indonesia, personal communication.

⁹ Mohammad Saykir. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, personal communication.

a, and the L/W exponent, b, are located respectively in the 'a' and 'b' fields of the FB PopGrowth table. This information is summarized in Table A.1.1.

The biomass density of reef fish species is determined as the total observed biomass divided by the area scanned. As with herbivorous fish, we assume that the length of one transect is 100 m. However, when counting piscivorous fish, the divers were instructed to include all fish in their visible range, not just fish occurring within 5 m of the transect line as was done with herbivorous fish counts (Mous and Muljadi, 2007). This was done because piscivorous fish typically occur in fewer numbers. Therefore, we calculate biomass density for each species based on a transect area that considers the visibility on dives sighting each species. Visibility (V) for dives sighting a given species ranged from 5.3 to 12 m on either side of the transect line in Kofiau, and 1.5 - 20 m in Misool; area scanned is assumed to equal $2V \cdot 100 \text{ m}^2$. It is determined on a per-dive basis, biomass density is determined for each dive site and species.

The biomass density (B) for EwE functional group (j) is calculated as the sum product of the biomass density of reef health monitoring herbivorous or piscivorous fish family (i) and the ratio of the number of species in that family that contribute to the makeup of the EwE group. The total amount of biomass described for reef health monitoring fish families therefore remains the same in the EwE representation (eq. 2.5). The ratio is provided in Table A.1.5.

$$B_j = \sum_i \left[B_i \cdot \frac{X_{ij}}{\sum_j X_{ij}} \right] \quad (2.5)$$

Area ratio conversions

Biomass calculations for piscivorous fish at Kofiau and Misool Islands are calculated based on the reef health monitoring surveys. Body lengths recorded in transect studies were converted to body weights using the L/W conversion in Eq. 2.4 with species-specific L/W parameters from FB. The L/W coefficient, a, and the L/W exponent, b, are located in respectively in the 'a' and 'b' fields of the FB PopGrowth table. This information is summarized in Table A.1.1.

The biomass density of reef fish species is determined as the total observed biomass divided by the area scanned. As with herbivorous fish, we assume that the length of one transect is 100 m. However, when counting piscivorous fish, the divers were instructed to include all fish in their visible range, not just fish occurring within 5 m of the transect line as was done with herbivorous fish counts (Mous and Muljadi, 2007). This was done because piscivorous fish typically occur in fewer numbers. Therefore, we calculate biomass density for each species based on a transect area that considers the visibility on dives sighting each species. Visibility (V) for dives sighting a given species ranged from 5.3 to 12 m on either side of the transect line in Kofiau, and 1.5 - 20 m in Misool; area scanned is assumed to equal $2V \cdot 100 \text{ m}^2$. It is determined on a per-dive basis, biomass density is determined for each dive site and species.

The biomass density (B) for a given EwE functional group (j) is calculated from the sum of the product of the biomass density of reef health monitoring herbivorous or piscivorous fish family (i) and the ratio of the number of species in that family that contribute to the make up of the EwE group. The total amount of biomass described for reef health monitoring fish families therefore remains the same in the EwE representation (eq. 2.5). The ratio is provided in Table A.1.5.

Reef area ratio

Table 2.1 Hard coral coverage reported for Raja Ampat.

Area	Source	Average (%)	SD	# sites
Waigeo Is.	McKenna et al. (2002)	28.5	14.8	44
Waigeo Is.	COREMAP (2001)	45.2	11.9	8
Waigeo Is.	COREMAP (2005)	38.9	32.5	35
Waigeo Is.	Donnelly et al. (2003)	37.2	21.6	25
Waigeo average		37.5		
Kofiau Is.	A. Muljadi (unpublished data) BHS EBM reef health monitoring	25.3	16.4	450
Kofiau Is.	Donnelly et al. (2003)	30.0	22.4	35
Kofiau average		27.7		
Misool Is.	M. Syakir (unpublished data) BHS EBM reef health monitoring	45.9	14.4	53
Misool Is.	Donnelly et al. (2003)	30.0	22.4	11
Misool average		37.9		
Avg. Raja Ampat	Donnelly et al. (2003)	32.8	22.9	94
Indonesia	Spalding et al. (2001)	1.8	-	-

Biomass for coral groups (azooxanthellate corals, hermatypic scleractinian corals, non-reef building scleractinian corals and soft corals) were assumed to vary between Kofiau, Waigeo and Misool Island study areas in direct proportion to the relative areas covered by hard coral. The area of hard coral coverage is calculated from various sources, including recent BHS EBM reef health monitoring data (Table 2.1). The biomass density of these coral groups is therefore based on the larger Raja Ampat model, and modified for each sub-area by a weighting factor that adjusts for the relative coverage. The coverage of hard coral in Raja Ampat by area (32.8 %) is relatively greater than Kofiau Island (27.7 %) and relatively less than Waigeo (37.5%) and Misool (37.9%) Islands. Biomass density of coral groups is therefore adjusted down for Kofiau (i.e., by a factor of 27.7 / 32.8) and up for Waigeo and Misool. Reef health monitoring data was assembled by Andreas Muljadi (Kofiau Is.) and Mohammad Syakir (SE Misool Is.)¹⁰. Reef health monitoring data was collected for Waigeo Is. by M. Erdi Lazuardi¹¹ but was not available at the time of writing of this final report.

Shelf area ratio

GIS data summarizes bathymetry as in Fig. A.2.1. The relative area is presented in Table 2.2. Bathymetry was determined using nautical charts held by the Indonesian Navy (TNI AL, 2002) and summarized into GIS format by Mohammad Barmawi¹².

Table 2.2. Area < 200 m depth.

Area	Shallow area <200 m (%)	Deep area < 200 m (%)	Source
Waigeo	38.9	61.1	Barmawi, M. (unpublished data)
Kofiau	16.6	83.4	Barmawi, M. (unpublished data)
Misool	70.8	29.2	Barmawi, M. (unpublished data)
Raja Ampat	58.2	41.8	Barmawi, M. (unpublished data)
Indonesia	63.4	36.6	Spalding et al. (2001)

Mangrove area ratio

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¹¹ CI. Jl.Gunung Arfak.45. Sorong, Papua, Indonesia. Email: erdi@conservation.or.id

¹² TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia. Unpublished data. Contact: joanne_wilson@tnc.org

GIS data summarizes mangrove coverage as in Fig. A.2.1. The relative area is presented in Table 2.3. The source of the mangrove area data is from LandSat imagery (2000-2002) (NASA Landsat Program, 2006), and it was summarized into GIS format by Mohammad Barmawi.

Table 2.3. Area occupied by mangroves.

Area	Mangrove area (km ²)	Total area (km ²)	Relative mangrove coverage (%)	Source
Waigeo	46.6	6101	0.76	Barmawi, M. (unpublished data)
Kofiau	31.5	2391	1.32	Barmawi, M. (unpublished data)
Misool	35.1	4273	0.82	Barmawi, M. (unpublished data)
Raja Ampat	455.2	45000	1.01	Barmawi, M. (unpublished data)
Indonesia	42550.0	2915000	1.46	Spalding et al. 2001

Catch and fishing effort parameter revision

Catch matrices for the Raja Ampat model, Dampier St., Misool Is. and Kofiau Is. models are provided in Tables D.2.1, D.2.2, D.2.3 and D.2.4, respectively. The catch for Raja Ampat is determined based on governmental statistics assembled in Ainsworth et al. (2007) and includes revised estimates of illegal, unreported and unregulated (IUU) catch for some functional groups made by Varkey et al. (in prep).

Table 2.4. IUU proxy groups assigned to EwE functional groups

EwE group name	Proxy IUU group	EwE group name	Proxy IUU group
Reef assoc. turtles	not changed	Juv. medium reef assoc.	as reef
Green turtles	not changed	Ad. small reef assoc.	as reef
Oceanic turtles	not changed	Juv. small reef assoc.	as reef
Ad. groupers	as reef	Ad. large demersal	not changed
Sub. groupers	as reef	Juv. large demersal	not changed
Juv. groupers	as reef	Ad. small demersal	not changed
Ad. snappers	as reef	Juv. small demersal	not changed
Sub. snappers	as reef	Ad. large planktivore	as half tuna
Juv. snappers	as reef	Juv. large planktivore	as anchovy
Ad. Napoleon wrasse	as reef	Ad. small planktivore	as half anchovy
Sub. Napoleon wrasse	as reef	Juv. small planktivore	as anchovy
Juv. Napoleon wrasse	as reef	Ad. anchovy	as anchovy
Skipjack tuna	as tuna	Juv. anchovy	as anchovy
Other tuna	as tuna	Ad. deepwater fish	not changed
Mackerel	as tuna	Juv. deepwater fish	not changed
Billfish	as tuna	Ad. macro algal browsing	as reef
Ad. coral trout	as reef	Juv. macro algal browsing	as reef
Juv. coral trout	as reef	Ad. eroding grazers	as reef
Ad. large sharks	as shark	Ad. scraping grazers	as reef
Juv. large sharks	as shark	Juv. scraping grazers	as reef
Ad. small sharks	as shark	Detritivore fish	as reef
Juv. small sharks	as shark	Hermatypic corals	not changed
Adult rays	as half of shark	Penaeid shrimps	as invertebrates
Juv. rays	as half of shark	Shrimps and prawns	as invertebrates
Ad. butterflyfish	as reef	Squid	as invertebrates
Juv. butterflyfish	as reef	Octopus	none
Cleaner wrasse	as reef	Sea cucumbers	as sea cucumbers
Ad. large pelagic	as tuna	Lobsters	as lobsters
Juv. large pelagic	as tuna	Large crabs	as invertebrates
Ad. medium pelagic	as tuna	Small crabs	as invertebrates
Juv. medium pelagic	as tuna	Giant triton	as invertebrates
Ad. small pelagic	as anchovy	Herbivorous echinoids	as invertebrates
Juv. small pelagic	as anchovy	Bivalves	as invertebrates
Ad. large reef assoc.	as reef	Sessile filter feeders	as invertebrates
Juv. large reef assoc.	as reef	Epifaunal det. inverts.	as invertebrates
Ad. medium reef assoc.	as reef	Epifaunal carn. inverts	as invertebrates

The IUU estimates themselves are presented in Table D.2.5. The IUU analysis was done for illegal fishing of reef fishes using cyanide and blast fishing; unreported catches were determined for reef fish, anchovy, tuna, shark, lobster and sea cucumber. The percentage level of IUU fishing for reef fish was used as a proxy to approximate the IUU catch for all the reef fish functional groups in the model. Similarly, IUU estimates for tuna, anchovy and shark were used to calculate the IUU in pelagic groups and the estimates for lobster and sea cucumber were used to calculate IUU for the invertebrate groups in the model.

Each functional group in the model was assigned an IUU factor, which represents a certain percentage of reported catch based on the most appropriate proxy IUU group. Table 2.4 shows the IUU factor assigned to each functional group in the EwE model.

In addition to incorporating IUU catch, data gathered from three field surveys are used to improve the catch matrix. The three field surveys include an aerial survey of effort conducted in the lifetime of the BHS EBM project by TNC, a resource use survey of Kofiau Is. and a Coastal Rural Appraisal conducted by TNC in 2003. Information from the three surveys is used to refine the distribution of catch between different fishery gear types based on the number of vessels and their sizes.

Aerial survey for fishing effort

TNC field teams conducted an aerial survey of fishing effort in Raja Ampat. The survey was conducted in two phases; the first was from January 9 to 13, 2006; the second was from October 18 to 22, 2006. There were 10 flights in each phase to cover all the waters of Raja Ampat. The survey recorded the following point features: vessels (transport, fishing, industrial, tourist, others, unknown), fish cages, fishing shelters, fish platforms, fish aggregating devices (FADs, also known as rumpon), whales, dolphins, manta, dugong, tuna feeding / bait schools. The size of the vessels, the type of engine and the type of activity the vessels were engaged in was also noted. The results from the aerial survey were used as an input in estimating the IUU catches and hence this data contributed to the improvement of the catch matrix in the model.

Protocol for the aerial photography survey is provided in Mous (2005); highlights of the aerial survey results are provided in Barmawi (2006a). An online interactive map is available to access the geo-referenced aerial photography (www.rajaampat.org); alternatively, a two-DVD set of photographs is available through the TNC Bali office¹³. Detailed survey results with raw data are provided in Barmawi (2006b) and an additional analysis is forthcoming in the final aerial survey technical report due in 2008¹⁴. We present here a preliminary analysis of the data in Fig. 2.1 that supports the current catch matrix calculations.

Resource use survey

The resource use survey for Kofiau Is. in Raja Ampat was conducted by TNC field team for Raja Ampat¹⁵. The survey consisted of a mobile monitoring team that traveled by boats to the fishing villages around the Kofiau Is. and also intercepted fishers in the waters around Kofiau. The survey was conducted on 8 days between December 2005 and July 2006. The marine area around Kofiau was divided into 6 sectors totaling an area of 2350 km² (the average area of each sector: 390 km²). The survey collected information on number and names of vessels observed, the type of activity they were engaged in, the engine types and the gears used when the vessels were found fishing. They also noted the composition and quantity of the fish catch. In addition to monitoring vessels, the survey also monitored fixed gears that included karambas (floating net cages) and temporary huts on water.

From the resource use survey it is interesting to see that all of the boats with inboard engines except one are used by Maluku or Sulawesi fishers. All the lobster catch shown in the figure is caught using compressors by fishers from Sulawesi. The fishers from Maluku catch tuna using gillnets while fishers from the 3 villages in Kofiau Is. mostly use troll, longline or bottom gill net. The survey reports a catch of 1477 kg of dry tuna by the Maluku fishers. This is much higher than the tuna caught by the Raja Ampat (RA) fishers. This data point was discarded. Information resulting from the resource use survey is summarized in Fig. 2.2.

¹³ Contact: Joanne Wilson, TNC CTC. Jl Pengembak 2, Sanur, Bali, Indonesia joanne_wilson@tnc.org.

¹⁴ M. Barmawi. In preparation. TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia, 80228. Contact: joanne_wilson@tnc.org.

¹⁵ Andreas Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. Unpublished data.

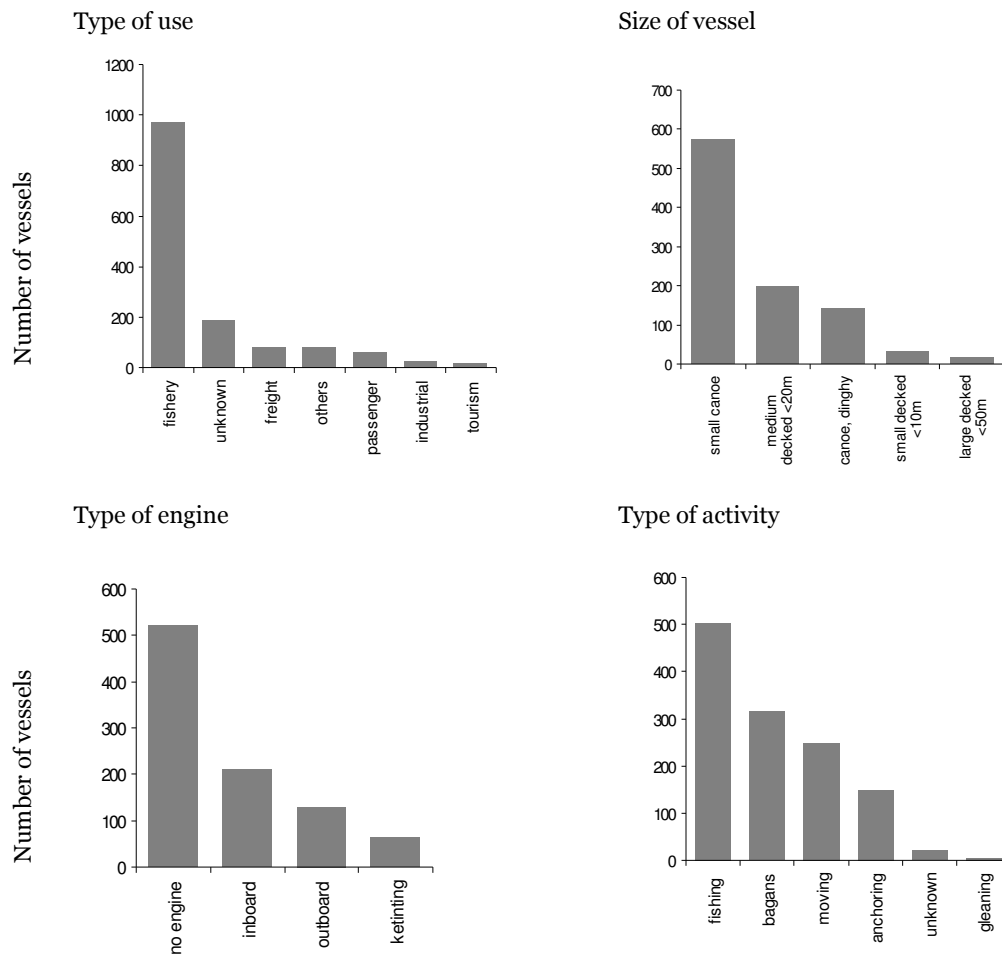


Figure 2.1. Raja Ampat fishing effort from the aerial survey. The figures for the size of vessel, the type of engine and the type of activity includes only the 970 vessels that were found fishing. Source: M. Barmawi (*unpublished data*); contact: Joanne Wilson, TNC CTC. Jl Pengembak 2, Sanur, Bali, Indonesia joanne_wilson@tnc.org.

Coastal rural appraisal survey (CRA)

The coastal rural appraisal survey (CRA) reports about 39% of the catch from Raja Ampat to be reef fish. After the incorporation of the IUU, the catch of reef fish in the model accounts for about 36% of the total catch in the model. This shows that the model catches for reef fish are in agreement with the estimates from local surveys. The model includes more catch for tuna than is reported in the CRA survey, however the CRA publication cautions that the survey did not take into account the tuna catches by the pole and line fishers in Yelu and Misool. Crustacean catches in the model account for about 4% of total catch, whereas the CRA reports that 13% of the total catch consists of lobsters and shrimp. Similarly, the sea cucumber catch in Ainsworth et al. (2007) was much lower than that reported by the CRA.

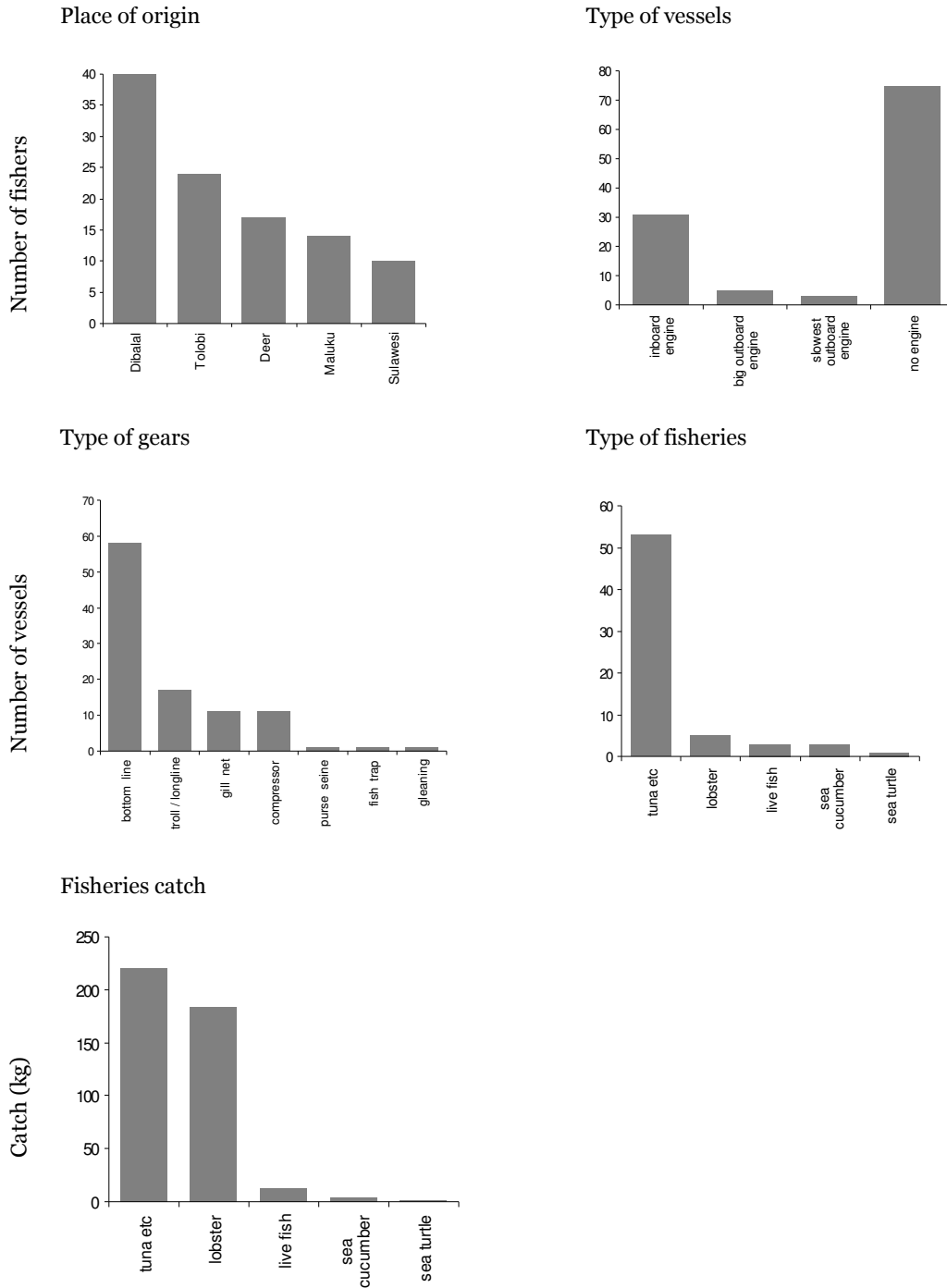


Figure 2.2. Resource use survey results. Source: Andreas Muljadi. (TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. Unpublished data).

The catch of other invertebrates, such as gastropods, also appears to be underestimated by Ainsworth et al. (2007). The IUU estimates from Varkey et al. (in prep) for invertebrates is reported in Table D.2.5; the revised Raja Ampat model catch is in Table D.2.1. Hook and line gear was not included in the model of Ainsworth et al. (2007) and this catch was aggregated into a more generic gear type called trolling. As it accounts for more than 40% of the catch according to the CRA, we have updated the gear types in the current volume to reflect this. The CRA report states that about 40% of the catch in Kofiau and Misool

(this study excluded pole and line fishing in Misool) was caught by hook and line fishery. After incorporating the IUU catches the catch matrix had a low proportion of hook and line catch. Hence the catch matrix was further adjusted to increase the component of landings from the hook and line fishery.

Comparison of preliminary and revised catch estimates

Figure 2.3 compares the revised catch estimate made in this report for Raja Ampat (Table D.2.1), including estimates of IUU catch, with the preliminary catch estimates made for the area (see Table A.3.4 in Ainsworth et al., 2007). The functional groups in the model have been aggregated for this figure.

The original precautionary placeholder estimates for illegal and unreported fishing made by Ainsworth et al. (2007) were about 200% of the reported catch for reef fishes and about 400% for anchovy fishery. Fig. 2.3 does not represent this difference; the placeholder IUU values used by Ainsworth et al. (2007) were omitted so the dark grey area in Fig 2.3 shows only the catch determined by those authors from government statistics. Sources of the fishery statistics include the Sorong Regency Fisheries Office, Departemen Kelautan dan Perikanan (DKP); the Raja Ampat Regency Fisheries Office; the Trade and Industry Office (Departemen Perindustrian dan Perdagangan); the Agricultural Quarantine Office, Badan Karantina Pertanian).

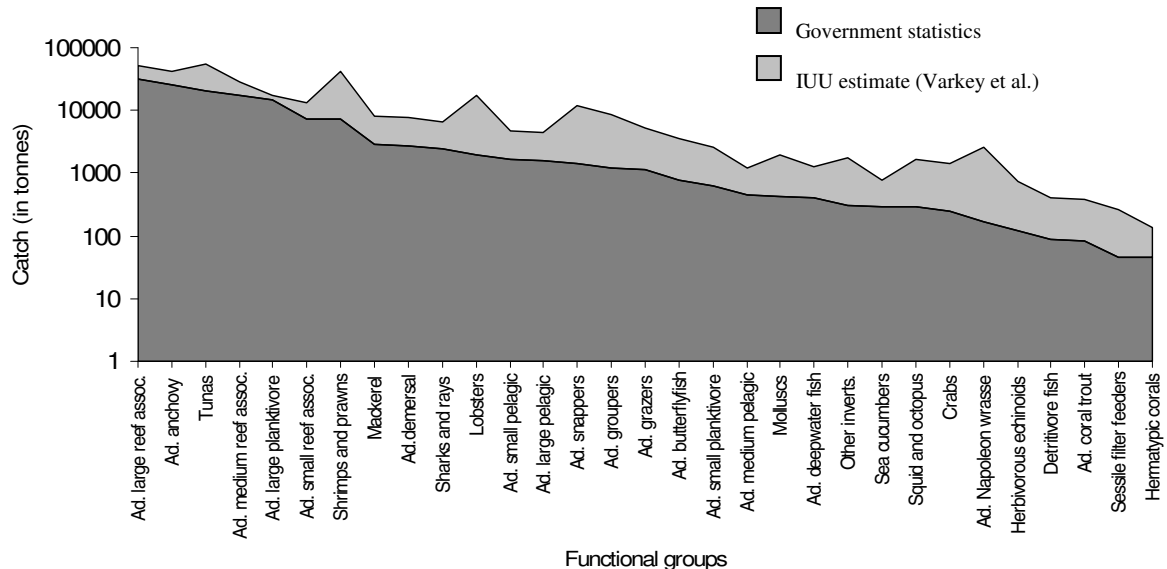


Figure 2.3. Raja Ampat fisheries catch. The catch shows landings from governmental statistics assembled by Ainsworth et al. (2007) (dark grey area) and the IUU calculated by Varkey et al. (in prep) (light grey). IUU is based on a qualitative methodology, and uses data from the BHS EBM project (aerial surveys, resource use survey and coastal rural appraisal survey). The Y-axis indicates total catch as shown on a log scale.

Table 2.5 shows the IUU incorporated into the revised catch estimates for this contribution, the total catch estimated by (Ainsworth et al., 2007) (including precautionary IUU placeholders) and the final estimate of total catch used in the current Raja Ampat model catch matrix. Note that the IUU estimates for the model functional groups from Varkey et al. (in prep)¹⁶ and the total catch in the previous version of the model (Ainsworth et al., 2007) do not add up to the total in the current revised catch matrix (Table D.2.1). This is due to changes made based on the information from the three field surveys described earlier.

¹⁶ Varkey, D., Ainsworth, C.A., Pitcher, T.J., Goram, J. (in preparation). Estimating illegal and unreported catches in Raja Ampat Regency, Papua, Indonesia. Contact: d.varkey@fisheries.ubc.ca.

Table 2.5. Comparison of preliminary and revised catch estimates for Raja Ampat. Catch is in $t \cdot km^{-2}$. IUU catch is estimated by Varkey et al. (in prep) based on a subjective methodology. Preliminary catch estimates were made by Ainsworth et al. (2007) and include placeholder estimates of IUU. Column 'This report' shows revised catch estimates based on the governmental statistics (assembled by Ainsworth et al., 2007 and including revisions based on BHS EBM field surveys) and estimates of IUU catch. Some catches have gone down after including IUU catches; this is because some precautionary assumptions for unreported catches were included in Ainsworth et al. (2007). The catch estimates with precautionary placeholders are highlighted in grey.

Group Name	IUU total ($t \cdot km^{-2}$)	Ainsworth et al. 2007 total ($t \cdot km^{-2}$)	This report total ($t \cdot km^{-2}$)	Catch increase	Group Name	IUU total ($t \cdot km^{-2}$)	Ainsworth et al. 2007 total ($t \cdot km^{-2}$)	This report total ($t \cdot km^{-2}$)	Catch increase
Ad. groupers	0.069	0.017	0.094	5.5	Juv. small reef assoc.	0.012	0.015	0.016	1.1
Sub. groupers	0.035	0.009	0.048	5.5	Ad. large demersal	0.019	0.024	0.039	1.6
Juv. groupers	0.016	0.002	0.022	11.1	Juv. large demersal	0.005	0.005	0.009	1.9
Ad. snappers	0.084	0.014	0.114	8.3	Ad. small demersal	0.028	0.028	0.057	2.0
Sub. snappers	0.063	0.014	0.086	6.2	Juv. small demersal	0.003	0.003	0.006	2.0
Juv. snappers	0.024	0.003	0.032	10.5	Ad. large planktivore	0.005	0.300	0.025	0.1
Ad. Napoleon wrasse	0.023	0.001	0.031	33.0	Juv. large planktivore	0.023	0.030	0.025	0.8
Sub. Napoleon wrasse	0.012	0.001	0.016	17.7	Ad. small planktivore	0.011	0.013	0.024	1.9
Juv. Napoleon wrasse	0.003	0.000	0.005	26.0	Juv. small planktivore	0.017	0.001	0.018	12.6
Skipjack tuna	0.260	0.348	0.608	1.7	Ad. anchovy	0.328	0.509	0.356	0.7
Other tuna	0.022	0.047	0.051	1.1	Juv. anchovy	0.003	0.051	0.036	0.7
Mackerel	0.048	0.064	0.112	1.7	Ad. deepwater fish	0.008	0.008	0.017	2.0
Billfish	0.037	0.050	0.084	1.7	Juv. deepwater fish	0.001	0.001	0.002	2.0
Ad. coral trout	0.005	0.002	0.006	3.8	Ad. macro algal browsing	0.002	0.001	0.003	3.8
Juv. coral trout	0.000	0.000	0.001	3.8	Juv. macro algal browsing	0.000	0.000	0.000	3.8
Ad. large sharks	0.019	0.025	0.045	1.8	Ad. eroding grazers	0.001	0.000	0.001	3.8
Juv. large sharks	0.002	0.003	0.005	1.8	Juv. eroding grazers	0.000	0.000	0.000	2.0
Ad. small sharks	0.004	0.006	0.010	1.8	Ad. scraping grazers	0.062	0.022	0.085	3.8
Juv. small sharks	0.000	0.001	0.001	1.8	Juv. scraping grazers	0.006	0.002	0.008	3.8
Ad. rays	0.005	0.019	0.024	1.3	Detritivore fish	0.005	0.002	0.007	3.8
Juv. rays	0.001	0.002	0.002	1.3	Hermatypic corals	0.001	0.001	0.002	2.0
Ad. butterflyfish	0.043	0.016	0.059	3.8	Penaeid shrimps	0.550	0.145	0.695	4.8
Juv. butterflyfish	0.004	0.002	0.006	3.8	Shrimps and prawns	0.065	0.017	0.082	4.8
Cleaner wrasse	0.002	0.001	0.003	3.8	Squid	0.024	0.006	0.030	4.8
Ad. large pelagic	0.023	0.031	0.054	1.7	Octopus	0.000	0.000	0.000	2.0
Juv. large pelagic	0.003	0.004	0.007	1.7	Sea cucumbers	0.005	0.006	0.011	1.7
Ad. medium pelagic	0.005	0.007	0.012	1.7	Lobsters	0.132	0.044	0.353	8.0
Juv. medium pelagic	0.002	0.003	0.005	1.7	Large crabs	0.010	0.003	0.013	4.8
Ad. small pelagic	0.029	0.034	0.063	1.9	Small crabs	0.010	0.003	0.013	4.8
Juv. small pelagic	0.003	0.004	0.007	1.9	Giant triton	0.002	0.003	0.006	1.7
Ad. large reef assoc.	0.266	0.577	0.362	0.6	Herbivorous echinoids	0.010	0.003	0.013	4.8
Juv. large reef assoc.	0.056	0.112	0.076	0.7	Bivalves	0.022	0.006	0.028	4.8
Ad. medium reef assoc.	0.149	0.350	0.203	0.6	Sessile filter feeders	0.004	0.001	0.005	4.8
Juv. medium reef assoc.	0.027	0.035	0.037	1.1	Epifaunal det. inverts.	0.012	0.003	0.015	4.8
Ad. small reef assoc.	0.081	0.150	0.110	0.7	Epifaunal carn. inverts	0.014	0.004	0.017	4.8
					Total	2.860	3.213	4.424	1.4

Catch matrices for sub-area models

The catch matrices for the three sub-area models were calculated based on three assumptions:

- The three areas Kofiau, Misool and Dampier Strait contribute 70% of the catch from Raja Ampat;
- The catch in each sub-area model is proportional to the biomass density of species groups, the fishers population density and the area of the models;
- The population density can be used to approximate fishers density.

A value of 70% was assumed based on the fact that the sub area model for Kofiau accounts for all the Kofiau and nearby areas, the model for Misool is located in SE Misool, where almost all the fishery is also concentrated. The catch that is not included is the catch from all parts of Waigeo other than Dampier strait and the catch by fishers from Sorong. The biomass density of the species was calculated based on the results from the reef health monitoring and the area of the habitats available in the sub area models for the different species groups.

The population density was used to approximate the fishers density. This population density was obtained

from Jacinta and Imbir (2007). The population density estimates are as follows: Kofiau 0.9, Dampier St. 1.11 and Misool 1.08 persons \cdot km $^{-2}$ of model area. The fishers density estimates from the same source were: Kofiau 0.005, Dampier St. 0.22 and Misool 0.08 persons \cdot km $^{-2}$ of model area. Firman and Azhar (2006) give the following estimates for the three areas respectively: 0.9, 0.88 and 1.88 persons \cdot km $^{-2}$ and 0.49, 0.46 and 0.98 men \cdot km $^{-2}$. The statistics bureau (BPS) provides: Kofiau 0.005, Dampier St. 0.22 and Misool 0.08 persons \cdot km $^{-2}$ of model area. Thus there were several population estimates that we could use, we chose to use the population density from Jacinta and Imbir (2007) as this seemed to be most recent and reasonable. The catch estimates for the Raja Ampat model and the three sub-area models (Dampier Strait, SE Misool and Kofiau Island) are summarized in Figure 2.4.

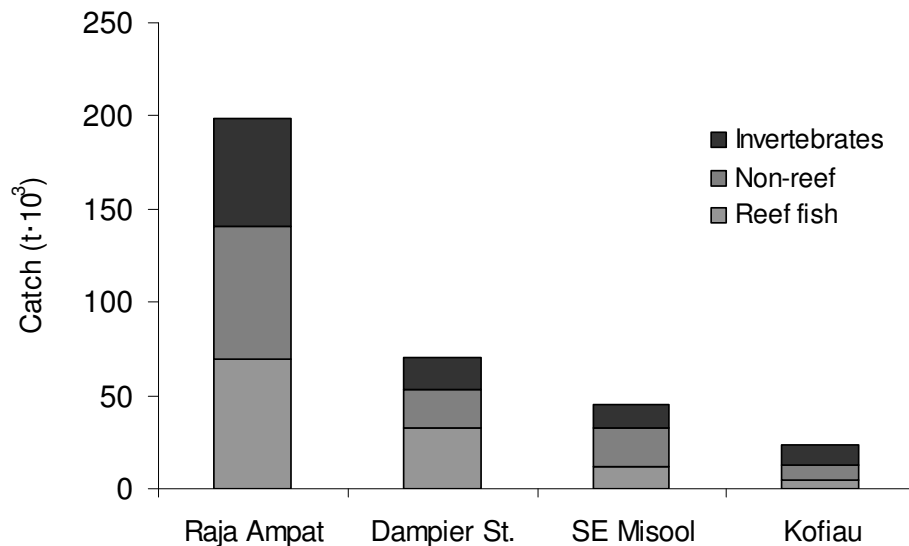


Figure 2.4. Catch for Raja Ampat and sub-area models. Values are estimated in this report based on relative targeted species biomass and human population density.

Cost matrix

For estimating the cost for the different fisheries, it was assumed that the fixed cost was 100 dollars per boat. This was approximated from Bailey et al. (2008) who have estimated the cost of boat and net set up to be \$156 per year. The costs for the gears were approximated using the fishery costs for different groups obtained from Farid and Anggraeni, 2003. Shore gillnet was assumed to have a similar cost pattern as bagan (lift-net) fishery; diving, cyanide and blast fishing were assumed to have similar cost patterns. The costs were converted to percentage values as is the requirement for Ecopath. The costs matrix for the RA model is shown in Table 2.6.

Table 2.6. Cost matrix for the RA model. Costs are estimated as percentage of total revenue for each type of fishery. The last column 'Cost estimate' is the estimate on which the cost for each fishery is based.

Type of fishery	Fixed cost (%)	Effort related cost (%)	Sailing related cost (%)	Profit percent (%)	Cost estimate
Spear and harpoon	5.1	27.2	9.4	58.3	live fish
Reef gleaning	0.0	45.4	0.0	54.6	trochus
Shore gillnet	1.3	0.0	0.0	74.8	bagan
Driftnet	10.4	6.9	16.7	66.0	fresh reef fish
Permanent trap	0.3	37.5	0.0	62.1	sea cucumber
Portable trap	1.7	30.1	15.3	52.9	lobster
Diving spear	5.1	27.2	9.4	58.3	live fish
Diving live fish	5.1	27.2	9.4	58.3	live fish
Diving cyanide	5.1	27.2	9.4	58.3	live fish
Blast fishing	5.1	27.2	9.4	58.3	live fish
Trolling	11.7	20.1	11.4	56.8	shark fin
Purse seine	3.1	2.9	13.7	80.3	mackerel
Pole and line	3.1	2.9	13.7	80.3	mackerel
Hook and line	5.1	27.2	9.4	58.3	live fish
Lift net	1.3	0.0	0.0	74.8	bagan
Foreign fleet	0.0	40.0	40.0	20.0	Ainsworth et al. (2007)
Shrimp trawl	0.0	40.0	40.0	20.0	Ainsworth et al. (2007)

Price matrix

The price matrix was modified using the prices from the valuation report (Dohar and Anggraeni, 2006) which is a summary of the economic valuation of the resources of Raja Ampat. The prices in the previous version of the model were based on the data from the Trade and Industry office in Sorong. The prices from the valuation report (Dohar and Anggraeni, 2006) were used because they were better estimates of local price and were more recent than the data from the Trade and Industry office. The price matrix for the RA model is shown in Table 2.7.

Fisher interviews

Between the months of September and December in 2006 fisher interviews were conducted in Raja Ampat (SE Misool Is. and Kofiau Is.) by field staff from Conservation International (CI) and the State University of Papua (Universitas Negeri Papua, UNIPA) with the aim of gathering local ecological knowledge (LEK) regarding the exploitation and population status of fish, invertebrates, reptiles and mammals.

This LEK information has been used in the current modeling study to establish the likely abundance trend for functional groups and the unexploited biomass for some. Two hundred and nine fisher interviews were conducted in 13 villages (Table 2.8) using a convenience sampling approach. Fishers were interviewed opportunistically at workshops and other functions under the TNC Coastal Rural Appraisal survey¹⁷. A list of villages sampled in Misool and Kofiau Islands is available in Muljadi (2004).

¹⁷ J. Wilson. TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia, 80228. Unpublished data.

Table 2.7. Raja Ampat price matrix. Price values are in 10³ Rp•kg⁻¹. The grey cells are the prices based on (Dohar and Anggraeni, 2006); unshaded prices are from Ainsworth et al. (2007).

Group names	Spear and harpoon	Reef gleaning	Shore gillnet	Driftnet	Permanent trap	Portable trap	Diving spear	Diving live fish	Diving cyanide	Blast fishing	Trolling	Purse seine	Pole and line	Hook and line	Lift net	Foreign fleet	Shrimp trawl
Ad. groupers	7.71				50.52		50.52	68.40	68.40	18.57				50.52			
Sub. groupers	7.71				7.71		7.71	68.40	68.40	7.71				7.71			
Juv. groupers	2.89				2.89									2.89			
Ad. snappers	7.71		7.71		31.13		31.13		31.13	15.57				31.13			
Sub. snappers	7.71		7.71		31.13		31.13		31.13	7.71				31.13			
Juv. snappers	2.25		2.25		2.25		2.25							2.25			
Ad. Napoleon wrasse								120.00	120.00	60.00				120.00			
Sub. Napoleon wrasse								120.00	120.00	60.00				120.00			
Juv. Napoleon wrasse								21.46	21.46	2.89				21.46			
Skipjack tuna											9.44	9.44	9.44	9.44			
Other tuna											3.16	3.16	3.16	3.16			
Mackerel											5.17	5.17	5.17	5.17			
Billfish											10.17						
Ad. coral trout	7.71		7.71	7.71	7.71	7.71				7.71							
Juv. coral trout	2.90		2.90	2.90	2.90	2.90				2.90							
Ad. large sharks														5.84			
Juv. large sharks														3.30			
Ad. small sharks														4.32			
Juv. small sharks														4.32			
Adult rays			3.28	3.28	4.93	4.93											
Juv. rays			1.00	1.00	1.00	1.00											
Ad. butterflyfish	7.71		7.71	7.71	12.50	12.50			12.50	7.71							
Juv. butterflyfish	7.71		7.71	7.71	7.71	7.71				7.71							
Cleaner wrasse			0.90	0.90	0.90	0.90				0.90							
Ad. large pelagic			2.90	2.90	3.03	3.03											3.03
Juv. large pelagic			2.90	2.90	2.90	2.90											2.90
Ad. medium pelagic			2.90	2.90	3.04	3.04											3.04
Juv. medium pelagic			2.90	2.90	2.90	2.90											2.90
Ad. small pelagic			1.34	1.34	1.34					1.34							1.34
Juv. small pelagic			1.34	1.34	1.34					1.34							1.34
Ad. large reef assoc.	7.71		7.71	7.71	13.44	13.44			13.44	7.71				13.44			
Juv. large reef assoc.	2.90		2.90	2.90	2.90	2.90								2.90			
Ad. medium reef assoc.	7.71		7.71	7.71	13.33	13.33			13.33	7.71				13.33			
Juv. medium reef assoc.	2.90		2.90	2.90	2.90	2.90				2.90				2.90			
Ad. small reef assoc.	2.90		2.90	2.90	3.22	3.22				3.22				3.22			
Juv. small reef assoc.	2.90		2.90	2.90	2.90	2.90				2.90				2.90			
Ad. large demersal	2.90				3.04	3.04				3.04				3.04			
Juv. large demersal	2.90				2.90	2.90				2.90				2.90			
Ad. small demersal	2.90				3.11	3.11				3.11							
Juv. small demersal	2.90				2.90	2.90				2.90							
Ad. large planktivore	8.75		8.75	8.75	8.75	8.75				8.75							
Juv. large planktivore	8.75		8.75	8.75	8.75	8.75				8.75							
Ad. small planktivore	8.75		8.75	8.75	8.75	8.75				8.75							
Juv. small planktivore	8.75		8.75	8.75	8.75	8.75				8.75							
Ad. anchovy			5.19	5.19	5.19	5.19											5.19
Juv. anchovy			5.19	5.19	5.19	5.19											5.19
Ad. deepwater fish			2.90	2.90	3.47	3.47											
Juv. deepwater fish			2.90	2.90	2.90	2.90											
Ad. macro algal browsing			7.71	7.71	8.69	8.69											
Juv. macro algal browsing			2.90	2.90	2.90	2.90											
Ad. eroding grazers			2.90	2.90	3.47	3.47											
Juv. eroding grazers			2.90	2.90	2.90	2.90											
Ad. scraping grazers			2.90	2.90	3.47	3.47											
Juv. scraping grazers			2.90	2.90	2.90	2.90											
Detritivore fish			7.71	7.71	8.69	8.69											
Hermatypic corals										0.00							
Penaeid shrimps																	50.00
Shrimps and prawns																	7.16
Squid														25.72			
Octopus	6.50	6.50					67.99			67.99							
Sea cucumbers	65.85	122.50					122.50			122.50							
Lobsters		32.50					32.50			32.50							
Large crabs		4.05					4.05			4.05							
Small crabs		4.05					4.05			4.05							
Giant triton		30.000					30.000			30.000							
Herbivorous echinoids		6.08					6.08			6.08							
Bivalves		15.00															
Sessile filter feeders		1.15															
Epifaunal det. inverts.		1.15					1.15			1.15							
Epifaunal carn. inverts		1.15					1.15			1.15							

Table 2.8. Fisher interviews conducted in Raja Ampat for abundance trend study.

Village	District	# interviews
Yelu	SE Misool	9
Gamta	SE Misool	12
Fafanlap	SE Misool	3
Fishouys	SE Misool	1
Harapan jaya	SE Misool	6
Lilinta	SE Misool	20
Usaha jaya	SE Misool	20
Kapacol	SE Misool	18
Dibalal	Kofiau Is.	30
Tomolol	SE Misool	20
Biga	SE Misool	18
Tolobi	Kofiau Is.	26
Deer	Kofiau Is.	24
blank	-	2
Total		209

The questionnaire form used by CI/UNIPA has been translated into English and presented in Ainsworth et al. (2007) (Appendix C.1). Data fields include a qualitative ranking of abundance for commercial and artisanal fish and invertebrate families, and charismatic animals including reptiles (turtles and crocodiles), birds and mammals (Mysticetae, Odontocetae and dugong, *Dugong dugon*). Fishers characterized the abundance of each family or species group into one of three categories (high, medium or low) for each of the time periods 1970, 1980, 1990 and 2000. We also asked them to score three yes/no depletion indicators referring to whether the interviewees had noticed a reduction in the abundance of each family or species group, whether they have noticed a size reduction, and whether there had been a price increase. For the price increase indicator, an approximate year was

also recorded representing when the price increase took effect.

Fuzzy expert system for LEK abundance quantification

A new fuzzy logic expert system is developed by Ainsworth et al. (2008) to convert the qualitative interview abundance information concerning family and species groups to quantitative scores of relative abundance. A fuzzy logic method was chosen in order to systematically address the potential bias of between-fisher interpretations of abundance categories. That is, fishers may hold different perceptions regarding what constitutes 'high', 'medium' or 'low' abundance. The interpretation may vary with fisher experience, gear type or fishing sector specialization, or some other demographic descriptor. The interpretation may also vary with the species group under review. For example, the abundance change in targeted species to which fishers owe their earnings or family's sustenance, may be perceived differently than in untargeted species that hold no commercial or nutritional value.

Having generated a time series of perceived relative abundance change from 1970 to present using the fuzzy logic algorithm, the output results, which are categorized by taxonomic family or species group, are converted into relative abundance trends for EwE functional groups. For each period (1970, 1980, 1990 and 2000), the relative abundance of a EwE functional group is assumed to be represented by a weighted average of the abundance scores for relevant families or species groups. The weighting factor applied to each family is proportional to the number of species in that family contributing to the EwE functional group, as a fraction of the total number of contributing species that are described by the LEK data. The abundance score for a EwE functional group (A_j) is therefore calculated as the sum product of the family abundance score (A_i) and the ratio of the number of species (X) in family (i) belonging to the EwE functional group (j) (Eq. 2.6). The ratios are provided in Table A.1.4.

$$A_j = \sum_i \left[A_i \cdot \frac{X_{ij}}{\sum_i X_{ij}} \right] \quad (2.6)$$

Ainsworth et al. (2008) used the LEK data trends to back-calculate the relative biomass of functional groups in 1970. Their methodology used CPUE data trends (from 1990-2005) to scale the output from the fuzzy logic algorithm and establish an absolute range of biomass change between 1970 and 2000. These authors assumed that the decline in CPUE between 1990 and 2000, which was quantified by Ainsworth et al. (2007), is representative of the proportional decline in biomass between those periods. They scaled the LEK trend so that 1990 and 2000 values agree with the CPUE values for those periods, and maintaining the ratio between all time periods derived from the fuzzy logic algorithm, this provided an estimate of biomass for 1970 and 1980. For many functional groups, the 1970 biomass was assumed to be similar to the unexploited biomass (B_0), and this allowed Ainsworth et al. (2008) to reconstruct the unfished ecosystem for Raja Ampat. They established a potential range for the unexploited biomass by combining

this LEK-based estimate with predictions of B_0 derived from the present-day Raja Ampat model described in this report.

Gut content analysis

In November and December 2006 an analysis of fish gut contents was conducted in Raja Ampat by CI staff and two students from UNIPA¹⁸. The protocol for obtaining samples, dissecting stomachs and analyzing the results is presented in Appendix C.2 of Ainsworth et al. (2007). Briefly, fish were purchased at markets and the stomachs removed, or else fishers were paid a fee in order to extract the stomachs. Stomachs were preserved in formalin and later dissected in the lab. Prey items were weighed and identified to the species or family level. The protocol was devised especially to support the current EwE models, so it was not important to identify prey species beyond the functional group level. Nevertheless, taxonomies were identified to a more precise level in order to make the data more valuable to future scientific studies. The diets of predator fish families are converted to percent composition values and scaled to total 100%. The following assumptions were made in order to apply the stomach content data to the EwE models:

Fish were included as part of the diet of several species of small coral fish. We therefore split the fish component into the following groups: large reef associated (20%), medium reef associated (20%), small reef associated (30%), macro-algal browsers (10%), eroding grazers (10%) and scraping grazers (10%).

Entries for shrimp were divided equally between the two shrimp groups, 'penaeid shrimps' and 'shrimps and prawns'. There were sand and coral fragments in the diet of several families of fish sampled. Half of this amount was assumed to be biogenic, originating from the hard coral functional group 'Hermatypic scleractinian corals'; the other half was assumed to be sand and was omitted from the diet matrix. We assumed those species that ate hard coral would also eat soft coral and non-reef building scleractinian corals. We assumed that those species would eat about half as much soft coral and non-reef building coral. There were several entries for unidentifiable brown liquid. These were omitted from the diet composition.

Diet information for families is distributed into 22 functional groups using conversion ratios in Table C.1.1. The conversion is based on the relative number of species from each family contributing to the composition of the aggregated EwE functional groups. The diet information collected from stomach samples is compared with the results of the diet allocation algorithm¹⁹ developed for Raja Ampat by Ainsworth et al. (2007), and with the final Raja Ampat model presented in Ainsworth et al. (2007) after balancing and tuning to time series data. Numerous *ad hoc* changes that were made to the Raja Ampat diet matrix during balancing and tuning would hopefully have maneuvered the model closer to a state representing reality.

The rank order of diet items is compared in order to study the difference between the prediction of the diet algorithm and the stomach data collected. There are a total of 156 interactions common to both the data sets. These interactions were scored for each data set as a rank (out of 156) where low ranks indicate a major diet component. The squared difference in ranks between the data sets was used as an indicator of agreement so that a low sum of squares (i.e., for all prey items combined) indicated high agreement between the two diet composition sources. The upper quartile of squared rank differences is assumed to represent critical disagreement in interactions between the two data sets (Fig. 2.5). Below this level, the two data sets are assumed to be in agreement.

¹⁸ Contact: Christovel Rotinsulu. CI. Jl.Gunung Arfak.45.Sorong, Papua, Indonesia. E-mail: chris@conservation.or.id

¹⁹ The diet algorithm processes FishBase diet information to allocate generic or imprecise prey categories into EwE functional groups using habitat information, predator gape size and prey body size (Ainsworth et al., 2007).

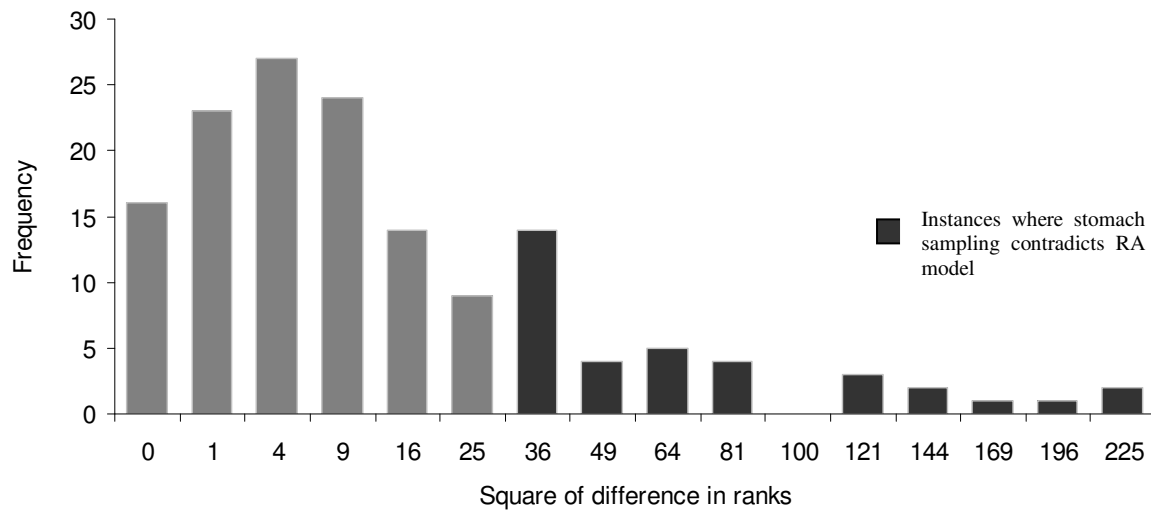


Figure 2.5. Agreement between Raja Ampat model and stomach sampling diet composition data. Raja Ampat model diet parameters are based on an allocation algorithm and modified by balancing and tuning (Ainsworth et al. 2007). The upper quartile of interactions (dark grey bars) represents instances where stomach sampling strongly contradicts Raja Ampat model. 37 Raja Ampat model interactions are contradicted by stomach data.

Table 2.9 indicates which interactions in the Raja Ampat model and in the original diet algorithm results are contradicted by the stomach sampling information. Where stomach data contradicts the diet algorithm interactions are marked with an 'A'; these may represent where the process of balancing and tuning the models corrected diet errors in the algorithm. There are 48 diet algorithm interactions contradicted by the stomach data. Where stomach data contradicts the final Raja Ampat model interactions are marked with an 'M'; these represent a necessary increase in residuals versus the ground-truthing stomach sample data in order to balance the model. There are 37 Raja Ampat model interactions contradicted by the stomach data. Only interactions for which the stomach data contradicts both the Raja Ampat model and the original diet allocation algorithm were revised here. These are marked by 'Both' in grey cells; there are 29 interactions.

Table 2.10 demonstrates the direction of disagreement between stomach sample data and the final Raja Ampat model diet matrix used by Ainsworth et al. (2007). The direction of disagreement determines what change must be made to the Raja Ampat diet matrix for the current revision. Among the 56 interactions marked in Table 2.10, the stomach sampling data contradicts only 3 interactions in different directions with respect to the Raja Ampat model and the original diet algorithm. Adjustments made during the process of balancing and tuning the model therefore had a minimal impact on the accuracy of the diet matrix, as revealed by the stomach sampling data.

Table 2.9 Raja Ampat model and diet algorithm disagreement versus stomach sampling data. M: stomach data contradicts model; A: stomach data contradicts algorithm; BOTH: stomach data contradicts model and algorithm. Grey cells indicate interactions modified by current diet matrix revision.

Prey / Predator	Snap'rs	Skipj'k tuna	Other tuna	Large sharks	B'fly fish	Large pelagic	Large reef assoc.	Med. reef assoc.	Large plank.	Deep. fish
Large reef assoc.							A	BOTH	M	A
Medium reef assoc.								A		BOTH
Small reef assoc.	M						A	A	A	BOTH
Macro algal browsing	BOTH							BOTH	A	
Eroding grazers	BOTH						BOTH	BOTH	BOTH	M
Scraping grazers								A		M
Hermatypic corals					A		BOTH	BOTH		
Soft corals							BOTH			
Shrimps and prawns	BOTH									BOTH
Squid	M								BOTH	
Octopus		A	A	A						
Large crabs							M			
Small crabs							A	A		
Bivalves							A	A		
Epifaunal det. inverts.							BOTH	A		BOTH
Epifaunal carn. inverts							BOTH	BOTH		BOTH
Infaunal inverts.	M						M	BOTH	BOTH	BOTH
Large herb.					A					
Macro algae					A	BOTH	BOTH	BOTH		
Sea grass						BOTH		BOTH	BOTH	

Table 2.10. Direction of disagreement between model and stomach sampling data. "+": stomach samples indicate a greater proportion of this prey than was predicted by the Raja Ampat model; "-": samples indicate less prey. Grey cells indicate interactions modified by current diet matrix revision.

Prey / Predator	Snap'rs	Skipj'k tuna	Other tuna	Large sharks	B'fly fish	Large pelagic	Large reef assoc.	Med. reef assoc.	Large plank.	Deep. fish
Large reef assoc.							+	-	-	-
Medium reef assoc.								-	-	-
Small reef assoc.	-						-	-	-	-
Macro algal browsing	-							-	-	
Eroding grazers	-						-	-	-	-
Scraping grazers								-		-
Hermatypic corals					-		-	-		
Soft corals							-			
Shrimps and prawns	+									+
Squid	+								+	
Octopus		-	-	-						
Large crabs							-			
Small crabs							+	+		
Bivalves							-	-		
Epifaunal det. inverts.							+	+		+
Epifaunal carn. inverts							+	+		+
Infaunal inverts.	+						+	+	+	+
Large herb.					-					
Macro algae					-	-	-	+		
Sea grass						-	-	+	+	

ECOPATH BALANCING

Present-day Raja Ampat model

Revisions made to the 2005 Raja Ampat catch matrix to include better estimates of illegal and unreported catch forced the model out of balance for the following commercial groups: groupers, snappers, Napoleon wrasse, large and medium pelagics and lobsters. Although Ainsworth et al. (2007) had included conservative placeholder estimates of unreported catch for the three reef fish groups (amounting to 60%, 50%, 100% of reported catch for groupers, snappers and Napoleon wrasse, respectively), the addition of more qualified IUU estimates by Varkey et al. (in prep.) increased fishing mortality (F) by an average of almost 15 times for these functional groups across age stanzas. To maintain the improved catch estimates we could either permit an instantaneous biomass decline, which we did do to some degree for all highly commercial groups, or increase the productivity of these groups by altering the production rate (P/B), biomass, or both. The production rate for these long-lived species groups should remain low however, and the P/B values from Ainsworth et al. (2007) (adult P/B = 0.225, 0.4 and 0.5 yr⁻¹, respectively) cannot be increased enough to reasonably provide the additional production required by fisheries. Fortunately, better biomass estimates have since become available from the BHS EBM reef health monitoring project for reef fish species²⁰. The data tend to indicate higher biomass densities than were estimated in Ainsworth et al. (2007) and, on the whole, the revised biomass estimates satisfy the production demands from IUU fisheries. Ecotrophic efficiencies were set to 95% for these reef fish groups, the revised biomass data were entered, and the resulting biomass accumulation rates were deemed to be acceptable if they satisfied the constraint that fisheries could remove no more than 60% of a group's total annual biological production. A similar criterion was used for large and medium pelagics and lobsters.

Groupers

The grouper functional groups experienced at least a 5.4 times increase in fishing mortality as a result of adding the IUU catch compared to the model of Ainsworth et al. (2007). To allow for the additional biological production required in the adult group, we held the P/B rate as previously estimated (0.225 yr⁻¹). This is a low production rate compared with some published grouper statistics (e.g., 0.37 yr⁻¹, Caribbean coral reef, Opitz 1993; 0.37 yr⁻¹, Great Barrier Reef, Gribble, 2001; 0.45 yr⁻¹, Gulf of Mexico, Arreguín-Sánchez et al., 1993a), however it may be appropriate for Raja Ampat if the average body size remains large after historically light exploitation. Instead, we increased biomass from 0.184 t•km⁻² to 0.5 t•km⁻². The old value was based on transect fish counts in S. Waigeo island (COREMAP 2005). The new value is also based on this data, but in addition incorporates reef health monitoring survey data from Kofiau and SE Misool (Tables A.1.1 and A.1.2). Biomass densities for these three areas are scaled proportionately to account for their relative reef coverage, and then the value is averaged to represent Raja Ampat. The resulting biomass density for adult groupers in Raja Ampat, 0.518 t•km⁻², is reduced to 0.5 t•km⁻² in order to obtain a similar instantaneous rate of biomass decline as calibrated in the previous technical report. Biomass for subadult and juvenile stanzas is calculated using the existing EwE age structure model for a combined grouper biomass density of 0.699 t•km⁻² (Table D.1.1). Fisheries remove about 6% of the available annual production, resulting in a ~2% loss of stock size per year in the initial simulation years.

Snappers

The snapper functional groups experienced a 6-10 times increase in fishing mortality as a result of adding IUU catch. To allow for the additional biological production required in the adult group we held the P/B rate as previously estimated (0.4 yr⁻¹), although, according to previous tropical EwE studies, the value for lutjanids could potentially be higher (e.g., 0.7 yr⁻¹, Pauly and Christensen, 1993; 0.44 yr⁻¹ Arreguín-Sánchez et al., 1993b) or lower (0.3 yr⁻¹, De La Cruz-Agüero, 1993; 0.36 yr⁻¹, Arreguín-Sánchez et al., 1993a). Instead, we increased biomass from 0.081 t•km⁻² to 0.345 t•km⁻². The old value was based on transect fish counts in S. Waigeo island (COREMAP 2005). The new value incorporates reef health monitoring data from SE Misool (Table A.1.2). The Kofiau data exhibited high densities for lutjanids, 2.53 t•km⁻² due mainly to *Lutjanus rivulatus*. We assume that this is not representative of Raja Ampat. In fact, the model could not easily be made to accommodate such a high biomass. An average biomass density was therefore calculated without the Kofiau data point, using SE Misool reef health monitoring and COREMAP

²⁰ Kofiau: A. Muljadi; SE Misool: M. Syakir. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. Email: msyakir@tnc.org. Unpublished data.

(2005) estimates. The value was standardized to reflect the relative reef coverage in SE Misool versus Raja Ampat. Biomass density for subadult and juvenile groups is determined with the existing age structure parameters, and an overall biomass for snappers is estimated to be $0.651 \text{ t}\cdot\text{km}^{-2}$ (Table D.1.1 Biomass). Fisheries remove about 12% of the available annual production, resulting in a $\sim 1\%$ loss of stock size per year in the initial simulation years.

Napoleon wrasse

The Napoleon wrasse (*Cheilinus undulatus*) functional groups were affected most by the addition of the unreported catch. Despite the placeholder estimate for IUU used by Ainsworth et al. (2007), which was 100% of reported catch, the fishing mortality increased on this group by 33 times with the addition of IUU catch. We opted to keep the revised estimates of catch, reducing predation mortality and increasing biomass. Predation mortality on adult Napoleon wrasse was reduced from 0.4 to 0.2 yr^{-1} . This helped offset the impact of additional fishing mortality and allowed the biomass accumulation rate to stay close to the previously calibrated level. The reduced value for predation mortality now lies closer to the values used for grouper, snapper and large reef associated adult fish ($F = 0.038, 0.156$ and 0.225 yr^{-1} , respectively). Predation mortality should be highest in the large reef associated fish group because it contains smaller species on average than the more selective groups: groupers, snappers and Napoleon wrasse. We also increased the biomass estimate of Napoleon wrasse in the Raja Ampat model from $0.034 \text{ t}\cdot\text{km}^{-2}$ to $0.152 \text{ t}\cdot\text{km}^{-2}$. The previous estimate simply assumed 10 fish per hectare in reef environments (Russel, 2004); the new estimate is based on species-level identification of *Cheilinus undulatus* in reef health monitoring transects in SE Misool. The calculated value of $0.166 \text{ t}\cdot\text{km}^{-2}$ (Tables A.1.1 and A.1.2) was assumed to include adult and sub-adult stanzas. The figure was then scaled to reflect the relative shelf area ($<200 \text{ m}$ depth) in SE Misool and Raja Ampat; biomass density was reduced slightly to represent the comparatively deep area of Raja Ampat. The new biomass estimate for Napoleon wrasse is divided into three age stanzas according to the existing multi-stanza model (Table D.1.1). Fisheries remove 47% of the available annual production, resulting in an initial 8% annual biomass decline in forward simulations of the adult group. The decline stabilizes in 5-10 years.

Pelagic fish

Once we incorporated IUU catch, the fishing mortality on large and medium pelagics increased by 1.75 times; the discrepancy is not severe as in reef species. To permit the higher rates of capture in the large pelagic group we increased the biomass pool from $0.054 \text{ t}\cdot\text{km}^{-2}$ (adult stanza) to $0.074 \text{ t}\cdot\text{km}^{-2}$. The previous estimate was determined using an approximate method where abundance of large pelagic species was inferred using qualitative rankings of abundance found in McKenna et al. (2002), and then absolute biomass was estimated using species-level anchor points from transect counts (COREMAP, 2005).

The revised biomass estimate includes this value, but it is now averaged along with values from Kofiau and SE Misool Islands. Values from Kofiau and SE Misool Islands were determined by scaling the Raja Ampat biomass value in direct proportion to the relative amount of sea area in each local area model, so that models containing relatively less sea area have lower abundances of pelagic fish overall. Biomass in the juvenile group is determined based on the adult biomass using previous multistanza parameters. Total large pelagic biomass is $0.122 \text{ t}\cdot\text{km}^{-2}$ (Table D.1.1). Fisheries remove 14% of the available annual production, which causes an initial biomass decline for the adult group of about 5% per year in the first few simulation years.

Similarly, the biomass of medium pelagics was increased from $0.011 \text{ t}\cdot\text{km}^{-2}$ (adult stanza) to $0.030 \text{ t}\cdot\text{km}^{-2}$ to make more production available to fisheries. The new biomass term includes information from Kofiau and SE Misool reef health monitoring studies. It now represents an average of transect biomass densities for these areas, and the biomass level previously estimated for Raja Ampat from qualitative sources (as large pelagics; McKenna et al. 2002). Biomass in the juvenile group is determined based on the adult biomass using previous multistanza parameters. Total medium pelagic biomass is $0.122 \text{ t}\cdot\text{km}^{-2}$ (Table D.1.1). The biomass accumulation rate is slightly positive under baseline levels of fishing effort, but biomass quickly assumes an equilibrium position under baseline dynamic simulations that is close to the baseline level.

The skipjack catch calculated by a CI valuation report (Dohar and Anggraeni, 2007) looks at catches from only 2 tuna companies out of 150 operating in the area, so the catch estimates may be unrepresentative of

the total amount from Raja Ampat. We have therefore elected to use DKP and Trade and Industry Office statistics collected in Indonesia (Ainsworth et al., 2007). These government sources are likely to include skipjack catch from regions outside of Raja Ampat such as the Halmahera Sea, Seram Sea, Maluku, Cendrawasih Bay, Fak-fak, Kaimana and elsewhere in the Pacific Ocean²¹. However, we assume that records kept in Sorong will be more representative of Raja Ampat. The gross quantity of catch was typically adjusted upwards to account for IUU (Varkey et al., in prep.).

Lobsters

The only invertebrate group heavily affected by the addition of IUU catch is lobsters. Considering the IUU estimates, a total of 0.262 t•km⁻² of lobsters is captured in reef gleaning operations, and 0.354 t•km⁻² is captured in Raja Ampat over all gear types (Table D.2.1). Although important in commercial and artisanal fisheries, this high level of catch is at least an order of magnitude more than the original lobster groups that the model of Ainsworth et al. (2007) could accommodate. In order to resolve the discrepancy, we opted to increase both the biomass and production rate of the adult functional group. Biomass and production rate were both highly uncertain data points, and their values may have been improved by the additional constraint of unreported fisheries catch. The previous biomass estimate, 0.219 t•km⁻², was calculated by Ainsworth et al. (2007) from reef top transects along the South coast of Waigeo Is. (COREMAP, 2005). Although it is based on sampling, an approximate scaling factor was used by Ainsworth et al. (2007) to convert the Waigeo abundance into Raja Ampat biomass density; the scaling factor depends on the assumption that lobsters occupy mainly reef areas. This is a potential source of error. We increased biomass to 0.5 t•km⁻². Put in context, this value represents about 87% of crab biomass in the model, and about 51% of sea cucumber biomass. The previous P/B for lobsters, 0.446 yr⁻¹, is based on an empirical formula (Brey, 1995) calculated using life history parameters from four Australian genera (BRS, 1999). We increased the P/B substantially to 0.8 yr⁻¹ in order to agree with the large biological production rate predicted by our revised fishery estimates. This estimate is not unreasonably high compared with values used by other authors in tropical systems (e.g., Mexico: 0.9 yr⁻¹, Arreguín-Sánchez, 1993b; 0.62 yr⁻¹, Vidal and Basurto, 2003). Still higher values (~3 yr⁻¹) are typically used for aggregated groups of heterotrophic benthos (e.g., Sivestre et al., 1993).

Raja Ampat model for 1990

Reef fish

The addition of revised IUU estimates from Varkey et al. (in prep) improved the catch values for reef fish used by Ainsworth et al. (2007) for all Ecopath models including the 1990 Raja Ampat model. The revised catch estimates for 1990 include year-specific IUU data, as estimated based on the historical trend of misreporting. With few exceptions, adding the revised catch estimates did not greatly disturb commercial reef fish groups. That is, the rate of production in the preliminary 1990 model was generally sufficient for target functional groups to supply the revised fishery catches, unlike with the 2005 model. However, 1990 biomasses for Raja Ampat were also revised and entered into the model. The 1990 biomasses for reef fish were estimated using the same methodology as Ainsworth et al., 2007, in which past biomass is determined relative to the 2005 level on the basis of CPUE data from government fishery statistics. With the incorporation of these new predator biomass values, consistently revised upwards from the preliminary estimates based on results of the reef health monitoring study in Kofiau and SE Misool, many invertebrate groups seemed over-predated. To balance the 1990 model, we increased the biomass of infaunal invertebrates from 27.4 t•km⁻² to 35 t•km⁻². We also broadened the diet of some predators to provide additional resources to them. It was necessary to reduce the biomass of snappers in 1990 below the amount estimated using the CPUE conversion; also for medium reef associated fish. Revised biomass estimates for these groups are provided in Table D.1.1.

Sharks

Addition of the IUU catch increased fishing mortality on adult large sharks by 20% over the level estimated by Ainsworth et al. (2007); juvenile fishing mortality was increased by more than 3 times. Combined with reduced prey availability following the catch and biomass revisions, these changes in the

²¹ Anita Gracia. CI. Jl.Gunung Arfak.45.Sorong, Papua, Indonesia, personal communication.

influential group large sharks introduced system-wide instability to the 1990 model. It was resolved by altering the age-class mortality parameters (Z) (adults: 1.1 to 0.7 yr⁻¹; juveniles: 1.3 to 0.9 yr⁻¹) so that juveniles compose a greater fraction of the total population biomass. This reduced fishing mortality on them. This change was also incorporated in the 2005 Raja Ampat model since it is likely that the population of large sharks is now similarly skewed towards juvenile age classes as a result of heavy exploitation. Finally, it was necessary to significantly reduce predation mortality through the diet matrix on juvenile large sharks, juvenile small demersals and juvenile coral trout as a consequence of increased predator biomasses recorded in reef health monitoring data.

Turtles

Several changes were required to recreate the observed decline in turtle populations for all turtle groups (reef associated, green turtles and oceanic turtles) which, in initial tests of the revised 1990 model, failed to deplete as is thought to have happened in Raja Ampat since 1990²². The production rates (P/B) for these groups were reduced relative to the 2005 model to reflect the prevalence of larger individuals in 1990. The P/B values, 0.143 yr⁻¹ for reef associated, 0.053 yr⁻¹ for green turtles and 0.05 yr⁻¹ for oceanic turtles, used by Ainsworth et al. (2007) for both 1990 and 2005 models, have been reduced to 0.09, 0.03 and 0.03 yr⁻¹, respectively in the 1990 model. Although we have no reliable biomass time series for any turtle group, the dynamics now fall close to the estimated 1990 and 2005 start/end points. Following the same logic, the consumption rates (Q/B) have been reduced from the preliminary estimates of 3.5 yr⁻¹ to 3.0 yr⁻¹ for all turtle groups. Catch rate was increased from the preliminary estimate of Ainsworth et al. (2007) from 2, 1.1 and 1.1 kg·km⁻² to 8, 6 and 6 kg·km⁻², respectively. Finally, ecotrophic efficiency was lowered from 0.95 in the preliminary model for all groups, to 0.4 (reef associated and green turtles) and 0.1 (oceanic turtles). These lower values are more appropriate for wide ranging species; lower values reflect a substantial proportion of mortality that occurs outside of the modelled system. For a discussion on the challenges of modelling migratory behaviour in Ecosim see Martell (2004).

The oceanic turtles, including the wide-ranging species leatherback turtle (*Dermochelys coriacea*) represent an extreme example of migratory species. A recent study in Raja Ampat confirms anecdotal reports with regards to the importance of the area for leatherbacks, and especially North Papua as a nesting area, a migration corridor, and perhaps also a breeding and foraging area (Hitipeuw et al., 2007). Although too few individuals have been tagged to draw conclusions regarding the population status, the wide-ranging nature of these animals and their use of Raja Ampat habitat for a variety of purposes are confirmed in this study. The BHS EBM turtle tracking and monitoring project indicates that green turtles too (in the EwE reef-associated functional group), are known to range in and out of Raja Ampat. One animal (named Mona by WWF staff) was tracked as far away as Borneo in a time span of only 60 days²³. The implicit assumption for these and other wide-ranging species is that the amount of fishing and predation mortality in the modelled system is similar to the mortality sources outside of the system. The trophic impact of turtles should be adequately represented in the models; however, estimates regarding the population resiliency, especially with regards to fishing activity, are not easily represented except by applying the assumption that the level of fishing activity in the modelled area is representative over their entire range.

Sub-area models

Ecosim models were prepared as the basis for four Ecospace models presented here: Raja Ampat, Dampier Strait, SE Misool Island and Kofiau Island. Catch for the sub-areas was apportioned according to the methodology reported above; a scaling factor was used to adapt the Raja Ampat catch matrix to the sub-areas, which is based on the relative biomass of targeted species and the human population density. However, some manual adjustments were required for the sub-area models to correct substantial imbalance. Most of the difficulties in balancing the sub-area models were related to excessive predation mortality caused by the input of reef health monitoring transect biomass data (the biomass estimate for many functional groups was revised upwards based on reef health monitoring data). We considered reef health monitoring data to be high quality, and so to achieve balance we adjusted the diet matrix to relieve the excessive predation. In only a few cases it was necessary to reduce the amount of catch estimated for the sub-area models.

²² Andreas Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, personal communication.

²³ Geoffrey Gearheart; WWF Pejaten, Tabanan, Bali, personal communication; satellite tracking data available at SeaTurtle.org.

In order to balance the Kofiau model we reduced the catch of Napoleon wrasse to 20% of the level estimated above using target species biomass and human population density. We also increased biomass density, which was modified from the Raja Ampat value using relative reef area ratio (Table 2.1), by 67% to $0.015 \text{ t} \cdot \text{km}^{-2}$. This further reduced fishing mortality on Napoleon wrasse so that fisheries consumed half of the available surplus production. This amount is representative of a fully exploited species. Similarly, we reduced the catch of adult large demersals, adult small demersals and skipjack tuna to 50% of the values estimated using ratios above. We reduced mackerel catch to 40% of its preliminary value.

Except for these adjustments which required us to reconsider catch, all other adjustments to the Kofiau model for the purposes of balancing were made using the diet matrix.

ECOSIM TUNING

Vulnerability parameterization

Vulnerabilities for the 1990 model were parameterized initially using an automated search algorithm (Christensen and Walters, 2004); manual adjustments were then made during the process of tuning to time series data. The fitted vulnerabilities are presented in Table D.3.2. We first determined the critical vulnerability interactions in the model by use of an automated sensitivity analysis (a subroutine of the vulnerability optimization routine). We adjusted values for 75 out of 92 potential predator groups based on their interaction strengths; the 75 chosen were shown to have the greatest impacts on ecosystem dynamics. The remaining predator groups were allowed to retain default mixed control values (vulnerability = 2).

The values for interaction vulnerabilities were set using Ecosim's automatic optimization routine, and initially searching by predator (columns) so that each prey item receives the same value. Ecologically, this approach assumes that all prey are similarly vulnerable to a given predator. The assumption may be appropriate for the Raja Ampat suite of models because functional groups are partitioned in order to provide a highly detailed representation of reef associated species. If we assume that reef associated species generally rely on reef structure as a refuge from predators, this default assumption will be applicable to a large number of predator functional groups; all except a few highly specialized groups that employ distinctive hunting methods.

As tuning continued through manipulation of the catch (Table D.2.1) and diet matrix (Table D.3.1), new optimal vulnerability values were determined for individual interactions. The automated routine was again used for this. However, the automated routine is designed to minimize data residuals between observed and predicted time series of catch and biomass. Often, a subjective improvement in the data fit is not accompanied by a reduction in residuals due to the fact that we have incomplete knowledge of ecosystem trends. A simple data fitting criterion, to reduce the sum of squares residuals between predicted dynamics and available time series, is usually not sufficient when there are large uncertainties surrounding time series information, as in the present case. We therefore manipulated vulnerability parameters manually to affect the shape of specific predation mortality trends.

Mediation functions

A mediation function as used by Ecosim represents a non-trophic interaction in which the vulnerability of a given prey towards a given predator is affected by the biomass of a third mediating group. The mediation routine is used to represent protection and facilitation effects in the ecosystem (Christensen et al., 2004), and can capture key animal behaviours. Some applications of mediation functions in EwE are described by Okey et al. (2004) (sea floor shading by plankton blooms) and Cox et al. (2002) (tunas mediating forage fish mortality caused by birds).

The preliminary Raja Ampat models of Ainsworth et al. (2007) applied four types of mediation functions to various ecosystem interactions. We use similar relationships here. The first function represents the facilitation effect that tuna can have in corralling small pelagics to the surface. When the mediating tuna groups (skipjack and other tuna) are in high abundance, the vulnerability of small pelagic fish groups (juv/ad small pelagic, juv/ad anchovy) to sea birds increases as sea birds forage more effectively. The second mediation function represents the protection offered by reef building corals on juvenile and subadult reef fish groups and octopus. With this mediation function, a high biomass of reef building corals

(hermatypic scleractinian corals) reduces the vulnerability of prey groups to all their predators. The third mediation function represents the positive effect that cleaner wrasse have on reef associated fish. We assume that the symbiotic grooming relationship improves the health of the client fish and provides them with a lower vulnerability to all their predators. The fourth mediation effect represents the protection offered by sea grass and mangroves to juvenile reef fish (juv. grouper/snapper) and shrimp (penaeid shrimps, other shrimps and prawns). We assume these prey are protected somewhat from all their predators. The shapes of the mediation functions are shown in Fig. 2.6; Table 2.11 shows the functional group assignments.

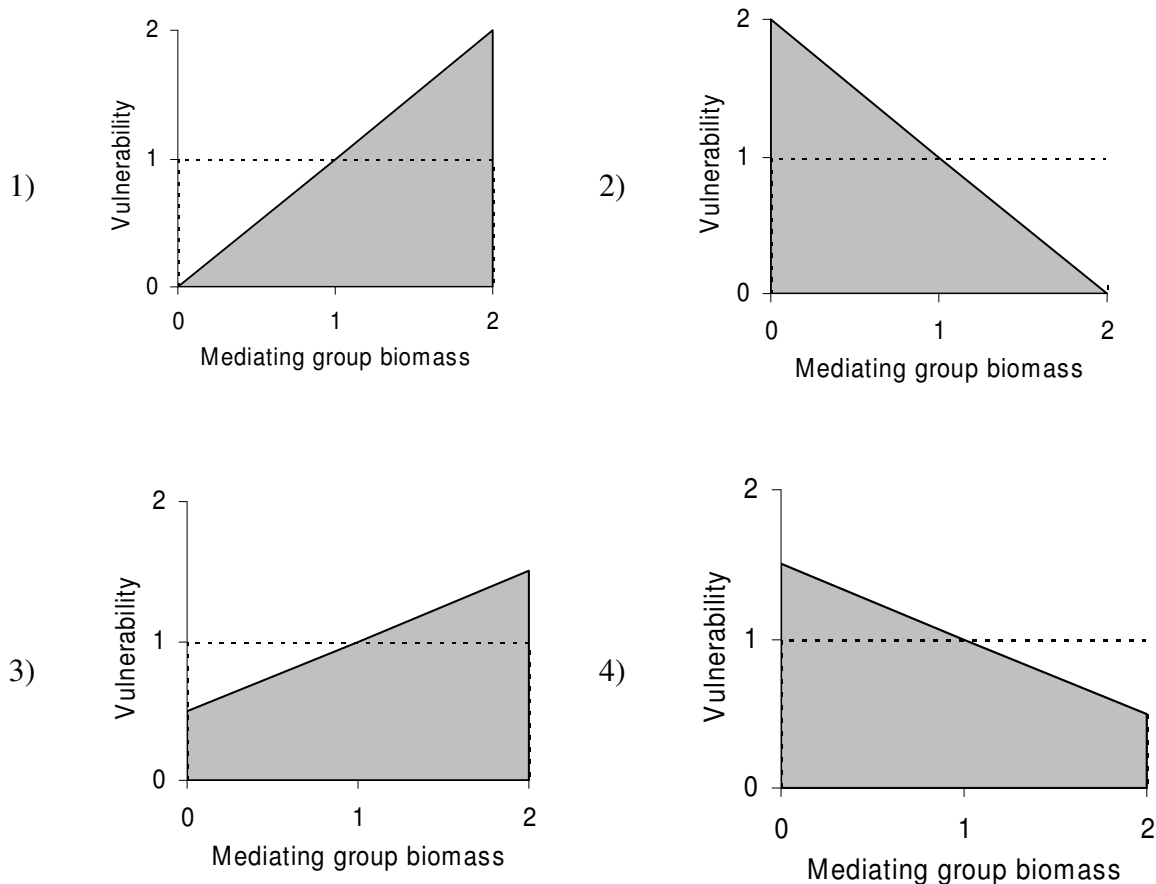


Figure 2.6. Ecosim mediation functions. Vulnerability of prey versus mediating group biomass. 1.) Tuna facilitating small pelagic predation by birds; 2.) reef-building coral protection of reef fish and invertebrates; 3.) cleaner wrasse symbiosis with large reef associated fish; 4.) sea grass and mangrove protection of juvenile reef fish. X and Y axes are relative to model baseline values.

The first and second mediation functions represent major behavioural effects in which the vulnerability of the prey group can be reduced close to 1 during periods of low / high abundance of the facilitating / protecting functional group. The vulnerability to predators can increase up to two times the baseline model value during periods in which the biomass of mediating groups is unfavourable for the prey. The second and third mediation functions represent minor behavioural effects in which the vulnerability of the prey can increase to 1.5 times the baseline value, or decrease to 0.5 times the baseline value. All mediation functions are linear, so that vulnerabilities increase or decrease linearly with the biomass of mediating groups. We used this simple assumption because the true relationships that govern mediation effects are likely to be complex, highly variable between functional groups, dependent on the baseline model, and difficult to parameterize empirically. The simplifying assumption can provide only a rough approximation to the true relationships occurring in the ecosystem because the ecological effects of a changing vulnerability term in the model are not linear throughout its potential range of values (1 to infinity). An increase of 10%, for example, will have a greater influence on system dynamics for a donor controlled

interaction (e.g., 1 to 1.1) than for a predator controlled interaction (e.g., 10000 to 11000).

Until recently, there was a limitation in the mediation routine such that each predator-prey interaction could be governed by only one mediation function. Modellers were forced to choose only the most influential effects for any given predator-prey interaction. They could not, for example, model the protection that coral reefs impart on reef fish, while simultaneously representing the advantage conferred on them by cleaner wrasse. However, EwE Version 5 (revision of May 2007) has removed this limitation, and we can now represent multiple mediation effects on a single feeding interaction.

Table 2.11. Mediation functions.

Prey group	Mediation #	Prey group	Mediation #
Ad. groupers	2,3	Juv. small reef assoc.	2,4
Sub. groupers	2	Ad. large planktivore	2,3
Juv. groupers	2,4	Juv. large planktivore	2,4
Ad. snappers	2,3	Ad. small planktivore	2
Sub. snappers	2	Juv. small planktivore	2,4
Juv. snappers	2,4	Ad. anchovy	1
Ad. Napoleon wrasse	2,3	Juv. anchovy	1
Sub. Napoleon wrasse	2	Ad. macro algal browsing	2,3
Juv. Napoleon wrasse	2,4	Juv. macro algal browsing	2,4
Ad. coral trout	2,3	Ad. eroding grazers	2,3
Juv. coral trout	2,4	Juv. eroding grazers	2,4
Ad. small pelagic	1	Ad. scraping grazers	2,3
Juv. small pelagic	1	Juv. scraping grazers	2,4
Ad. large reef assoc.	2,3	Penaeid shrimps	4
Juv. large reef assoc.	2,4	Shrimps and prawns	4
Ad. medium reef assoc.	2,3	Octopus	2
Juv. medium reef assoc.	2,4	Small crabs	2
Ad. small reef assoc.	2		

Primary production forcing

We use an automated routine in Ecosim to determine the primary production anomaly pattern that will minimize the discrepancy between the predicted biomass trajectories of functional groups from 1990-2005 and the observed catch and relative biomass estimates, based on governmental statistics. The production forcing routine, as integrated into Ecosim, adjusts the search rate of subject functional groups and so indirectly increases or decreases the annual production rate versus baseline²⁴. A production forcing trend can be applied to any functional group to represent the affects of climate fluctuation on primary or secondary production (EwE production forcing: Christensen et al. 2004). By applying it to the phytoplankton functional group, we assume that fluctuations in primary production can cascade up the food web and affect the abundance of higher order species (Beamish, 1995; McFarlane et al., 2000).

Ainsworth et al. (2007) did a similar search for an environmental production anomaly trend for Raja Ampat using an arbitrary number of spline points to smooth the resulting climate anomaly. They then re-scaled and re-entered the production modifier trend into the 1990 Raja Ampat model so that the predicted annual phytoplankton biomass variability from simulations matched the observed variability from SeaWiFS satellite primary production data (SeaWiFS, 2007. NASA Goddard Space Flight Center. Online resource. URL: <http://oceancolor.gsfc.nasa.gov/SeaWiFS/>).

Here we use a 4.2% coefficient of variation (CV) in phytoplankton biomass. A spline point is a function used by Ecosim's production anomaly search routine to smooth the resulting annual production anomaly trend. The routine uses a cubic spline method optimized with a nonlinear Levenberg-Marquardt search

²⁴ Villy Christensen. UBC Fisheries Centre, 2202 Main Mall, Vancouver BC, personal communication.

algorithm (Press et al., 1995). The expected CV represents an average for all cells listed in the *Sea Around Us* project (2006) database in our study area, and it represents the average variation of each 5 year period between 1990-2005.

We use this 'moving window' approach so that the coefficient of variation is not biased by directional biomass change, as may be caused by fishery depletions for example; instead, random environmental fluctuations are the main cause of interannual variation. The CV is based on data from the years 1998-2002. In the *Sea Around Us* project (2006) dataset, primary production is estimated from ocean colour; we assume that the trend is representative of our phytoplankton functional group biomass. Ainsworth et al. (2007) comment on the assumptions and caveats associated with this use of ocean colour data.

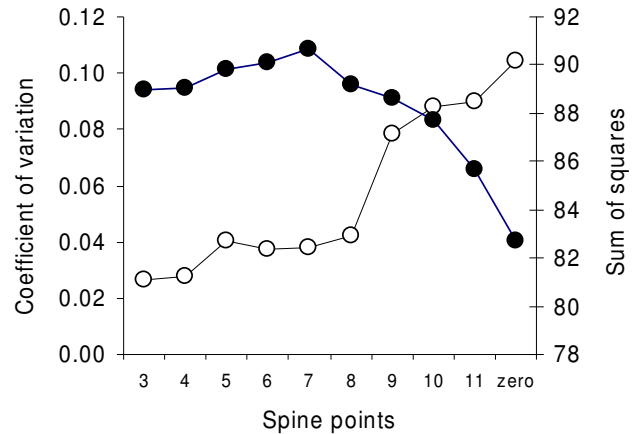


Figure 2.7. Primary production anomaly CV. Additional spline points results in more variable phytoplankton biomass in the 1990-2006 dynamic simulation, and reduced residuals (sum of squares) versus observations. 'Zero' spline points represents no smoothing. Satellite data indicates an annual 4.7% CV for Raja Ampat. Using 8 spline points reproduces the appropriate level of production variability.

Time series reconstruction

Using fitted vulnerabilities, mediation functions and primary production forcing in place we produce the best-fit to time series data in Fig. E.1.1. These figures compare the dynamic time series predictions by Ecosim and the empirically observed estimate of time series relative biomass derived from CPUE data (Ainsworth et al., 2007). Presented for comparison with the time series predictions are the 2005 model biomasses for functional groups as estimated in this report, along with confidence intervals representing an approximate ranking of data quality. The biomass values for all groups in the 2005 Raja Ampat model are presented in Table D.1.1. The confidence intervals are based on the default coefficients of variation used by the data pedigree routine in Ecosim as a ranking of data quality. These are: sampling based, high precision (c.v. = 10%); sampling based, low precision (c.v. = 30%); indirect method (c.v. = 50%); other method (c.v. = 80%). The biomass values for many functional groups are set in this report based on reef health monitoring dive transect studies; these received high data quality rankings (1-3). The top ranking of data quality (c.v. 10%) is reserved only for the grouper and snapper functional groups because all of the species in those groups (all Serranidae and Lutjanidae species, respectively) were specifically noted by divers. For aggregated functional groups like large reef associated fish, a fewer relative number of species were specifically recorded. These groups receive a lower ranking of data quality (4-5). Most other data is taken from outside the Raja Ampat ecosystem, or estimated by Ecopath (see Ainsworth et al., 2007 for EwE group descriptions).

In most cases, the 1990 model, when driven forward 15 years using historical fishing effort trends, mediation and forcing functions, produces a reasonable representation of the 2005 ecosystem. Although there are discrepancies between the end-state of the 1990-2005 simulation and the 2005 model, the discrepancies tend to occur within data-poor groups such as those representing many species (highly aggregated groups), and those representing poorly studied organisms; especially, basal species and unexploited invertebrates; these have large confidence intervals in Fig. E.1.1. In the case of aggregated groups we can, at best, know the biomass history for only a small fraction of the member species. The default assumption we have used, that other species in those groups have exhibited similar population dynamics over the last 15 years as the better-known species, provides us with only a rough idea of the aggregate biomass trends. Both the time series trends and the 2005 biomass values for these groups are therefore approximate. In some cases, the simulation biomass, which is constrained by the system's thermodynamic requirements, is probably more accurate than the relative biomass or catch information used to tune the model.

The dynamics of most well-studied and highly commercial functional groups, such as groupers, snappers and tuna, are adequately represented in simulations inasmuch as the CPUE trends are accurate reflections of their relative biomass. The dynamics of these groups tend to be dominated by the effects of fisheries. Therefore, the observed trend from CPUE data can be recreated with some accuracy using fishing drivers as the principle mortality source. For groups that are less exploited by fisheries, population dynamics are determined by a combination of fishing mortality and natural mortality. The latter is more difficult to estimate because it represents the combined effect of many predators, and each diet interaction carries uncertainty.

Biomass dynamics of immature and sub-adult life history stanzas tend to be poorly predicted, particularly for groupers and snappers, which each have here 3 life history stages. The biomass trajectories for these groups do not result in an end-state 2005 configuration that resembles the 2005 model, but this is partly due to a modelling limitation. The multi-stanza routine in Ecosim assumes a static (equilibrium) age structure. However, we intentionally adjusted the production rate of the age stanzas in the 2005 model relative to the 1990 model in order to represent a shift in the assemblage composition towards younger individuals for some exploited groups (Table D.4.1). It is therefore difficult in principle to fit both the adults and sub-adults simultaneously without age-specific biomass trends. Moreover, we cannot accomplish the life history parameter shift gradually using the dynamic facilities of Ecosim since we have no direct control over the age-structure short of forcing population biomass. We have chosen to focus on the adult stanzas in tuning, preferring to develop dynamics for this group that match the available CPUE trends, while allowing sub-adults and juvenile groups to take whatever biomass values are predicted by the stable age structure.

EQUILIBRIUM ANALYSIS

An equilibrium analysis provides an invaluable way of validating EwE model behaviour. It is second in importance only to fitting the dynamics against time series data. In an equilibrium analysis, we are interested in determining the absolute level of biomass that each functional group in the ecosystem assumes at long time scales under a given fishing pattern and level of fishing intensity, and the corresponding amount of catch. By holding the fishing level constant on all functional groups except our subject group, we can map out the estimated population response at a variety of fishing intensities. This method allows us to quantify and represent the exploitation status of stocks, and so to compare the behaviour of the model with our a priori understanding of the ecosystem.

The equilibrium analysis that is conducted for an ecosystem model produces outputs analogous to biomass dynamic models commonly used in single-species fisheries management. The biomass of an exploited group will usually be highest under zero fishing effort (the catch then will also be zero); this biomass level is referred as B_0 , or unfished biomass. As fishing intensity increases, catch on the subject functional group will increase to a maximum, which is called Maximum Sustainable Yield (MSY: Russell, 1931; Graham, 1935). When fisheries take exactly this amount, the biomass at maximum sustainable yield (B_{MSY}) can be maintained at equilibrium (in principle, with caveats). However, when catches exceed this amount overfishing occurs. Biomass is removed from the stock faster than the replenishment rate from growth and reproduction, and the population assumes depressed biomass equilibrium; catches will be sub-optimal. Other useful fishery indicators can be determined through the equilibrium catch and biomass curves including the precautionary fisheries management objective $F_{0.1}$. $F_{0.1}$ represents the point on the yield per recruit curve at which the slope of the line tangential to the curve is equal to one-tenth the slope of a line tangential to the curve at the origin (Gulland and Boerema, 1973). $F_{0.1}$ is always lower than F_{MSY} , and it has been suggested as a safer target for management.

An equilibrium analysis using an ecosystem model offers a major advantage over single species methods because it accounts for species interactions. Even though an ecosystem model represents a greatly simplified abstract of the true ecosystem, the number of trophic and non-trophic interactions increases exponentially with the number of functional groups. These interactions can combine in unexpected ways to greatly affect stock dynamics. The multispecies surplus production curves can differ drastically compared to a similar single species estimate, and the sources of these discrepancies are important to consider in an EBFM framework. We perform this comprehensive review of model behaviour here and

present the results in a series of equilibrium catch and biomass curves for exploited species. As with analogous single species methods, the equilibrium analysis relies on the assumption of deterministic population behaviour in growth, recruitment and mortality, and so is subject to similar criticisms (e.g., Larkin, 1977; Punt and Smith, 2001). Climate variation, for example, can only reduce the estimate of safe harvest limits.

Ecosim contains an automated routine to establish the equilibrium catch and biomass curves. However there is a technical problem with the routine that will prevent the curves from being comparable to analogous single-species procedures. This problem is accentuated in models that use multiple ontogenetic stanzas, like the present Raja Ampat models. The problem is that the automated routine can only increment the fishing mortality on a single age stanza. If all of the fishery catch is directed to a single stanza, the adult group for example, this limitation is not an issue. But if, however, there is significant fishing on other age classes, such as the sub-adult or immature stanzas, the automated routine will assume a constant (baseline) fishing pressure on these stanzas. The result is that the adult group will seem unrealistically resilient to the effects of fishing as the younger age classes, unaffected by all but a baseline level of fishing pressure, continue to recruit into the adult stanza. The catch curve for the adult group in this case will be shifted towards the right (e.g., see Figure E.2.1), indicating that it can support a high level of fishing mortality. In reality, however, an increase in fishing mortality on the adult group will usually be accompanied by an increase of fishing mortality on the younger age classes due to the unselective nature of fishing gear.

Hence, because the Raja Ampat models contain many multi-stanza groups whose sub-adult and juvenile age stanzas are subject to fishing, we opted to avoid the use of the automated equilibrium routine and instead perform the calculations manually – incrementing fishing mortality on all fished age classes simultaneously and allowing the populations to come to their fishery-induced equilibrium biomass level. Although the procedure is far more time consuming than the automated method, it generates more realistic equilibrium curves that better reflect the exploitation status of stocks.

RESULTS

RECONSTRUCTED HISTORICAL BIOMASS FROM LEK DATA

The following results are supplemental to the findings in Ainsworth et al. (2008). The unprocessed responses obtained from the LEK interviews are presented in Fig. B.1.1 for the 44 species groups tested. The LEK trend for the periods 1970, 1980, 1990 and 2000 were determined by Ainsworth et al. (2008) for all species groups based on the output of the fuzzy logic routine; these are presented in Fig. B.2.1. Using the scaling factor from the CPUE data set relative to 1990 and 2000, those authors back-calculated the relative change from 1970 to present. They presented a selection of the outputs, but the complete results are in this document (Fig. B.2.2). By assuming an absolute biomass in 2000 which is based on the Ecopath estimates of Ainsworth et al. (2006), Ainsworth et al. (2008) determined the biomass for functional groups in 1970. This value was assumed to be similar to B_0 (Fig. 3.1; reproduced from Ainsworth et al., 2008). The other unexploited biomass estimates in Fig. 3.1 (represented by the lower trend line) are determined using the models presented in this report. Those values correspond to the left-most biomass value in the equilibrium graphs in Fig. E.2.1; they represent the biomass value of the functional group at equilibrium as established after a 20 year simulation from 2005 to 2025 under zero fishing mortality.

REEF HEALTH MONITORING

Results from the reef health monitoring study are expected to be published by TNC in 2008²⁵. Results from Waigeo Is. are also forthcoming from CI²⁶. We provide a preliminary summary of the data for Kofiau Is. and Misool Is. as follows to support the current biomass density calculations for the EwE models. The biomass calculated for these fish families was converted to represent EwE functional groups by the procedure detailed in the methods section; this yielded the final biomass values per EwE functional group

²⁵ Contact Andreas Muljadi (Kofiau Island; amuljadi@tnc.org) and Mohammad Syakir (SE Misool Is.; msyakir@tnc.org) at TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413.

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in Table D.1.1. Note that many of the biomass density estimates were modified by an arbitrary scaling factor during the process of model balancing and tuning to data (see Section 2.2); the scaling factors are also reported in Table D.1.1. The functional group biomasses that are set based on the reef health monitoring data are demarked by reference #1 in that table; Table D.1.2 describes the methods used for other functional groups.

Herbivorous fish

Biomass densities for herbivorous fish families in Kofiau are presented from the reef health monitoring data in Fig. 3.2 with average body weight per individual; Fig. 3.3 shows Misool results.

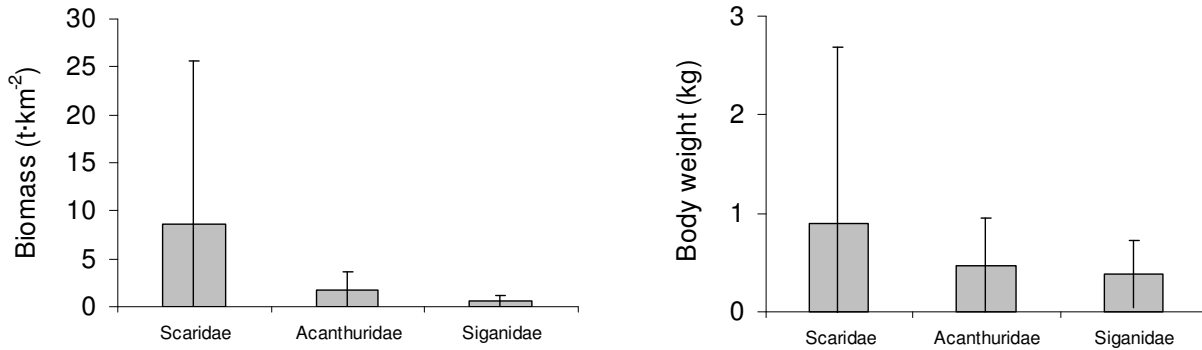


Figure 3.2. Herbivorous fish family biomass and individual body weight for Kofiau. Data from reef health monitoring. Mean values shown for 59 dives; error bars show 1 SD. Source: reef health monitoring study (Andreas Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, unpublished data).

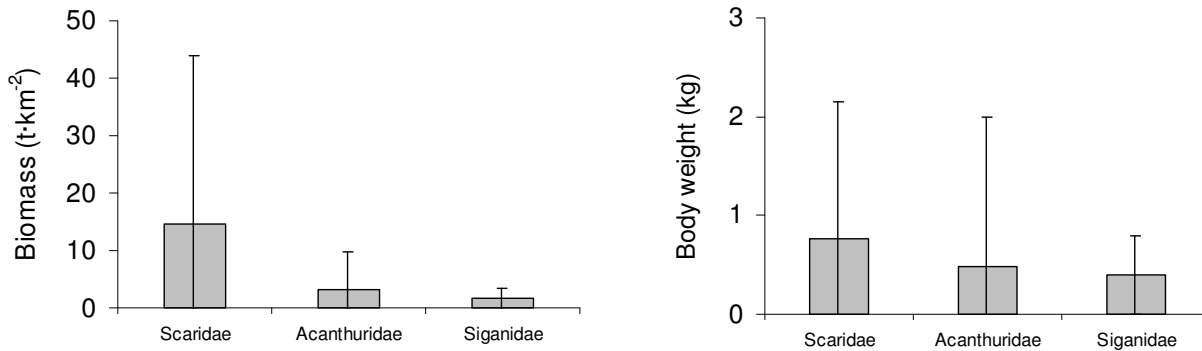


Figure 3.3. Herbivorous fish family biomass and individual body weight for Misool. Data from reef health monitoring. Mean values shown for 182 dives; error bars show 1 SD. Source: reef health monitoring study (Mohammad Syakir. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, unpublished data).

Piscivorous fish

The average biomass density for piscivorous fish in Kofiau Is. sites is reported by family in Fig. 3.4 along with individual body weights by family. Fig. 3.5 shows the results for SE Misool Is.. Fig. 3.6 shows the biomass of Kofiau Is. piscivorous fish by species and Fig. 3.7 shows the results for SE Misool Is..

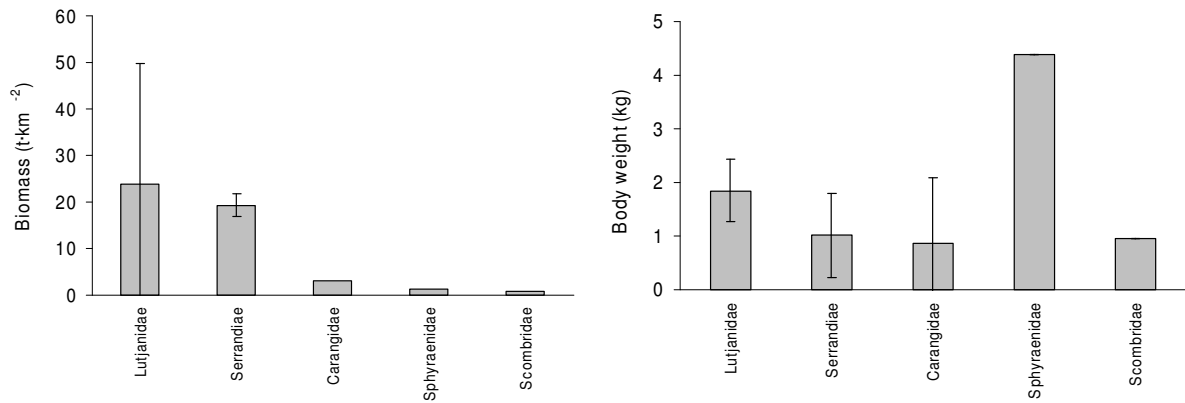


Figure 3.4. Biomass and individual weight of piscivorous fish at Kofiau Island by family. Mean values shown for 26 dives; error bars show 1 SD. Total number of fish observed: Lutjanidae (152), Serranidae (75), Carangidae (27), Sphyraenidae (1) and Scombridae (2). Source: reef health monitoring study (Andreas Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413., unpublished data).

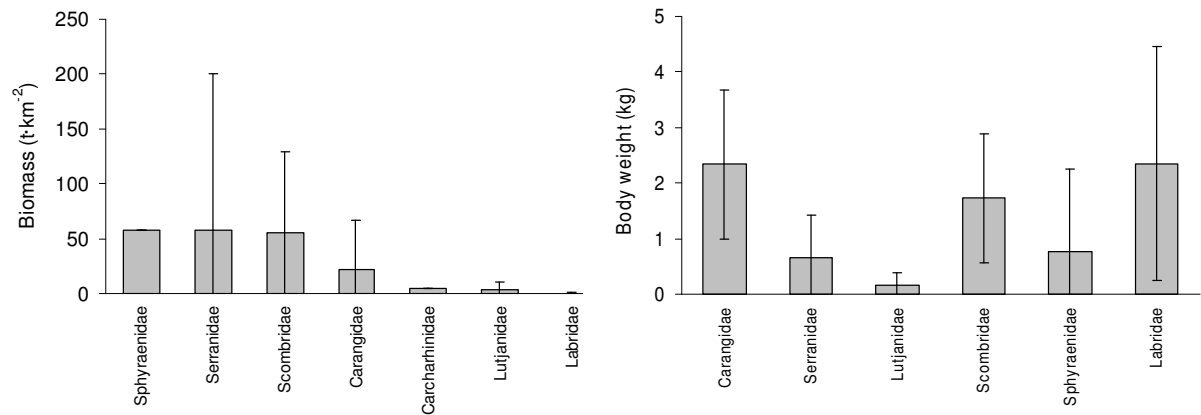


Figure 3.5. Biomass and individual weight of piscivorous fish at SE Misool by family. Mean values shown for 91 dives; error bars show 1 SD. Total number of fish observed: Sphyraenidae (12), Serranidae (1082), Scombridae (443), Carangidae (1878), Carcharhinidae (1), Lutjanidae (28), Labridae (2). Source: reef health monitoring study (Mohammad Syakir. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413., unpublished data).

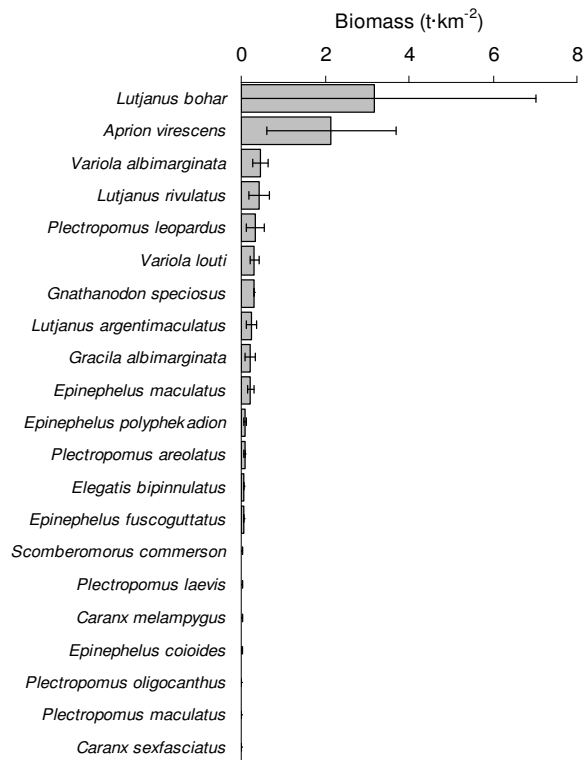


Figure 3.6. Biomass density of Kofiau piscivorous fish species. Mean values shown for 26 dives; error bars show 1 SD. Source: reef health monitoring study (Andreas Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, unpublished data).

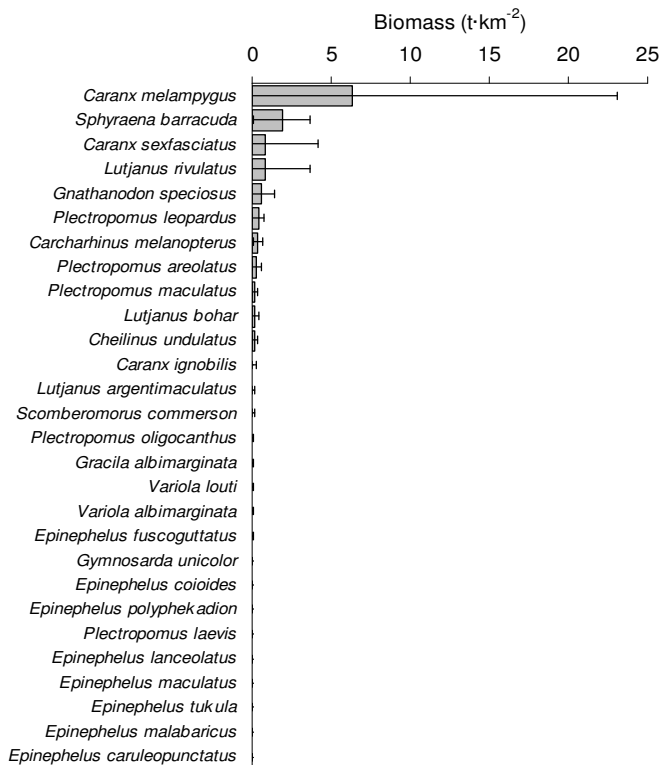


Figure 3.7. Biomass density of SE Misool piscivorous fish species. Mean values shown for 91 dives; error bars show 1 SD. Source: reef health monitoring study (M. Syakir. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, unpublished data).

GUT CONTENT ANALYSIS

Stomach sample results

The diet information for functional groups as determined by the stomach sampling program is presented in pie charts in Fig. 3.8.

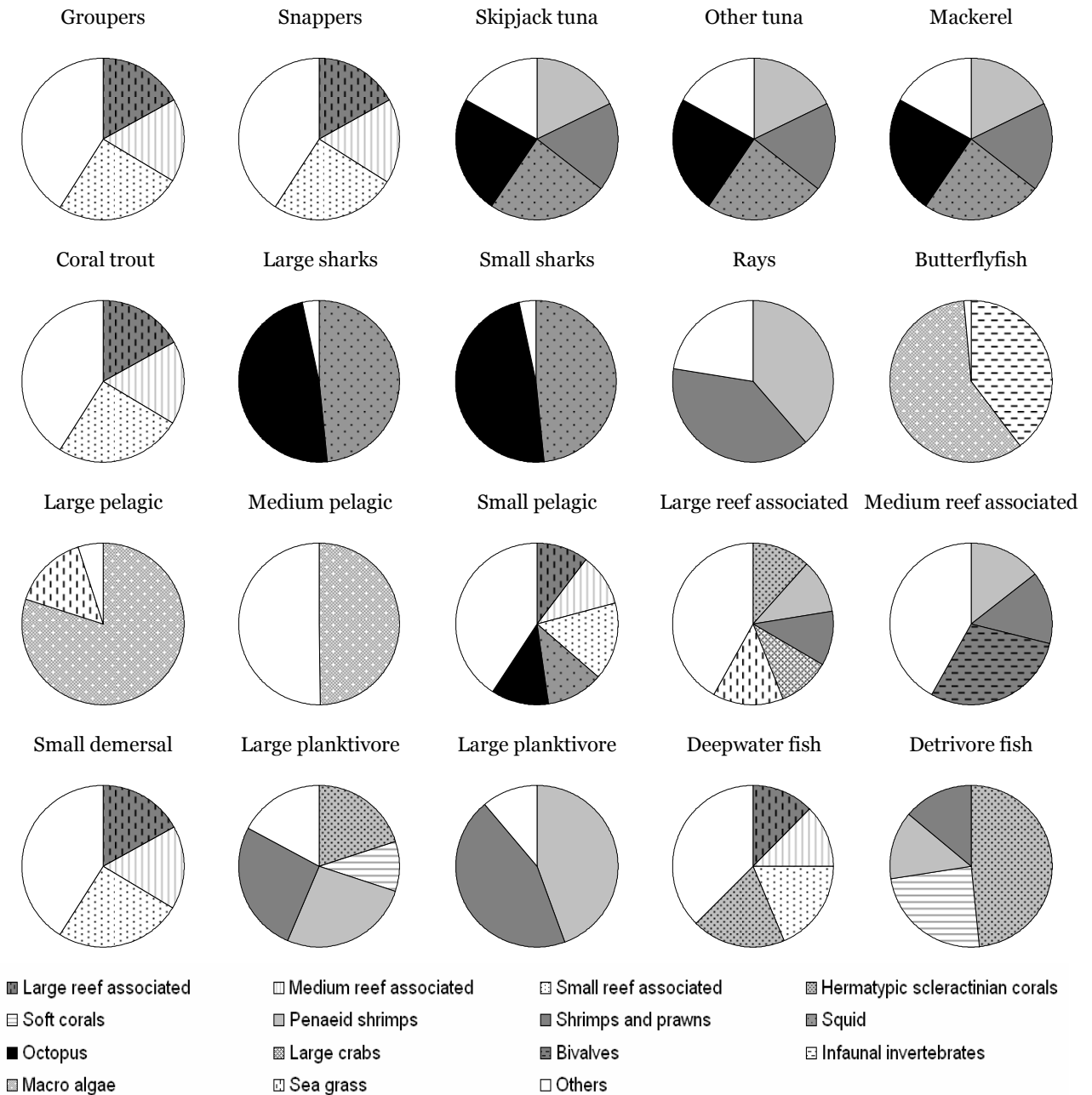


Figure 3.8. Diet for EwE functional groups estimated from family-level gut contents. Diet items contributing less than 10% are included in 'Others' category. Source: BHS EBM stomach sampling study (C. Rotinsulu, CI. Jl. Gunung Arfak. 45. Sorong, Papua, Indonesia, unpublished data).

Table C.2.1 shows the stomach sample data where prey groups have been assigned into their appropriate EwE groups without any further data processing (e.g., polychaetes are assigned to infaunal invertebrates). Entries in the Y-axis of this table represent a straight-forward summation of the stomach contents into the

appropriate categories. Table C.2.2 presents the results of the stomach sampling data for use in the models; predator fish families have been aggregated into EwE functional groups according to conversion ratios in Table C.1.1 (see Methods). Table C.2.3 provides the diet algorithm results from Ainsworth et al. (2007). These original data were subsequently modified by Ainsworth et al. (2007) in the process of balancing and tuning the model, but we have opted to compare the stomach sampling results with the original diet algorithm output.

Once the predators and prey items are aggregated into EwE functional groups, 66% of feeding interactions identified by the stomach sampling program are successfully predicted by the diet allocation algorithm of Ainsworth et al. (2007). For review, this algorithm processes FishBase diet information (Froese and Pauly, 2007) at the species and family level into a form more applicable to the specific functional group structure used in the present model. The remaining 34% are mainly minor interactions (Figure 3.9). Of the predator-prey interactions that are absent from the diet algorithm results, but identified by stomach sampling, only a small number (4.2%) constitute major diet components (i.e., consisting of 25% or more of a predator's diet). This suggests that the diet algorithm of Ainsworth et al. (2007) performed adequately in predicting the major diet interactions in the ecosystem.

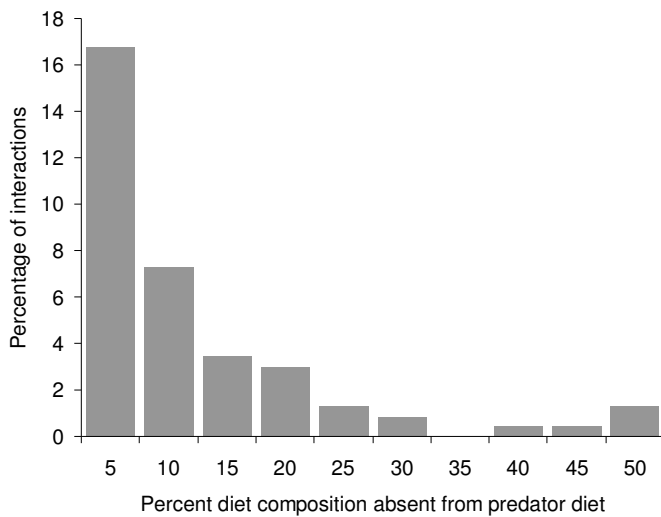


Figure 3.9. Feeding interactions identified by stomach sampling and not diet algorithm. The majority of interactions missed by the diet allocation algorithm are minor interactions, constituting less than 5 or 10 % of the predator's diet. Only a small fraction of major interactions were missed by the diet algorithm of Ainsworth et al. (2007).

In order to compare the output of the diet algorithm of Ainsworth et al. (2007) with the stomach sampling data we considered the rank order of all of the diet interactions (per predator) in both data sets (i.e., Tables C.2.2 and C.2.3 for stomach samples and diet algorithm respectively). Each prey item for a given predator was assigned a rank, where large diet items correspond to a low rank, small diet items correspond to a high rank and the rank of the smallest diet item is equal to the total number of prey items. The rank order direction is not important to the method. The squared difference between the ranks of each prey item was taken as a measure of the discrepancy between the data sets for that interaction. Using this technique we categorized the discrepancies among all predator-prey interactions common to both data sets, and the top 25 percentile of these discrepancies were said to represent critical disagreement. These interactions were considered for revision in the Raja

Ampat models. Table 2.9 shows the top 25 percentile of discrepancies using this rank squared difference method.

Among these critical disagreements, we consider whether the stomach sampling data conflicted with the balanced diet value of the preliminary models (Ainsworth et al., 2007), the diet algorithm, or both. If either the algorithm agrees with the stomach data, or the balanced model agrees with the stomach data, then the diet composition data point remained unchanged in the revised models. The reasoning is as follows. If the stomach data agrees with the algorithm but disagrees with the model, then we assume that the diet algorithm successfully predicted the interaction and the change made by Ainsworth et al. (2007) during the process of balance and tuning the model amounts to a necessary loss of agreement in order to achieve mass-balance and improve the fit to time series data. If the stomach data agrees with the model but disagrees with the algorithm, then we assume that the process of balancing and tuning the model has corrected an errant diet point predicted by the diet algorithm. Interestingly, far more interactions fall into the latter category, indicating that the process of balancing and tuning has improved the diet algorithm results (see Table 2.9). If both the algorithm and the balanced model conflict with the stomach samples, then we change this value in the present revised version of the model. These data points are marked by grey cells in Table 2.9.

Table C.2.4 and Table C.2.5 show the direction and absolute magnitude of the disagreement that the stomach sampling data shows compared to the balanced preliminary model and diet algorithm, respectively. For the interactions marked for revision, we adopted the stomach sample percent composition for that prey item in the model (Table 3.1), adjusting the other prey items with a straight scaling factor so that the total diet of a predator remains at unity. In some cases, the subsequent balancing and tuning of the revised models necessitated the changing of these parameters slightly to yield the final diet matrix for the 2005 Raja Ampat model in Table D.3.1. All of the models, including the 1990 Raja Ampat model and the sub-area models were assigned an identical diet matrix before balancing and tuning. Differences between these matrices should reflect the varying biomass densities of functional groups in the various habitat maps.

Table 3.1. Diet interactions changed to match stomach sampling compositions.

Prey	Predator				
	Snappers	Adult large reef assoc.	Adult medium reef assoc.	Adult large planktivore	Deepwater fish
Ad. large reef assoc.	-	-	0.0487	-	-
Ad. medium reef assoc.	-	-	-	-	0.1248
Ad. small reef assoc.	-	-	-	-	0.1872
Ad. macro algal browsing	0.0844	-	0.0244	0.0159	-
Ad. eroding grazers	0.0844	0.0194	0.0244	-	-
Hermatypic corals	-	0.1180	0.0994	-	-
Soft corals	-	0.0590	-	-	-
Shrimps and prawns	0.0131	-	-	-	0.0123
Squid	-	-	-	0.0006	-
Epifaunal det. inverts.	-	0.0009	-	-	0.0027
Epifaunal carn. inverts	-	0.0009	0.0011	-	0.0027
Infaunal inverts.	-	-	0.0026	0.0058	0.0066
Macro algae	-	0.0046	0.0007	-	-
Sea grass	-	-	0.0004	0.0045	-

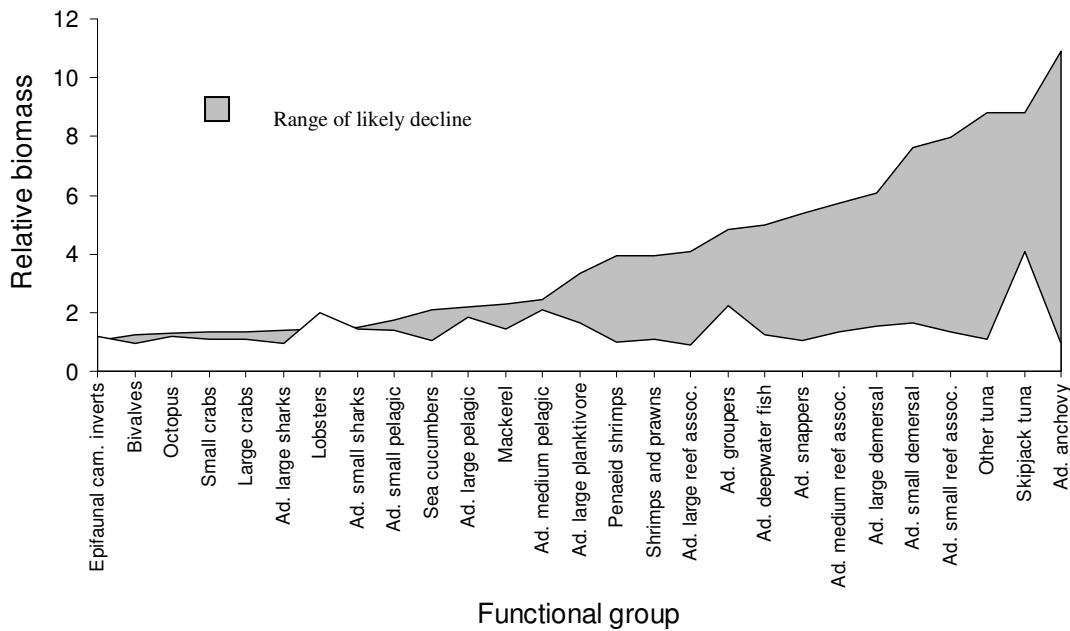


Figure 3.10. Likely range of group biomass depletion from unexploited levels to the present day. The upper bound shows the biomass decline suggested from LEK data; 1970 period is assumed similar to unexploited biomass, B_0 , and 2005 period indicates present day; the lower bound shows the biomass decline suggested by the EwE equilibrium analysis. LEK data indicates more severe declines from the unexploited biomass than equilibrium predictions by the model would suggest. Shaded area represents the range of likely decline. Reproduced from Ainsworth et al. (2008).

ECOSIM ANALYSIS

Equilibrium analysis

The equilibrium analysis is conducted for exploited functional groups in (Fig. E.2.1). These graphs show the level of catch and biomass that can be expected at biomass equilibrium under various levels of fishing mortality. The calculated fishing mortalities at F_{MSY} , $F_{0.1}$ and F_{2005} are presented in summary in Table 3.2. The right-most column in this table indicates the current level of exploitation with respect to the level of fishing that produces MSY. Functional groups approaching F_{MSY} can be considered to be fully exploited. Functional groups at F_{MSY} are likely to be overexploited once environmental variability and the inelasticity of fishing capital (and therefore fishing effort) are finally considered. Results suggest that some functional groups are overexploited.

Table 3.2. Equilibrium analysis results. Various fishing effort indicators and the corresponding amount of catch at biomass equilibrium.

Functional group	Catch at MSY (kg·km⁻²)	F_{MSY} (yr⁻¹)	Catch at F_{0.1} (kg·km⁻²)	F_{0.1} (yr⁻¹)	Catch in 2005 (kg·km⁻²)	F₂₀₀₅ (yr⁻¹)	F₂₀₀₅/F_{MSY} (-)
Groupers	114.5	0.376	114.5	0.365	87.7	0.188	0.50
Snappers	95.0	0.531	94.0	0.398	92.0	0.332	0.63
Napoleon wrasse	18.5	0.348	18.5	0.348	18.5	0.348	1.00
Coral trout	6.5	0.414	6.5	0.414	5.4	0.188	0.45
Large sharks	27.0	0.649	26.9	0.541	26.9	0.541	0.83
Small sharks	11.7	0.585	11.7	0.527	9.9	0.293	0.50
Butterflyfish	142.2	0.874	141.8	0.826	70.3	0.243	0.28
Large pelagic	50.7	0.734	50.7	0.734	50.7	0.734	1.00
Medium pelagic	12.1	0.649	12.1	0.649	10.7	0.405	0.63
Small pelagic	88.2	1.058	88.2	1.058	87.1	0.882	0.83
Large reef associated	770.9	0.232	770.9	0.232	616.9	0.116	0.50
Medium reef associated	286.5	0.275	284.4	0.344	208.5	0.138	0.50
Small reef associated	95.0	1.541	95.0	1.541	49.6	0.426	0.28
Large demersal	57.0	0.304	56.2	0.334	57.0	0.304	1.00
Small demersal	112.9	0.897	112.9	0.897	85.2	0.359	0.40
Large planktivore	439.4	0.763	439.4	0.763	344.4	0.381	0.50
Small planktivore	347.6	1.840	347.6	1.840	170.5	0.460	0.25
Anchovy	626.7	0.753	626.7	0.753	217.5	0.237	0.31
Deepwater fish	211.3	2.482	193.9	0.886	147.6	0.355	0.14
Macro algal browsing	110.3	1.000	110.3	1.000	110.3	1.000	1.00
Eroding grazers	165.5	1.439	165.5	1.439	165.5	1.439	1.00
Skipjack tuna	579.1	0.746	545.6	0.522	545.6	0.522	0.70
Other tuna	36.9	0.090	36.8	0.084	35.5	0.095	1.06

DISCUSSION

FISH BIOMASS

We have used the reef health monitoring assessments in this volume to estimate the biomass of reef fish for the models. However there are number of uncertainties associated with the procedure. Sites were selected randomly, and the scale of the sampling program was large compared to other previous TNC exercises in Komodo, and in other parts of Raja Ampat (e.g., Waigeo Is. in COREMAP 2002). Nevertheless the results of the study will be highly dependent on the local oceanography and biogeography of the reef structure. This introduces a good deal of uncertainty once we scale the results up to represent the total area of Raja Ampat. In effect we have assumed that population structure on the reef system around Kofiau and Misool Islands are similar to other parts of Raja Ampat. There is also some uncertainty as to whether fish are counted only once. In the case of sedentary and territorial reef fish like groupers (Serranidae) this source of error will be minimized. However, the uncertainty is potentially a large one for species such as snappers (Lutjanidae) which are mobile and tend to school. A single incidence of a large school can render the information unrepresentative of the area as a whole, so there are observational uncertainties. Cryptic species too may be underestimated in the reef health monitoring data, and we did not account for this. Unfortunately, we were not able to make use of a large part of the reef health monitoring data, the data from Waigeo Is., because it was not available in time for this study.

REQUESTED EBFM ANALYSES USING EwE MODELS

A workshop at the TNC office in Sanur, Bali held July 16-17, 2007 with TNC, CI, WWF, UBC and Packard staff provided very clear EBFM objectives for the EwE modelling study. In addition, we received specific requests for analyses by the Raja Ampat Regency fisheries bureau²⁷. Hence, the research questions investigated by the trophic modelling are as follows:

- What are the likely ecosystem effects of changes in the anchovy fishery under the following management scenarios?
 - Anchovy fishery is completely removed from Raja Ampat;
 - Limited anchovy fishery is allowed;
 - Anchovy fishery continues to increase in size.
- What are the likely effects of restricting the commercial exploitation of groupers?
- What are the likely effects of excluding all net fisheries for reef fish in Raja Ampat?
- What are the likely effects of blast fishing under the following scenarios?
 - Status quo;
 - Increase.
- What are the likely effects of an increase in the tuna fishery?
- What is the unfished biomass estimated by the model for Hawksbill turtles?
- What might the unexploited ecosystem of Raja Ampat have looked like?
- Under an optimal fishing policy, how might an increase in fishing levels affect the ecology and economy of Raja Ampat fisheries? (Alternatively, what economic benefits must be sacrificed to preserve an acceptable level of biodiversity?)

Some of these questions are addressed in a recent article by Ainsworth et al. (2008b), while a number of other articles have been submitted to peer-reviewed journals, or are in preparation, which attempt to answer other important questions for EBFM. Please see Appendix F for article titles, abstracts and journal to which they have been prepared or submitted.

²⁷ Becky Rahawarin. Kepala Dinas Perikanan dan Kelautan, Raja Ampat. Jl. A. Yani, Kuda laut, Sorong, Papua, personal communication.

FUTURE WORK

The analyses that were conducted in this contribution constitute a first attempt at understanding the influence of fisheries in an ecosystem context. However, there are additional scientific questions that could be addressed by use of the present suite of models in a follow-up project. There are also some questions that could be more fully investigated by use of a different modelling system.



Figure 4.1. Pearl farming operation in the Kofiau Island group. Photo: Cam Ainsworth.

Aquaculture, particularly mariculture, may have the potential in Eastern Indonesia for significant development (Priyono and Sumiono 1997). That is the current belief of the Raja Ampat fisheries office, and the Bureau intends to pursue expansion of aquaculture industries. They are interested in increasing the amount of pearl farming in Raja Ampat, for example, in the Kofiau-Boo Island group (Fig. 4.1), which would add to the already established industry in SW Misool Island. They also intend to facilitate the development of grouper grow-out operations in the south of Waigeo Is. Expanding the aquaculture industry could improve economic options for rural communities and companies in Raja Ampat, but there is concern that fisheries for grouper seed for grow-out operations could threaten stocks²⁸, as has happened elsewhere in South East Asia (Liu and Sadovy, in press).

Depletion of grouper has already been seen in Raja Ampat (Ainsworth et al. 2008) as a result of increased fishing, and there has been an apparent disappearance of many grouper spawning aggregations²⁹. So grouper grow out operations might further prejudice already depleted stocks. To accurately determine the exploitation status of groupers would require further study, and the comparison of outcomes from several modeling approaches would provide a more robust analysis than the work here can offer alone.

Despite the contributions made by the various studies in the BHS EBM project, Raja Ampat remains a data-poor area. One of the justifications for performing the type of ecosystem analysis attempted here is that we are guided to what may be a reasonable representation of the ecosystem by the thermodynamic constraints imposed by the better-understood parts of the ecosystem. There is of course a wide range of uncertainty associated with all of our estimates. And while more knowledge is certainly beneficial to fishery management and EBM, fully understanding the status and behaviour of the ecosystem will likely remain out of our grasp long after we have compromised the long-term productive potential of the ecosystem through the inaction of management. Instead, we are wise to adopt a precautionary approach to management, and one suggestion has been to implement marine protected areas as a hedge against our own uncertainty (Sumaila and Alder, 2001). The approach may be advisable in an area like Raja Ampat in particular, where compliance with community-based management approaches, especially area protection schemes, is forthcoming in reef areas close to settlements (Crawford et al., 2004). Subsequent studies using the models in this volume may provide further insight into the usefulness of area management schemes in Raja Ampat.

²⁸ Becky Rahawarin. Kepala Dinas Perikanan dan Kelautan, Raja Ampat. Jl. A. Yani, Kuda laut, Sorong, Papua, personal communication.

²⁹ Peter Mous. COREMAP II. Jl. Tebet Raya No. 91, Jakarta, Indonesia, personal communication; Coastal Rural Appraisal Study: J. Wilson. TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia, 80228, e-mail: joanne_wilson@tnc.org.

CONCLUSIONS

EXPLOITATION STATUS OF RAJA AMPAT REEF FISHERIES

When we compare the finalized Raja Ampat models in this volume, which include the latest project information, with the preliminary models of Ainsworth et al. (2007), we note two major changes have affected the parameterization and lead to quite different biomass dynamics being portrayed. Biomass estimates for fish functional groups have generally, though not always, been revised upwards based on outputs from the reef health monitoring dive transect studies. Reef fish biomass density, at least for reefs investigated, seems higher in Kofiau and SE Misool Is. than other areas of Raja Ampat which previous studies have considered (e.g., COREMAP 2005), and on which the preliminary biomass values were based in Ainsworth et al. (2007). The other major change is that the IUU analysis, which was conducted using project data from the CI Socioeconomic Valuation report (Dohar and Anggraeni, 2007), personal communications from in-field experts and other literature sources identified in Varkey et al. (in prep.), reduced the total catch estimates used by Ainsworth et al. (2007) for many functional groups. These included preliminary 'place-holder' IUU estimates which were uncertain and based either on expert communications or set arbitrarily. The result from these two major changes is that some of the functional groups that were considered to be over exploited by Ainsworth et al. (2007) (e.g., large sharks, large demersal fish) now appear to be fully exploited in the revised models, while some groups that were previously considered to be fully exploited are now set as being under exploited (e.g., medium pelagic). Relatively fewer groups have had their exploitation status revised upwards, and these tend to include only lightly exploited species (e.g., small demersal fish, small planktivorous fish).

These findings suggest that overfishing may not yet be the most serious threat facing most functional groups in the marine environment of Raja Ampat. Although there have certainly been serious depletions, highlighted for example by the conspicuous absence of previously identified grouper spawning aggregation sites³⁰, depletions have thus far been localized in space and restricted in terms of the number of species affected. Depletion of the most valuable stocks of grouper, snapper, Napoleon wrasse, coral trout and other high value reef fish have likely had a disproportionately large impact on the profitability of commercial reef fisheries, but artisanal fisheries continue unabated for mixed species catches. It is the opinion of the local community members in Raja Ampat that overfishing is not the largest threat facing the marine ecosystem (Halim and Mous, 2006); they more often cite destructive fishing practices, and this lends support to our conclusion that Raja Ampat must still retain a high exploitable biomass of reef fish species. The concern is that with increased human habitation and developing infrastructure aimed at facilitating commercial trade, exploitation will continue to increase in the short term.

BHS EBM PROJECT

The BHS EBM project has provided a rare and valuable opportunity to integrate field data collected directly in support of complex ecosystem models, and then to use that new information to address specific EBFM questions relevant to the region. Raja Ampat is relatively data-poor, especially when considering the large amount of initializing data required by an ecosystem model, so the new information collected by project is extremely useful. However, the cooperation of knowledgeable scientists in the BHS EBM project and from outside the project has made this holistic approach possible. Support from the community of marine researchers in Indonesia has been fostered by the excellent working relationship that TNC, CI and WWF share with stakeholders at the village level, in government and at academic institutes. The relationships they have built through cooperation and local involvement may prove to be one of the most useful outputs of this project towards eventually implementing an EBFM agenda. In fact, the rural communities of Raja Ampat have been very supportive of new initiatives to preserve the marine environment and implement EBFM measures (e.g., establishing new marine protected areas). Close ties to the marine environment and a tradition of stewardship among the rural people of Papua will lend support to the shared vision of EBFM in this valuable and biodiverse marine seascape.

³⁰ Peter Mous. COREMAP II. Jl. Tebet Raya No. 91, Jakarta, Indonesia, personal communication; Coastal Rural Appraisal Study: J. Wilson. TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia, 80228., email: joanne_wilson@tnc.org.

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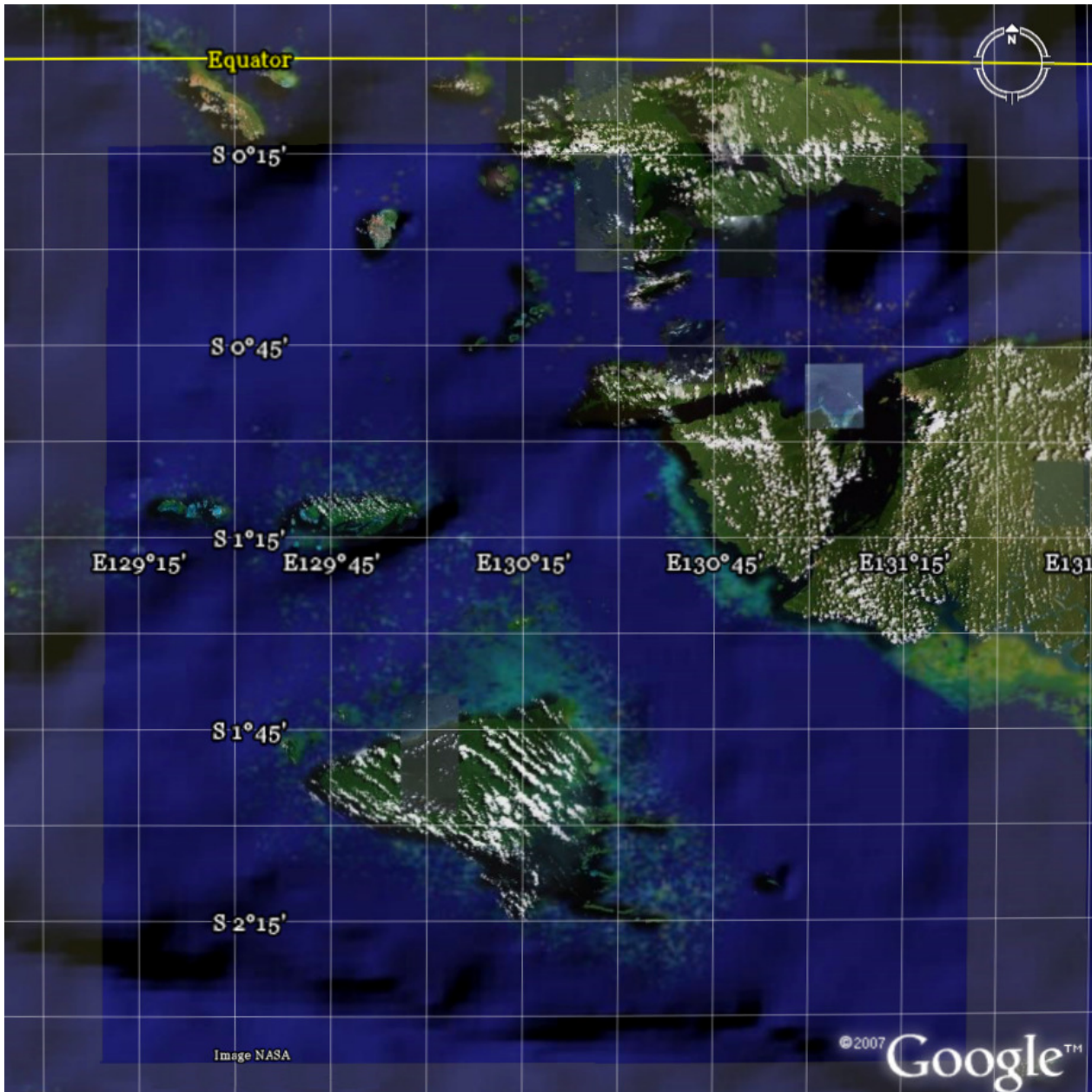
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Google Earth view of the Raja Ampat Islands.

APPENDIX A - BIOMASS CALCULATIONS

A.1. REEF HEALTH MONITORING

Table A.1.1 Piscivorous fish reef health monitoring biomass calculations for Kofiau. Total number of fish sighted in Kofiau transects (N); standard deviation (SD); tail length (TL); species length/weight parameters (a, b). Based on unpublished data from A. Muljadi. (2007) TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. Length-weight relationships from FishBase (www.fishbase.org).

<i>Species name</i>	Family	EwE group	Mean length (TL; cm)	Length SD (cm)	N	a	b	Mean weight (g)	Weight SD (g)	% dives spotted	Average biomass per dive (g)	Biomass SD (g)	Average visibility (m)	Area covered by transect (m ²)	Biomass density (t·km ⁻²)
<i>Lutjanus bohar</i>	Lutjanidae	Snappers	45.8	13.0	59	0.015	3.077	1023	1567	38%	5905	7140	8.8	1860	3.175
<i>Aprion virescens</i>	Lutjanidae	Large planktiv.	44.9	6.3	71	0.008	3.134	1522	301	15%	3856	2778	11.7	1800	2.142
<i>Variola albimarginata</i>	Serranidae	Groupers	31.5	8.5	22	0.021	3.004	421	566	50%	755	320	8.4	1669	0.453
<i>Lutjanus rivulatus</i>	Lutjanidae	Snappers	33.8	3.6	17	0.025	3.000	1023	335	27%	652	367	7.5	1543	0.423
<i>Plectropomus leopardus</i>	Serranidae	Coral trout	48.5	11.5	4	0.010	3.138	2314	1555	15%	356	228	5.3	1050	0.339
<i>Variola louti</i>	Serranidae	Groupers	36.4	9.5	14	0.015	3.024	976	837	31%	525	170	7.9	1663	0.316
<i>Gnathanodon speciosus</i>	Carangidae	Large reef assoc.	35.3	3.8	12	0.043	2.843	968	295	8%	504	-	8.0	1600	0.315
<i>Lutjanus argentimaculatus</i>	Lutjanidae	Snappers	45.0	12.7	5	0.015	3.059	1023	1902	19%	410	213	8.6	1720	0.238
<i>Gracila albimarginata</i>	Serranidae	Groupers	36.4	3.3	10	0.021	3.004	1023	226	19%	394	214	8.4	1760	0.224
<i>Epinephelus maculatus</i>	Serranidae	Groupers	42.5	8.0	9	0.014	2.990	1101	642	12%	381	124	8.7	1733	0.220
<i>Epinephelus polyphekadion</i>	Serranidae	Groupers	38.0	3.5	3	0.016	3.029	968	250	12%	112	24	6.0	1200	0.093
<i>Plectropomus areolatus</i>	Serranidae	Coral trout	42.7	6.4	3	0.021	3.004	1755	820	12%	202	41	11.7	2333	0.087
<i>Elegatis bipinnulatus</i>	Carangidae	Large planktivore	40.0	0.0	10	0.018	2.580	251	-	4%	96	-	8.0	1600	0.060
<i>Epinephelus fuscoguttatus</i>	Serranidae	Groupers	57.0	-	1	0.014	3.033	3026	-	4%	116	-	10.0	2000	0.058
<i>Scomberomorus commerson</i>	Scorpaenidae	Mackerel	50.0	-	2	0.007	3.010	421	-	4%	73	-	8.0	1600	0.046
<i>Plectropomus laevis</i>	Serranidae	Coral trout	35.0	7.1	2	0.020	3.000	901	518	4%	69	-	8.0	1600	0.043
<i>Caranx melampygus</i>	Carangidae	Large reef assoc.	37.5	3.5	4	0.024	2.943	1054	289	8%	65	-	8.0	1600	0.041
<i>Epinephelus coioides</i>	Serranidae	Groupers	28.0	12.0	5	0.012	3.054	487	557	4%	31	10	11.0	2333	0.013
<i>Plectropomus oligocanthus</i>	Serranidae	Coral trout	38.0	-	1	0.013	3.000	724	-	4%	28	-	12.0	2400	0.012
<i>Plectropomus maculatus</i>	Serranidae	Coral trout	30.0	-	1	0.016	3.000	2314	-	4%	16	-	8.0	1600	0.010
<i>Caranx sexfasciatus</i>	Carangidae	Large reef assoc.	27.0	-	1	0.028	2.836	316	-	4%	12.2	-	10.0	2000	0.006

Table A.1.2 Piscivorous fish reef health monitoring biomass calculations for SE Misool. Total number of fish sighted in Misool transects (N); standard deviation (SD); tail length (TL); species length/weight parameters (a, b). Based on unpublished data from M. Syakir (2007) TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. Length-weight relationships from FishBase (www.fishbase.org).

Species name	Family	EwE group	Mean length (TL; cm)	Length SD (cm)	N	a	b	Mean weight (g)	Weight SD (g)	Dives spotted (%)	Average biomass per dive (g)	Biomass SD (g)	Average visibility (m)	Area covered by transect (m ²)	Biomass density (t·km ⁻²)
<i>Caranx melampygus</i>	Carangidae	Large reef	53.5	7.0	446	0.024	2.943	3077	701	14	15194	39754	8.0	2385	6.372
<i>Sphyraena barracuda</i>	Sphyraenidae	Large reef	30.3	13.3	295	0.018	2.945	735	1863	4	3006	2913	11.5	1600	1.879
<i>Caranx sexfasciatus</i>	Carangidae	Large reef	43.7	18.5	109	0.028	2.836	1814	1591	21	2173	8423	16.7	2558	0.849
<i>Lutjanus rivulatus</i>	Lutjanidae	Snappers	16.4	2.9	1587	0.025	3.000	124	111	18	2037	7084	19.8	2471	0.824
<i>Gnathanodon speciosus</i>	Carangidae	Large reef	32.1	8.1	172	0.043	2.843	974	847	14	1408	1899	10.2	2388	0.590
<i>Plectropomus leopardus</i>	Serranidae	Coral trout	31.3	6.5	112	0.010	3.138	592	470	56	808	801	11.4	2143	0.377
<i>Carcharhinus melanopterus</i>	Carcharhinid	Large	125.0	-	1	0.003	3.649	145716	-	1	856	746	12.0	2400	0.357
<i>Plectropomus areolatus</i>	Serranidae	Coral trout	32.6	9.9	57	0.021	3.004	982	1251	27	699	720	10.8	2418	0.289
<i>Plectropomus maculatus</i>	Serranidae	Coral trout	30.3	7.2	54	0.016	3.000	503	271	26	298	248	8.0	1717	0.174
<i>Lutjanus bohar</i>	Lutjanidae	Snappers	31.2	8.0	79	0.015	3.077	701	617	25	483	648	14.1	2821	0.171
<i>Cheilinus undulatus</i>	Labridae	Napoleon	46.1	12.9	22	0.012	3.115	2353	2111	15	498	444	15.3	3000	0.166
<i>Caranx ignobilis</i>	Carangidae	Large reef	29.5	5.5	22	0.020	3.000	570	342	12	261	331	13.8	2745	0.095
<i>Lutjanus argentimaculatus</i>	Lutjanidae	Snappers	28.0	5.5	41	0.015	3.059	464	317	16	209	179	11.5	2333	0.090
<i>Scomberomorus commerson</i>	Scombridae	Mackerel	58.5	12.3	13	0.007	3.010	1726	1280	9	197	128	12.3	2400	0.082
<i>Plectropomus oligocanthus</i>	Serranidae	Coral trout	31.7	7.9	27	0.013	3.000	498	369	15	148	80	14.2	2643	0.056
<i>Gracila albimarginata</i>	Serranidae	Groupers	29.1	4.9	17	0.021	3.004	571	271	15	137	91	13.2	2629	0.052
<i>Variola louti</i>	Serranidae	Groupers	30.7	9.3	27	0.015	3.024	606	480	14	146	213	15.7	3038	0.048
<i>Variola albimarginata</i>	Serranidae	Groupers	27.2	5.5	32	0.021	3.004	480	246	13	119	87	13.8	3082	0.039
<i>Epinephelus fuscoguttatus</i>	Serranidae	Groupers	55.0	24.3	3	0.014	3.033	3715	2984	1	61	58	11.3	2200	0.028
<i>Gymnosarda unicolor</i>	Scombridae	Other tuna	44.0	3.5	3	0.026	2.933	1716	409	1	57	-	12.0	2400	0.024
<i>Epinephelus coioides</i>	Serranidae	Groupers	25.2	9.9	11	0.012	3.054	358	486	9	43.2	43	10.8	2075	0.021
<i>Epinephelus polyphekadion</i>	Serranidae	Groupers	29.0	6.0	9	0.016	3.029	470	290	7	39.9	17	13.8	2743	0.015
<i>Plectropomus laevis</i>	Serranidae	Coral trout	29.8	8.8	4	0.020	3.000	631	571	4	27.7	22	10.0	2000	0.014
<i>Epinephelus lanceolatus</i>	Serranidae	Groupers	50.0	-	1	0.017	3.000	2163	-	1	23.8	-	12.0	2400	0.010
<i>Epinephelus maculatus</i>	Serranidae	Groupers	26.1	8.4	10	0.014	2.990	313	244	4	23.0	12	11.7	2833	0.008
<i>Epinephelus tukula</i>	Serranidae	Groupers	40.5	12.0	2	0.106	2.560	1503	1057	1	16.5	8	17.5	3500	0.005
<i>Epinephelus malabaricus</i>	Serranidae	Groupers -	32.0	-	1	0.030	2.944	811	-	1	8.9	-	12.0	2400	0.004
<i>Epinephelus caruleopunctatus</i>	Serranidae	Groupers	26.0	-	1	0.021	2.907	278	-	1	3.1	-	8.0	1600	0.002

Table A.1.3 Reef fish family length-weight parameters. Family values represent average of Raja Ampat species. Parameters of length-weight relationships are from FishBase (Froese and Pauly 2007).

Scientific family name	Family name	a (mean)	b (mean)	a (N)	b (N)	Scientific family name	Family name	a (mean)	b (mean)	a (N)	b (N)
1 Orectolobidae	wobbeongs	-	-	2	2	45 Sillaginidae	sillagos/smelts/whitings	0.005	3.193	1	1
2 Hemiscylliidae	carpetsharks	-	-	1	1	46 Malacanthidae	tilefish	0.006	3.000	5	5
3 Ginglymostomatidae	nurse sharks	0.009	3.050	1	1	47 Echeneidae	remoras/sharksuckers	0.032	1.351	2	2
4 Carcharhinidae	requiem sharks	0.004	3.229	7	7	48 Carangidae	trevally/jacks/scads/pompanos	0.047	2.833	22	22
5 Dasyatidae	rays	0.034	2.989	2	2	49 Lutjanidae	sea perch/snappers	0.024	2.967	33	33
6 Myliobatidae	eagle rays	0.003	1.565	2	2	50 Caesionidae	fusilier	0.015	3.065	12	12
7 Mobulidae	manta rays	0.006	1.500	2	2	51 Gerreidae	silverbiddy	0.017	3.122	2	2
8 Moringuidae	eels	-	-	2	2	52 Haemulidae	sweetlips	0.023	2.957	10	10
9 Muraenidae	morays	0.002	3.058	12	12	53 Lethrinidae	bream/emperors	0.036	2.860	16	16
10 Ophichthidae	snake eels	-	-	3	3	54 Nemipteridae	whiptails/breams/false snappers	0.031	2.897	12	12
11 Congridae	garden eels	-	-	3	3	55 Mullidae	goatfish	0.023	2.998	10	10
12 Clupeidae	herrings	0.013	3.061	23	23	56 Pemppheridae	sweepers	0.012	3.026	3	3
13 Plotosidae	catfish	0.008	3.204	1	1	57 Toxotidae	archerfish	-	-	2	2
14 Synodontidae	lizardfish	0.005	3.233	6	6	58 Kyphosidae	chubs	0.029	2.930	3	3
15 Carapidae	pearlfish	-	-	1	1	59 Monodactylidae	moonies	0.033	2.921	2	2
16 Bythitidae	cuskeels	-	-	1	1	60 Chaetodontidae	butterfly fish/angelfish	0.036	2.934	57	57
17 Batrachoididae	toadfish	-	-	2	2	61 Mugilidae	mullets	0.012	3.095	5	5
18 Antennariidae	frogfish	0.001	0.750	4	4	62 Pomacentridae	damsel/sergeants	0.042	2.861	109	109
19 Gobiesocidae	clingfish	-	-	2	2	63 Labridae	parrotfish/rainbowfish/wrasses	0.018	3.005	97	97
20 Atherinidae	silversides	0.035	2.804	5	5	64 Scaridae	parrotfish	0.022	2.936	29	29
21 Belontiidae	needlefish	0.001	3.146	5	5	65 Trichonotidae	sanddivers	-	-	2	2
22 Hemiramphidae	halfbeaks/garfish	0.002	0.882	17	17	66 Pinguipedidae	sandperch	0.012	3.036	7	7
23 Holocentridae	soldierfish/squirrelfish	0.026	2.852	20	20	67 Pholidichthyidae	convict blennies	-	-	1	1
24 Pegasidae	dragonfish	-	-	1	1	68 Tripterygiidae	threadfin blennies	-	-	5	5
25 Aulostomidae	trumpetfish	0.001	3.160	1	1	69 Blenniidae	blennies	0.013	2.975	32	32
26 Fistulariidae	cornetfish	0.001	3.000	1	1	70 Callionymidae	dragonets/scotter blennies	-	-	6	6
27 Centriscidae	razorfish	-	-	2	2	71 Gobiidae	gobies	0.014	2.978	97	97
28 Syngnathidae	pipefish/seahorses	0.001	3.000	16	16	72 Microdesmidae	wormfish	-	-	2	2
29 Scorpaenidae	scorpionfish	0.030	2.936	11	11	73 Ptereleotridae	dart gobies	-	-	8	8
30 Tetrarogidae	waspfish	-	-	1	1	74 Xenisthmidae	wrigglers	-	-	1	1
31 Synanceiidae	stonefish/ghouls	0.025	2.829	3	3	75 Ephippidae	batfish	0.043	2.975	5	5
32 Caracanthidae	crouchers	0.020	3.000	1	1	76 Scatophagidae	scats	0.021	2.776	1	1
33 Dactylopteridae	gurnards	0.012	1.500	2	2	77 Siganidae	spinefoots	0.023	2.971	12	12
34 Platycephalidae	flatheads	-	-	5	5	78 Zanclidae	moorish idol	0.017	3.171	1	1
35 Centropomidae	seaperch	0.025	3.000	1	1	79 Acanthuridae	surgeonfish/unicornfish/tangs	0.038	2.917	33	33
36 Serranidae	groupers/sea bass	0.021	2.893	54	54	80 Sphyraenidae	barracudas	0.016	2.817	5	5
37 Pseudochromidae	dottybacks	0.018	2.931	15	15	81 Scombridae	tunas/mackerels	0.017	3.019	28	28
38 Plesiopidae	longfins	0.020	3.000	2	2	82 Bothidae	flounders	0.004	3.475	2	2
39 Acanthoclinidae	spiny basslets	-	-	1	1	83 Soleidae	soles	-	-	1	1
40 Cirrhitidae	hawkfish	0.026	2.992	8	8	84 Balistidae	triggerfish	0.051	2.981	14	14
41 Opistognathidae	jawfish/smilers	-	-	-	-	85 Monacanthidae	filefish	0.024	2.675	14	14
42 Terapontidae	grunters/tigerperch	0.021	1.416	4	4	86 Ostraciidae	boxfish	0.101	2.588	3	3
43 Priacanthidae	bullseyes	0.033	2.775	1	1	87 Tetraodontidae	puffers	0.057	2.734	12	12
44 Apogonidae	cardinalfish	0.023	2.985	62	62	88 Diodontidae	porcupine fish	0.409	2.310	2	2

A.2. AREA CALCULATIONS

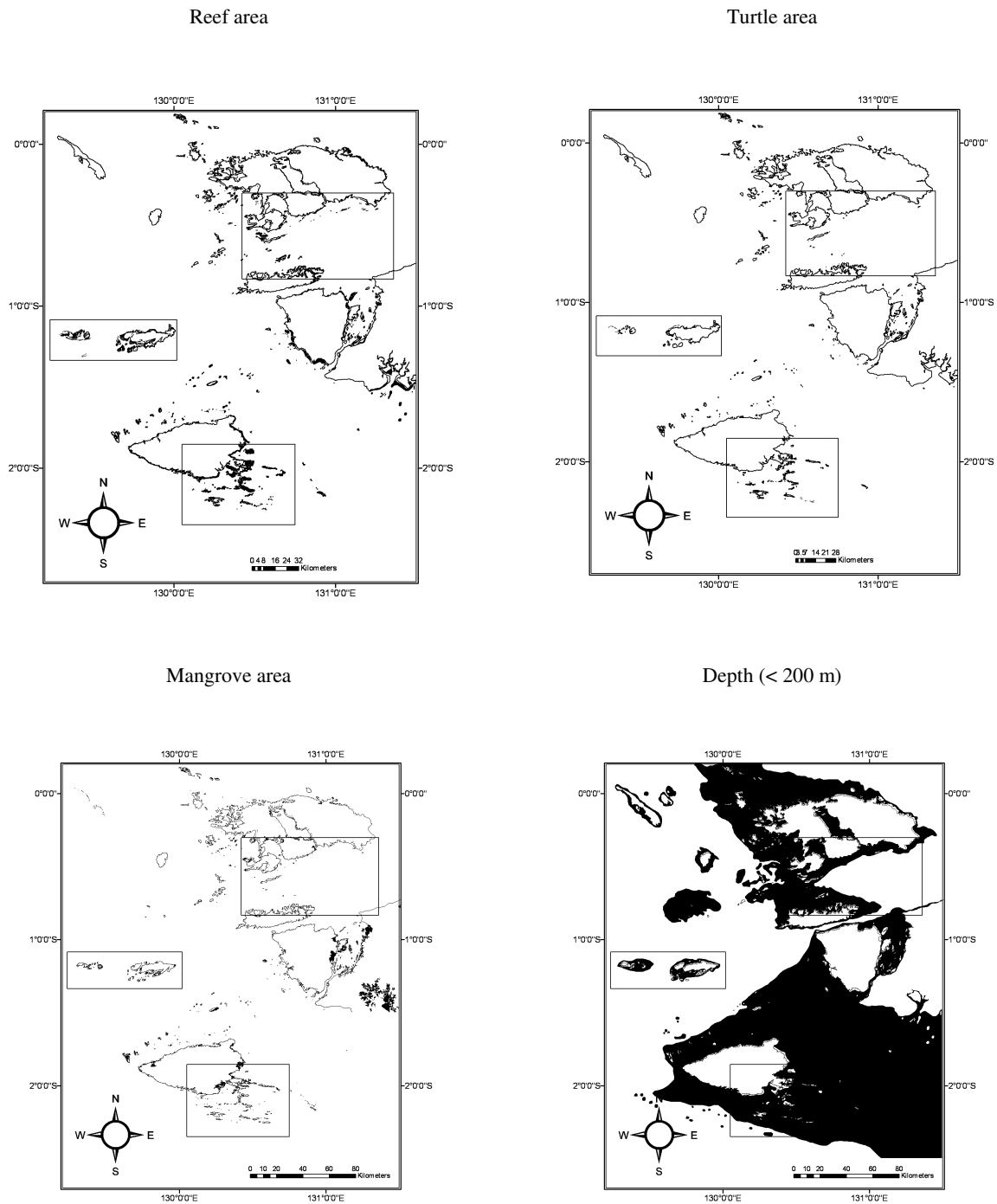


Figure A.2.1. Habitat area. Proportion of fisher reporting high abundance in black (+), medium abundance in grey (o) and low abundance in white (-) for Raja Ampat species groups. Reef area is available from LandSat imagery (o), but only to 20m depth or less. Additional reef area is determined by Indonesia Navy nautical charts to 50 m depth; this was determined using acoustic methods.

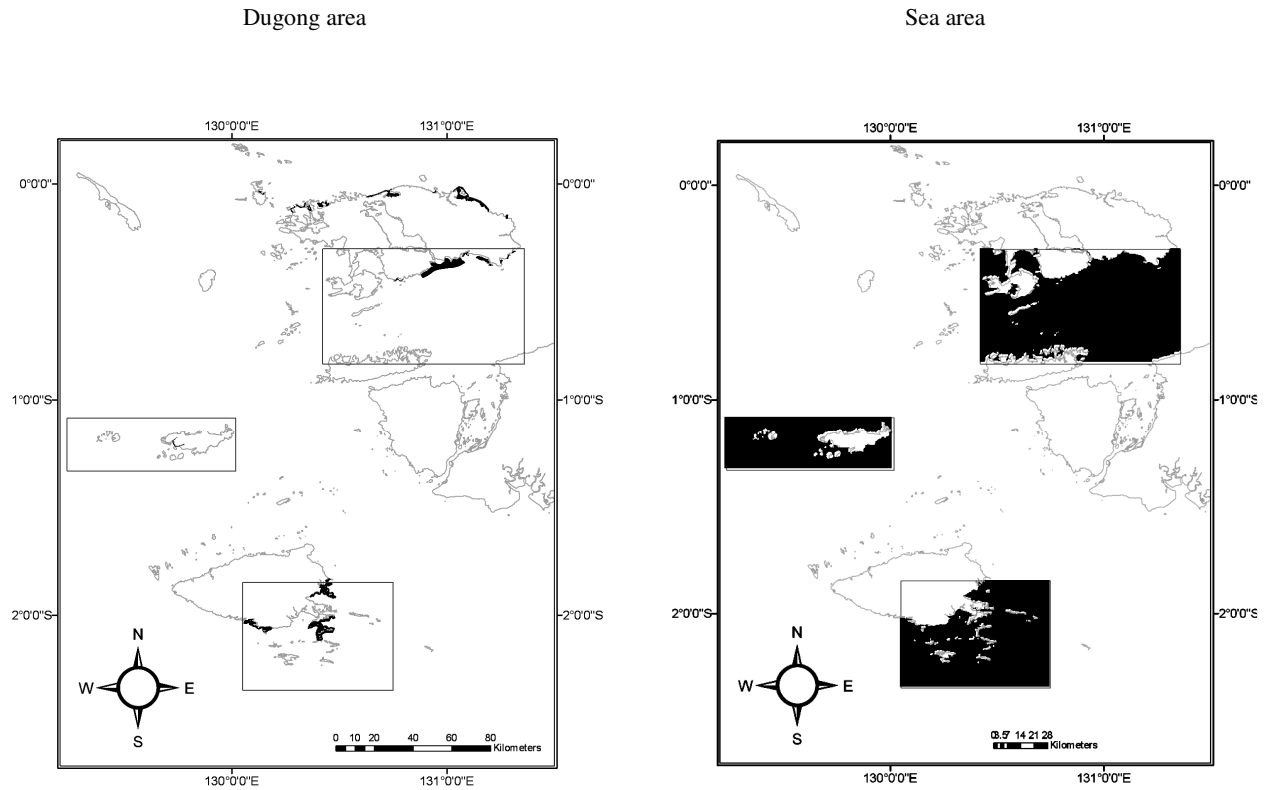


Figure A.2.1. cont. Dugong area is determined approximately from CRA surveys, and was entered in polygons based on expert opinion and local knowledge of occupied habitat (A. Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. Unpublished data. Email: amuljadi@tnc.org.)

APPENDIX B - INTERVIEW DATA

B.1. FISHER RESPONSES.

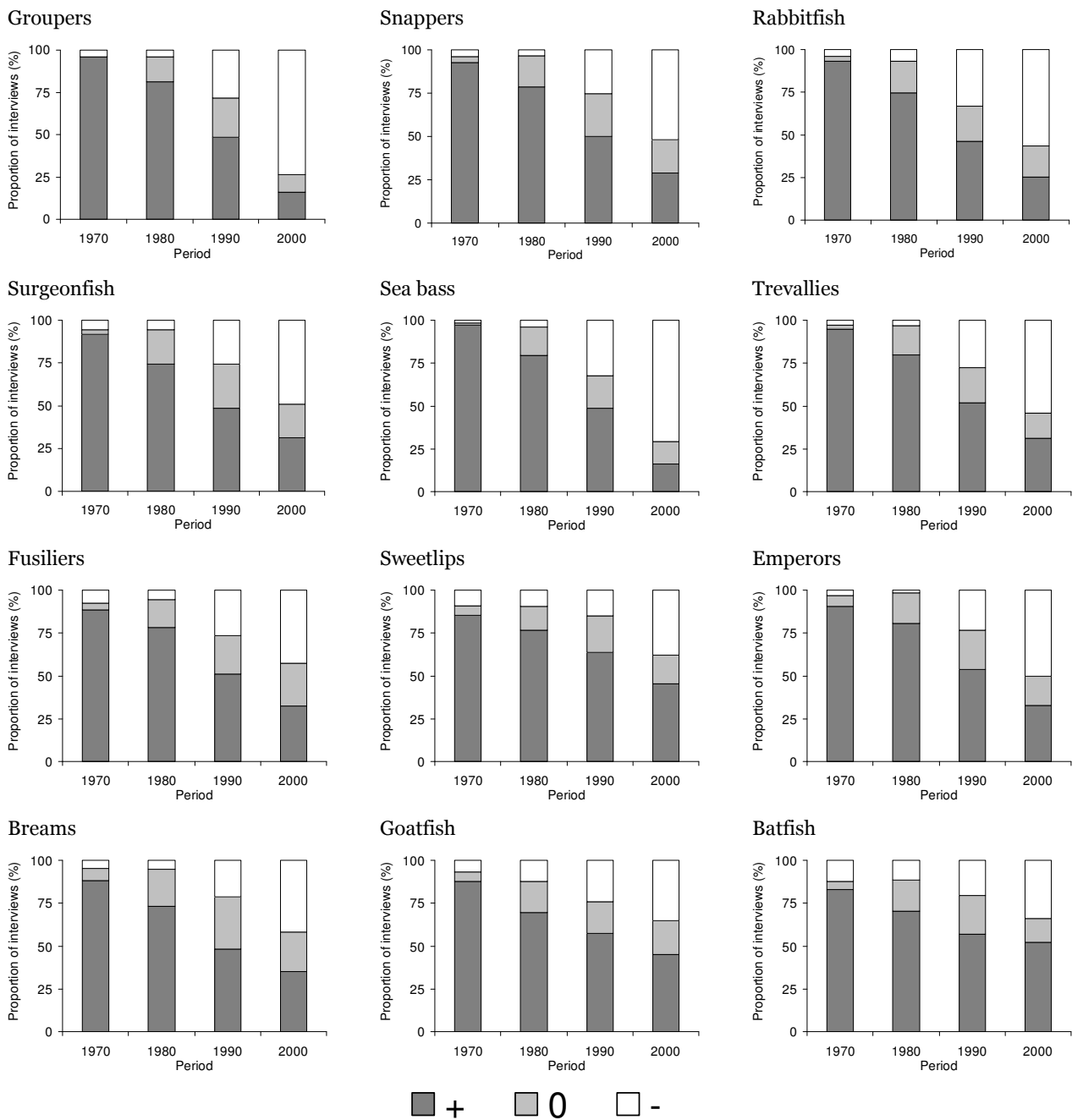


Figure B.1.1. Abundance scores reported by fishers by period and species. Proportion of fishers reporting high abundance in black.

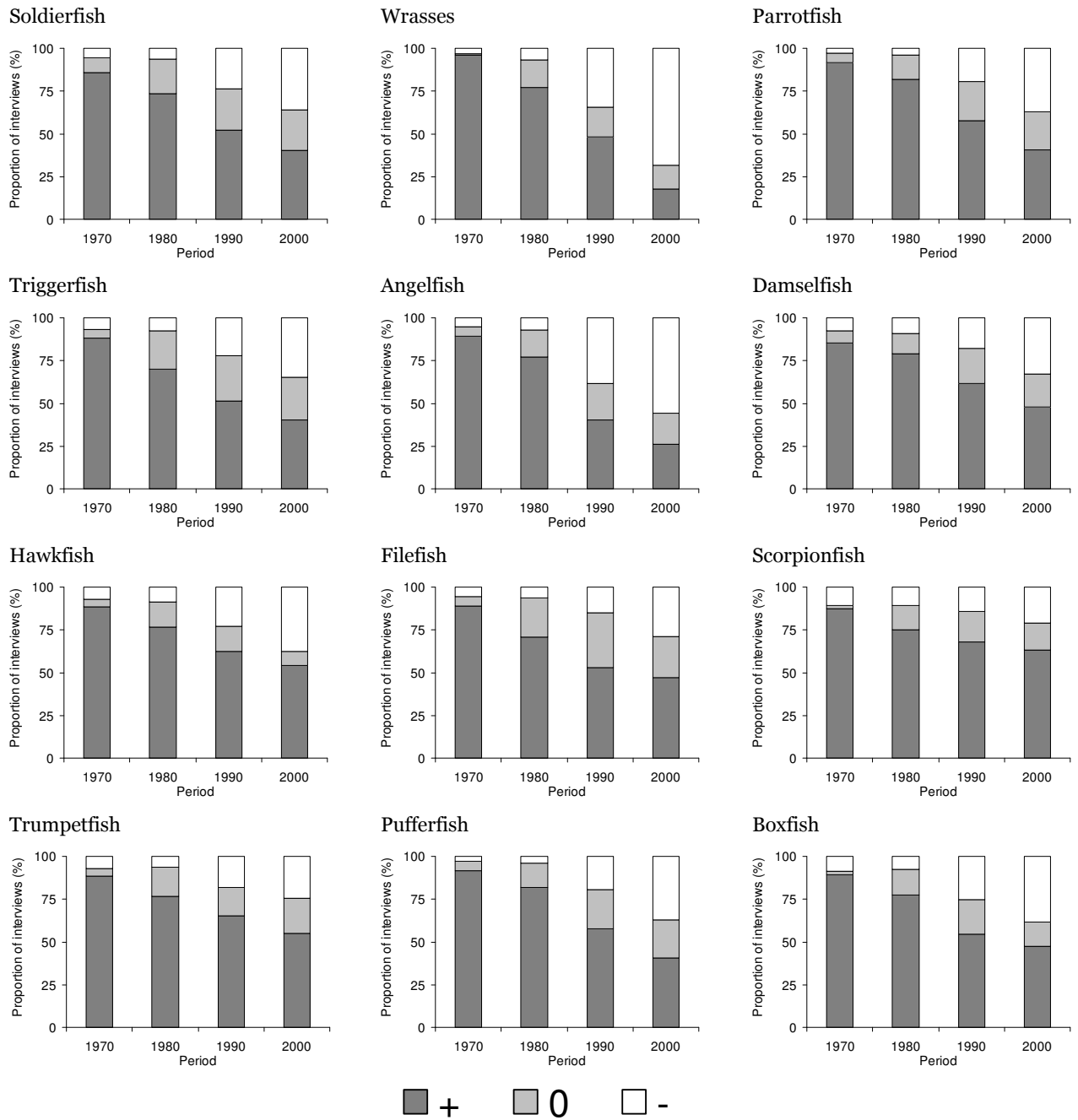


Figure B.1.1. Cont. Abundance scores reported by fishers by period and species. Proportion of fishers reporting high abundance in black.

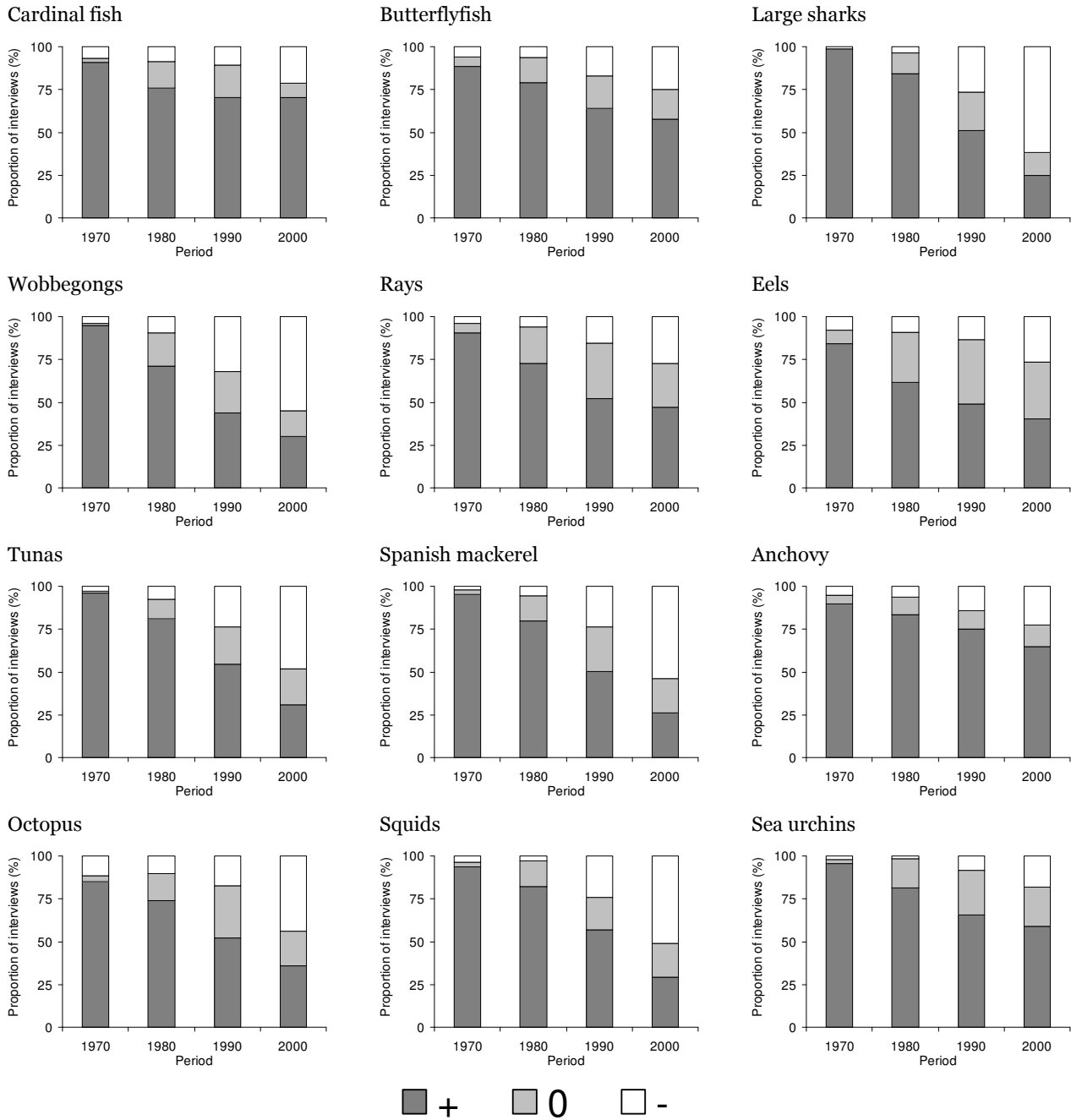


Figure B.1.1. Cont.Abandance scores reported by fishers by period and species. Proportion of fishers reporting high abundance in black.

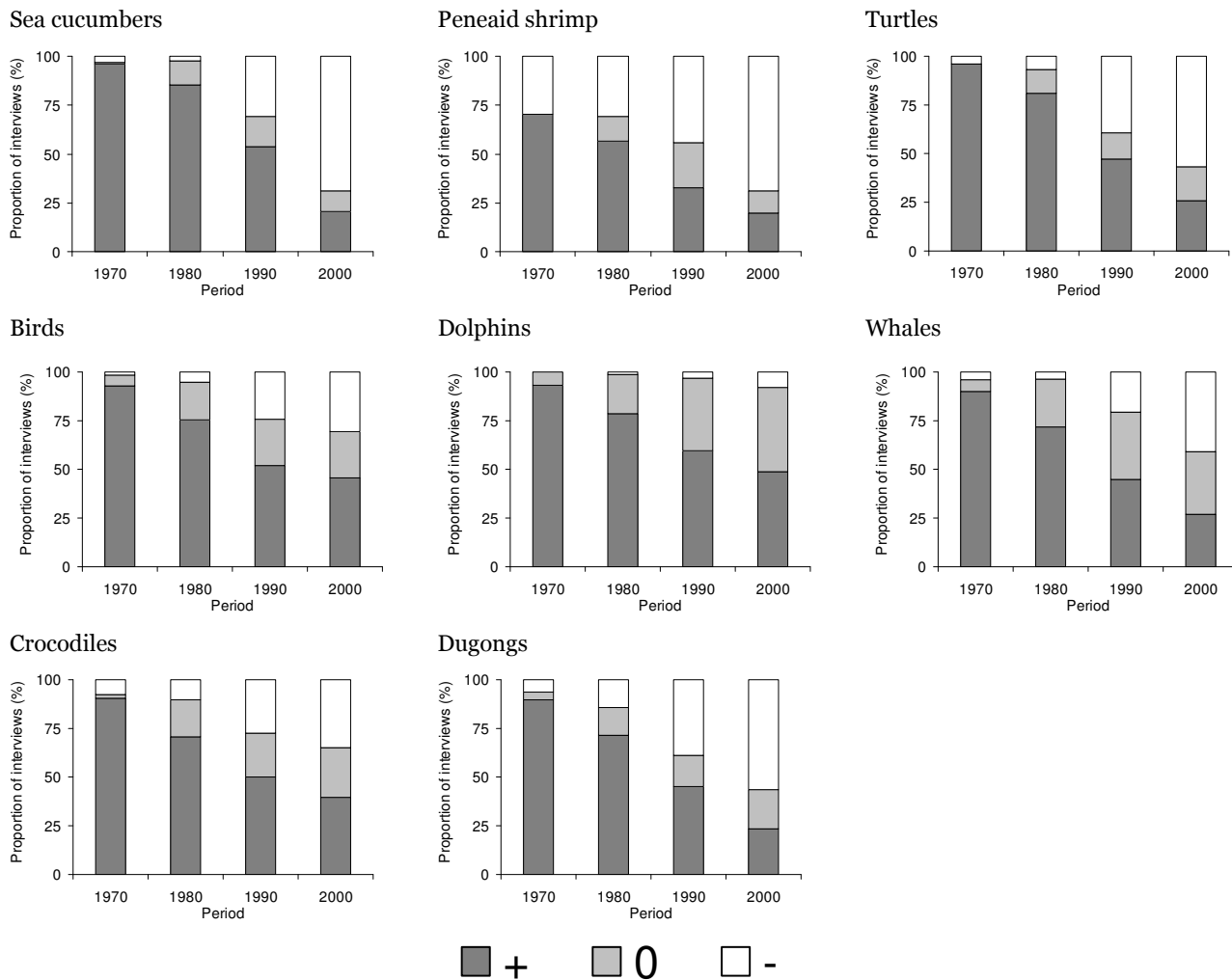


Figure B.1.1. Cont. Abundance scores reported by fishers by period and species. Proportion of fishers reporting high abundance in black.

B.2. ANALYSIS OF LEK DATA

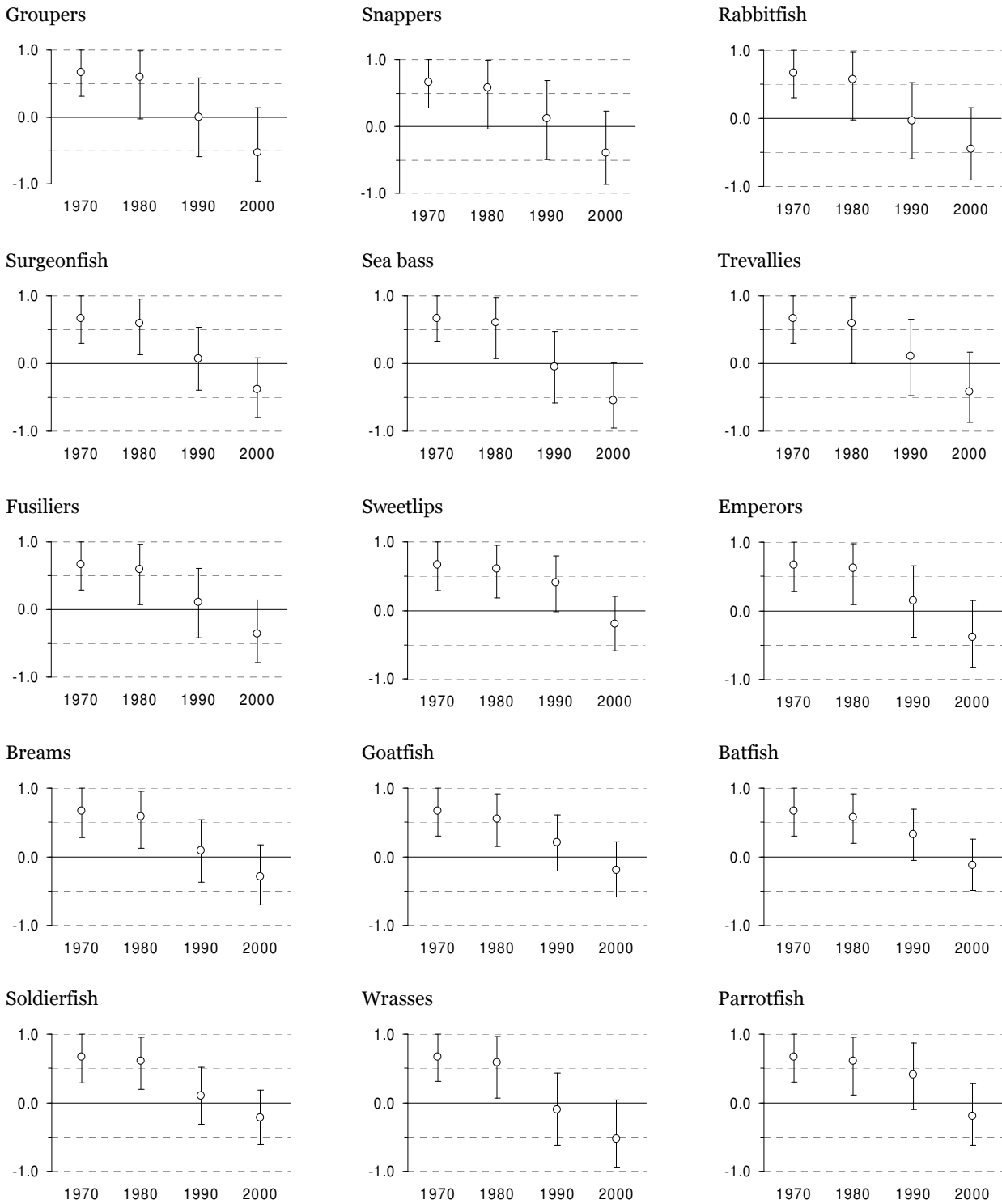


Figure B.2.1. Period abundance estimates from fuzzy logic algorithm rror bars show likely range around the fuzzy centroid based on the upper and lower extent of fuzzy set triangles.

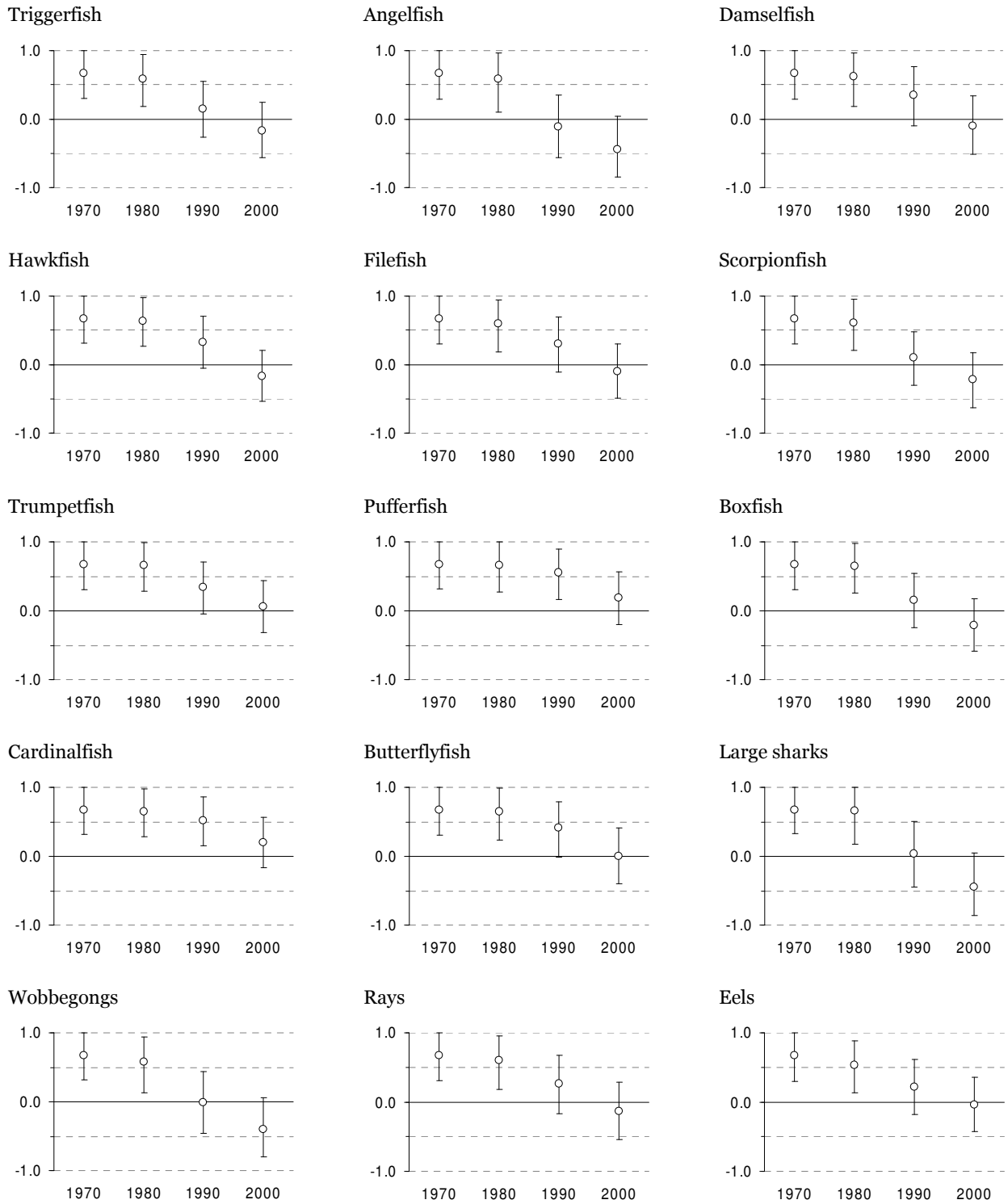


Figure B.2.1. Cont. Period abundance estimates from fuzzy logic algorithm error bars show likely range around the fuzzy centroid based on the upper and lower extent of fuzzy set triangles.

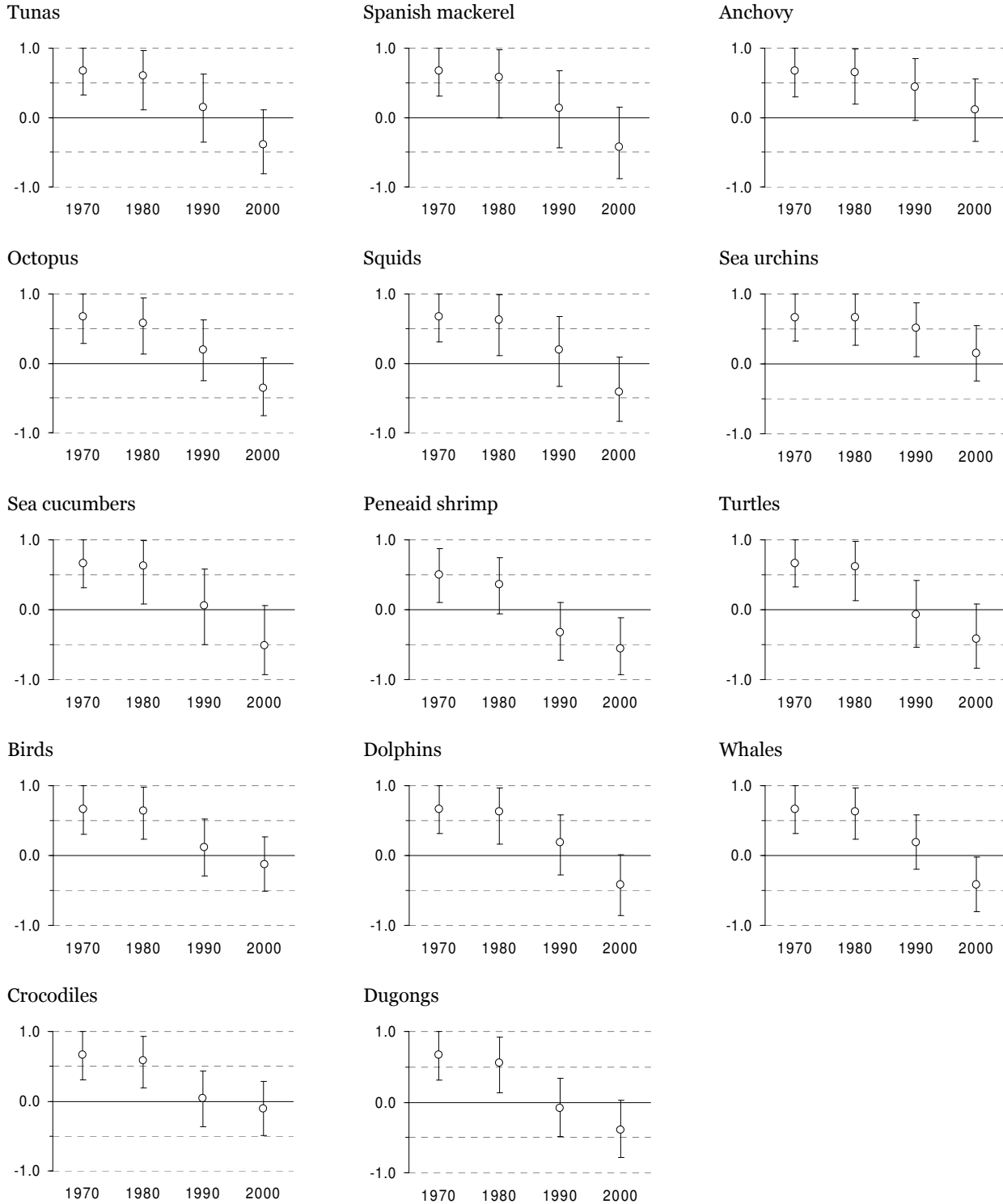


Figure B.2.1. Cont. Period abundance estimates from fuzzy logic algorithm rror bars show likely range around the fuzzy centroid based on the upper and lower extent of fuzzy set triangles.

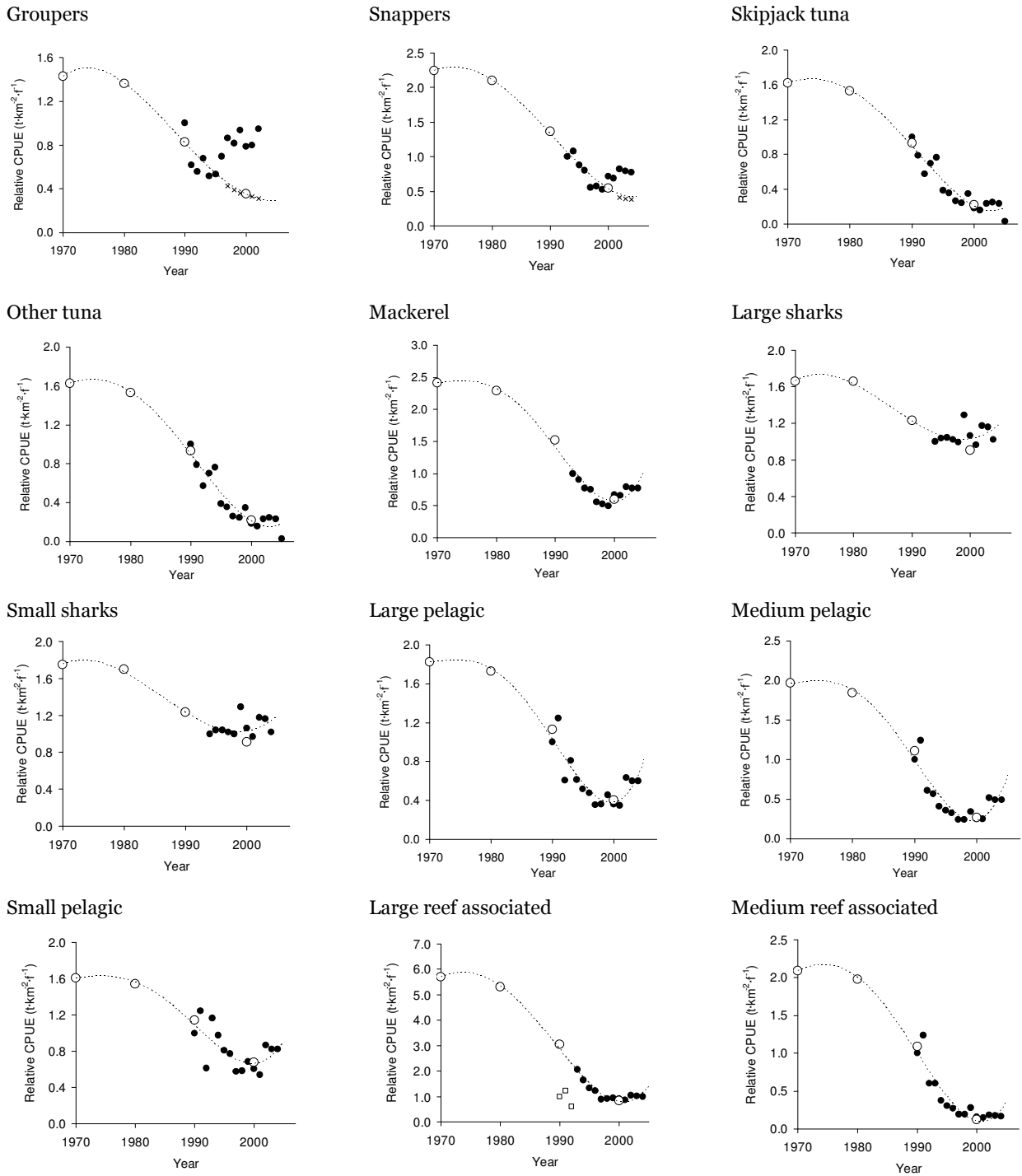
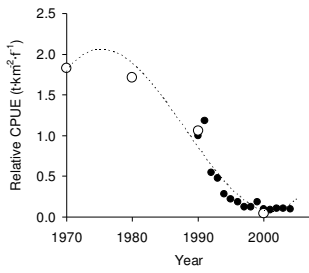
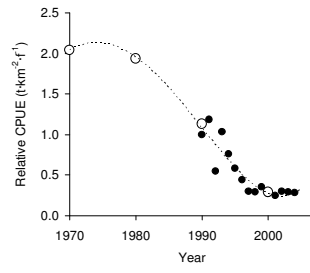


Figure B.2.2. Biomass time series derived from LEK interviews. Relative biomass estimates from fuzzy logic analysis of LEK interview data are scaled to match relative CPUE abundance trends from 1990 to 2000. Relative biomass ($t \cdot km^{-2} \cdot f^{-1}$) is scaled to 1 for the first CPUE data year (f). Biomass is extrapolated back to 1970 based on a polynomial regression. Open circles: mean relative biomass from fuzzy analysis of LEK data; closed circles: Raja Ampat CPUE data from Ainsworth et al. (2007); cross-thatch: ad hoc values to correct CPUE trend; squares: omitted CPUE data. See text for additional explanation.

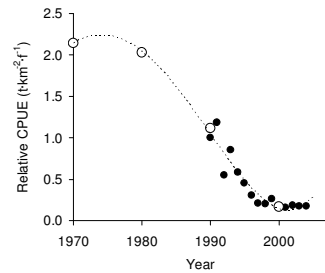
Small reef associated



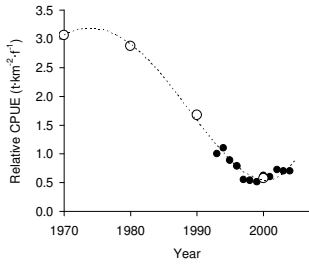
Large demersal



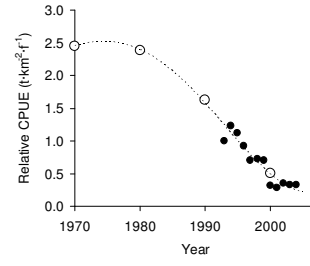
Small demersal



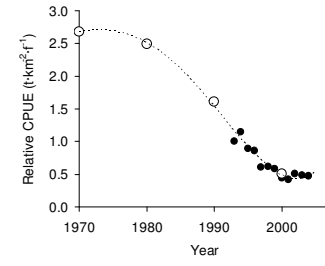
Large planktivore



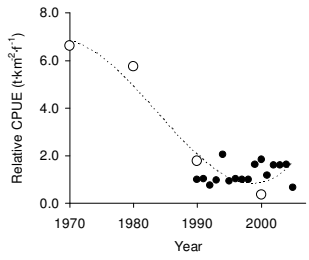
Anchovy



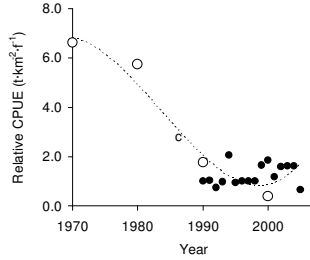
Deep water



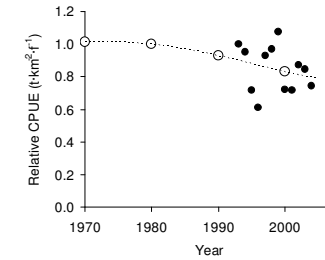
Penaeid shrimps



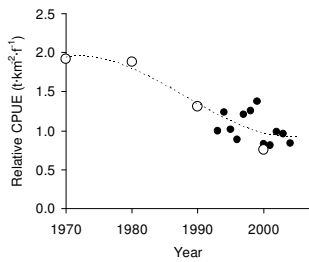
Shrimps and prawns



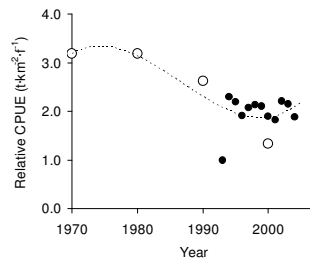
Octopus



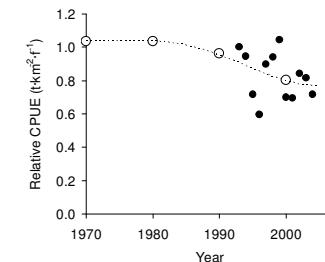
Sea cucumbers



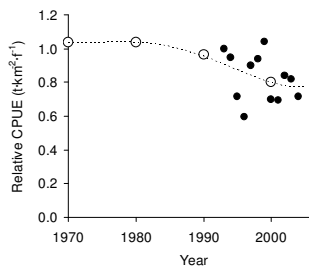
Lobsters



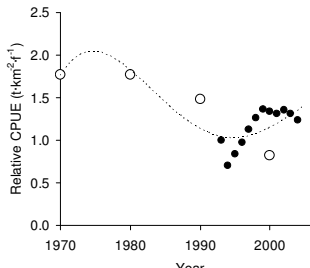
Large crabs



Small crabs



Bivalves



Epifaunal invertebrates

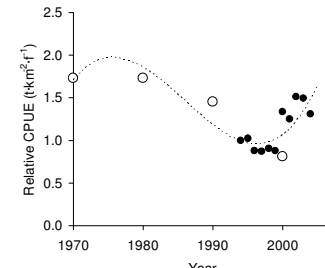


Figure B.2.2. Cont. Biomass time series derived from LEK interviews.

C.2. STOMACH SAMPLE RESULTS

Table C.2.1 Diet composition data from gut content analysis. Prey items have been sorted into EwE groups.

Prey \ Predator	Centropomidae	Nemipteridae	Carangidae	Caesionidae	Siganidae	Lethrinidae	Mullidae	Holocentridae	Balistidae	Serranidae	Lutjanidae	Chaetodontidae	Carchariidae	Dasyatidae	Scorpaenidae	Scombridae	Syngnathidae
Number of fish sampled	20	20	20	20	20	20	20	20	20	20	20	11	20	20	20	20	20
Number of species sampled	1	1	8	3	8	11	6	2	2	10	11	21	2	3	5	3	2
Juvenile groupers	0.070																
Adult medium pelagic																	0.053
Adult small pelagic																	0.053
Adult large reef associated			0.199	0.003	0.000	0.152	0.001	0.020		0.168	0.169		0.006	0.033			
Juvenile large reef associated	0.070																
Adult medium reef associated			0.199	0.003	0.000	0.152	0.001	0.020		0.168	0.169		0.006	0.033			
Adult small reef associated			0.299	0.004	0.000	0.228	0.002	0.030		0.253	0.253		0.010	0.050			
Adult anchovy																	0.053
Adult macro algal browsing			0.100	0.001	0.000	0.076	0.001	0.010		0.084	0.084		0.003	0.017			
Adult eroding grazers			0.100	0.001	0.000	0.076	0.001	0.010		0.084	0.084		0.003	0.017			
Adult scraping grazers			0.100	0.001	0.000	0.076	0.001	0.010		0.084	0.084		0.003	0.017			
Hermatypic scleractinian corals		0.043					0.038	0.600	0.483		0.004	0.002					
Non reef building scleractinian corals		0.022					0.019	0.300	0.242		0.002	0.001					
Penaeid shrimps	0.155	0.228		0.484	0.018	0.031	0.180		0.138	0.053	0.013			0.387			0.178
Shrimps and prawns	0.155	0.228		0.484	0.018	0.031	0.180		0.138	0.053	0.013			0.387			0.178
Squid											0.026		0.484				0.237
Octopus											0.026		0.484				0.237
Lobsters						0.034				0.053							
Large crabs	0.452						0.245				0.032						
Small crabs	0.086																
Herbivorous echinoids							0.217				0.029						
Bivalves		0.479					0.007										
Epifaunal detritivorous invertebrates							0.007										
Epifaunal carnivorous invertebrates							0.007										
Infaunal invertebrates			0.000	0.010	0.005	0.017	0.116				0.010	0.396		0.059		0.005	
Carnivorous zooplankton												0.004					
Large herbivorous zooplankton												0.004					
Small herbivorous zooplankton												0.004					
Phytoplankton												0.000					
Macro algae					0.027	0.004						0.588					0.843
Sea grass	0.012		0.004	0.008	0.932										1.000	0.005	0.157

Table C.2.4. Stomach samples versus Raja Ampat model. Values shown are weighting factors necessary to increase or decrease Raja Ampat model diet composition to match stomach samples [i.e., DCsamples/DCmodel]. Values > 1 are minor interactions in the model that appear more important according to stomach samples; values < 1 are major interactions in the model that appear less important according to the stomach samples. The values shown represent the top 25 percentile of interactions that were identified by the stomach sampling, but missed by the diet algorithm of Ainsworth et al. (2007). Grey cells indicate diet parameters improved in the final models (this volume).

Prey \ Predator	Snappers	Skipjack tuna	Other tuna	Large sharks	Butterfly fish	Large pelagic	Large reef assoc.	Medium reef assoc.	Large plank .	Deep. fish
Large reef assoc.							1.21	48.73	31.75	6.24
Medium reef assoc.								3.75		24.96
Small reef assoc.	12.06						9.71	7.31	15.87	26.74
Macro algal browsing	153							812	105	
Eroding grazers	444						> 1000	840	317	> 1000
Scraping grazers								3.48		20.80
Hermatypic corals							> 1000	382		
Soft corals							1372			
Shrimps and prawns	0.50									0.18
Squid	0.51								0.04	
Octopus		118	344	120						
Large crabs							52.47			
Small crabs							13.14	1.29		
Bivalves							2.39	7.33		
Epifaunal det. inverts.							0.46	0.21		0.09
Epifaunal carn. inverts							0.02	0.01		0.02
Infaunal inverts.	0.38						0.10	0.02	0.15	0.04
Large herb. zooplankton					0.38					
Macro algae					3.92	> 1000	0.05	0.01		
Sea grass						> 1000		0.00	0.13	

Table C.2.5. Stomach samples versus diet algorithm. Weighting factors required to increase or decrease Raja Ampat model diet composition (DC) to match algorithm estimate [DCsamples/DCalgorithm]. Interactions presented in this table represent the most important (top 25 percentile) predator-prey interactions which were identified by the stomach sampling but show discrepancies with the preliminary Raja Ampat model of Ainsworth et al. (2007) or the unprocessed diet algorithm results. Grey cells indicate diet parameters improved in the final models (this volume).

Prey \ Predator	Snappers	Skipjack tuna	Other tuna	Large sharks	Butterfly fish	Large pelagic	Large reef assoc.	Medium reef assoc.	Large plank.	Deep fish
Large reef assoc.							0.56	20.25	0.77	10.48
Medium reef assoc.								8.40		10.48
Small reef assoc.	5.22						3.20	13.43	3.55	15.72
Macro algal browsing	36.12							186	24.31	
Eroding grazers	121						23.28	199	73.47	5.24
Scraping grazers								13.85		5.24
Hermatypic corals					0.01		> 1000	10.06		
Soft corals							> 1000			
Shrimps and prawns	0.35									0.17
Squid	0.71								0.03	
Octopus		30.36	37.63	27.75						
Large crabs							0.98			
Small crabs							0.25	0.29		
Bivalves							2.74	22.83		
Epifaunal det. inverts.							0.03	0.03		0.06
Epifaunal carn. inverts							0.02	0.01		0.05
Infaunal inverts.	0.51						0.43	0.04	0.17	0.12
Large herb. zooplankton					1.37					
Macro algae					61.70	> 1000	0.08	0.01		
Sea grass						> 1000		0.01	0.17	

APPENDIX D - EWE PARAMETERIZATION

D.1. BIOMASS

Table D.1.1 Biomass for sub-area models ($t \cdot km^{-2}$). Biomasses for Kofiau, Dampier St. and SE Misool models are based on ratios and assumptions listed in Table D.1.2; the method used is indicated by Ref #. Modifier indicates subsequent changes made during balancing and tuning. A modifier greater than one indicates that biomass was increased during tuning; less than one indicates it was decreased (see Sections 2.3 and 2.4).

Group #	Functional group	Kofiau	Modifier	Ref #	Dampier St.	Modifier	Ref #	SE Misool	Modifier	Ref #
1	Mvsticetae	0.066		9	0.048		9	0.023		9
2	Pisc. odontocetae	0.060		11	0.031		11	0.033		11
3	Deep. odontocetae	0.181		9	0.133		9	0.064		9
4	Dugongs	0.007		6	0.131		6	0.226		6
5	Birds	0.366		12	0.366		12	0.366		12
6	Reef assoc. turtles	0.036		4	0.049		4	0.05		4
7	Green turtles	0.086		7	0.072		7	0.138		7
8	Oceanic turtles	0.091		7	0.076		7	0.146		7
9	Crocodiles	0.002	1.2	8	0.001	0.9	8	0.002	1.2	8
10	Ad. groupers	1.050		1	3.118		13	0.173		1
11	Sub. groupers	0.327		1	0.971	2.2	13	0.054		1
12	Juv. groupers	0.090		3	0.268	2.4	13	0.015		3
13	Ad. snappers	2.531		1	1.176		13	0.716		1
14	Sub. snappers	1.305		1	0.606	1.1	13	0.369		1
15	Juv. snappers	0.941		3	0.437		13	0.266		3
16	Ad. Napoleon wrasse	0.015	1.6	4	0.013		4	0.060		1
17	Sub. Napoleon wrasse	0.026	1.6	4	0.023		4	0.106		1
18	Juv. Napoleon wrasse	0.005	1.4	4	0.004	0.9	4	0.019	4.2	4
19	Skipjack tuna	0.803		11	0.411		11	0.396	0.9	11
20	Other tuna	0.020		2	0.321		11	0.096	2.1	2
21	Mackerel	0.100	2.2	1	0.100	2.0	11	0.100	1.2	1
22	Billfish	1.644		9	1.205		9	0.576		9
23	Ad. coral trout	0.491		1	0.511		13	0.910		1
24	Juv. coral trout	0.107		3	0.173	2.6	13	0.198		3
25	Ad. large sharks	0.122		9	0.089		9	0.356		1
26	Juv. large sharks	0.106		9	0.077		9	0.308		1
27	Ad. small sharks	0.041	1.2	3	0.047		3	0.047		3
28	Juv. small sharks	0.017	1.2	4	0.019		4	0.020		4
29	Whale shark	0.006		4	0.004	0.9	4	0.002		4
30	Manta ray	0.003	0.9	9	0.002	1.1	9	0.002		9
31	Adult rays	0.205		11	0.105		11	0.114		11
32	Juv. rays	0.078		11	0.151	3.7	11	0.044		11
33	Ad. butterflyfish	0.205		4	3.564		13	0.281		4
34	Juv. butterflyfish	0.068		4	1.188	1.1	13	0.323	3.4	4
35	Cleaner wrasse	0.008	1.1	4	0.134		13	0.010		4
36	Ad. large pelagic	0.063		11	0.032		11	0.125	0.1	1
37	Juv. large pelagic	0.038		3	0.019		11	0.075	0.1	11
38	Ad. medium pelagic	0.042		2	0.007	1.1	11	0.084	0.1	2
39	Juv. medium pelagic	0.064		3	0.011	1.1	11	0.128	0.1	3
40	Ad. small pelagic	0.022		2	0.042		11	0.381		2
41	Juv. small pelagic	0.034		3	0.064		11	0.581		3
42	Ad. large reef assoc.	3.617	10.0	1	8.146		4	7.406	0.9	1
43	Juv. large reef assoc.	2.290	10.0	3	5.157		4	9.724	1.9	3
44	Ad. medium reef assoc.	2.853	142.0	2	3.260		4	0.943	2.1	2
45	Juv. medium reef assoc.	2.356	142.0	3	2.692		4	0.779	2.1	3
46	Ad. small reef assoc.	0.874	4.0	4	2.147		13	0.300		4

Table D.1.1. Cont. Biomass for sub-area models ($t \cdot km^{-2}$).

Group #	Functional group	Kofiau	Modifer	Ref #	Dampier St.	Modifier	Ref #	SE Misool	Modifier	Ref #
47	Juv. small reef assoc.	0.455	4.0	4	1.119	0.3	13	0.156		4
48	Ad. large demersal	0.147		11	0.075		11	0.082		11
49	Juv. large demersal	0.157		11	0.080		11	0.088		11
50	Ad. small demersal	0.035		2	0.114		11	0.116	5.1	2
51	Juv. small demersal	0.025		3	0.080		11	0.082	5.1	3
52	Ad. large planktivore	2.202		1	4.405	0.1	13	1.264		2
53	Juv. large planktivore	1.954		3	3.909	0.1	13	1.122		3
54	Ad. small planktivore	0.035		2	0.345	0.1	13	0.414	12.5	2
55	Juv. small planktivore	0.052		3	0.512	0.0	13	0.615	12.5	3
56	Ad. anchovy	0.858	2.0	10	1.003		10	1.825		10
57	Juv. anchovy	1.279	2.0	10	1.496		10	2.721		10
58	Ad. deepwater fish	0.618	30.8	2	0.876		9	0.376		2
59	Juv. deepwater fish	0.817	30.8	3	1.159		9	0.497		3
60	Ad. macro algal browsing	0.071		10	0.167		10	0.304		10
61	Juv. macro algal browsing	0.142		10	0.334		10	0.608		10
62	Ad. eroding grazers	0.588		2	7.533		13	1.015		2
63	Juv. eroding grazers	0.286		3	3.667		13	0.494		3
64	Ad. scraping grazers	4.000	0.4	2	4.980		13	2.000	0.1	2
65	Juv. scraping grazers	4.160	0.1	3	23.716		13	9.525	0.1	3
66	Detritivore fish	0.019		11	0.223		13	0.016	1.6	11
67	Azooxanthellate corals	0.506		4	2.058	3.0	4	1.388	2.0	4
68	Hermatypic corals	0.738		4	3.000	3.0	4	2.024	2.0	4
69	Non reef building corals	0.506		4	2.058	3.0	4	1.388	2.0	4
70	Soft corals	0.506		4	2.058	3.0	4	1.388	2.0	4
71	Calcareous algae	0.029		10	0.201	3.0	10	0.244	2.0	10
72	Anemonies	1.416	9.9	10	1.002	3.0	10	1.216	2.0	10
73	Penaeid shrimps	2.317		11	3.561	3.0	11	2.576	2.0	11
74	Shrimps and prawns	2.317		11	3.561	3.0	11	2.576	2.0	11
75	Squid	0.828	3.0	11	0.423	3.0	11	0.306	2.0	11
76	Octopus	1.159		11	1.782	3.0	11	1.288	2.0	11
77	Sea cucumbers	1.718	1.5	11	1.728	3.0	11	1.250	2.0	11
78	Lobsters	0.254		11	0.650	5.0	11	1.128	8.0	11
79	Large crabs	0.962	2.9	11	0.510	3.0	11	0.368	2.0	11
80	Small crabs	1.222	3.7	11	0.510	3.0	11	0.368	2.0	11
81	Crown of thorns	0.185		4	0.750	3.0	4	0.506	2.0	4
82	Giant triton	0.058		11	0.090	3.0	11	0.064	2.0	11
83	Herbivorous echinoids	1.478	1.8	11	1.287	3.0	11	0.930	2.0	11
84	Bivalves	10.65		11	16.365	3.0	11	11.836	2.0	11
85	Sessile filter feeders	5.307		11	8.157	3.0	11	5.900	2.0	11
86	Epifaunal det. inverts.	3.469	2.1	11	2.493	3.0	11	1.804	2.0	11
87	Epifaunal carn. inverts	8.201	1.3	11	9.975	3.0	11	7.214	2.0	11
88	Infaunal inverts.	31.774		11	48.837	3.0	11	35.322	2.0	11
89	Jellyfish and hydroids	0.100		12	0.300	3.0	12	0.100		12
90	Carn. zooplankton	1.000		12	3.000	3.0	12	1.000		12
91	Large herb. zooplankton	0.560		12	1.680	3.0	12	0.560		12
92	Small herb. zooplankton	2.43.0		12	7.290	3.0	12	2.430		12
93	Phytoplankton	26.100		12	26.100		12	26.100		12
94	Macro algae	11.264		10	52.686	2.0	10	47.919		10
95	Sea grass	35.006		8	46.940	2.0	8	32.644		8
96	Mangroves	25.009		5	14.399		5	15.536		5
97	Fishery discards	6.817		14	20.265		14	15.600		14
98	Detritus	115.87		11	59.366		11	64.405	5.1	11

Table D.1.2. Biomass estimation method and data references. All biomass estimation methods rely on a relative physical ratio versus the Raja Ampat 2005 model (Table D.1.3.) except 1, 2, 3, 13 and 14.

Ref #	Estimation method	Rationale
1	Reef health monitoring dive transect data (by species) Kofiau: A. Muljadi (<i>unpublished data</i>). Misool: M. Syakir (<i>unpublished data</i>). TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413.	BHS EBM project sampling
2	Reef health monitoring dive transect data (by family). Biomass per family is assigned to EwE groups in the same proportion as the relative species count occurring in groups. Citation as Ref # 1.	BHS EBM project sampling
3	Immature life history stanza biomasses from EwE multistanza model (Christensen and Walters, 2004). Maturation and growth parameters provided in Ainsworth et al. (2007).	Age-structure of model
4	Coral reef area coverage. Reef area is available from LandSat imagery to 20m depth; (2000-2002) (NASA Landsat Program, 2006). Reef area to 50m depth is determined by Indonesia Navy nautical charts (TNI AL, 2002) obtained with acoustical methods; Additional ratios from literature sources (see Table 2.1: Hard coral coverage reported for Raja Ampat.).	Habitat area
5	Mangrove area. Based on LandSat imagery (2000-2002) (NASA Landsat Program, 2006), assembled by M. Barmawi (<i>unpublished data</i>); contact: Joanne Wilson, TNC CTC. Jl Pengembak 2, Sanur, Bali, Indonesia joanne_wilson@tnc.org.	Habitat area
6	Dugong area. BHS EBM Project Coastal Rural Appraisal Surveys. TNC. (A. Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413. Email: amuljadi@tnc.org. <i>unpublished data</i>).	Habitat area
7	Turtle nesting habitat area. BHS EBM Project Coastal Rural Appraisal Surveys. Citation as Ref # 6.	Habitat area
8	Coast line. Indonesian Navy nautical charts (TNI AL, 2002) digitized by M. Barmawi (<i>unpublished data</i>); contact: Joanne Wilson, TNC CTC. Jl Pengembak 2, Sanur, Bali, Indonesia joanne_wilson@tnc.org.	Physical oceanography
9	Deep area (>200 m) to total water area ratio. Indonesian Navy nautical charts. Citation as Ref # 8.	Physical oceanography
10	Shallow area (<200 m) to total water area ratio. Indonesian Navy nautical charts. Citation as Ref # 8.	Physical oceanography
11	Water to land area ratio. Indonesian Navy nautical charts. Citation as Ref # 8.	Physical oceanography
12	Biomass in sub-area models assumed same as Raja Ampat average. Values from Ainsworth et al. (2007).	Adapted from other source
13	Waigeo transect abundance COREMAP (2001).	Adapted from other source
14	Based on human population (inter-island ratios used for sub-area models). BHS EBM Project CI Valuation Report: Dohar and Anggraeni (2007).	Human population

D.2. CATCH

Table D.2.1 EwE catch matrix for 2005 Raja Ampat model (kg•km⁻²)

Group	Gear type																Sum	
	Spear and harpoon	Reef gleaning	Shore gillnet	Driftnet	Permanent trap	Portable trap	Diving spear	Diving live fish	Diving cyanide	Blas fishing	Trotling	Purse seine	Pole and line	Hook and line	Lift net	Foreign fleet		Shrimp trawl
Ad. groupers	1.45				2.89		1.45	7.23	7.23	1.45				72.30				94.0
Sub. groupers	0.73				1.47		0.73	3.67	3.67	0.73				36.70				47.7
Juv. groupers	0.49				0.98					0.49				19.60				21.6
Ad. snappers	4.36		8.71		8.71		4.36			4.36				84.00				114.5
Sub. snappers	4.36		8.71		8.71		4.36			4.36				55.50				86.0
Juv. snappers	0.97		1.94		1.94		0.97			0.97				25.40				32.2
Ad. Napoleon wrasse								0.80	0.80	0.16				28.90				30.7
Sub. Napoleon wrasse								0.80	0.80	0.16				14.70				16.5
Juv. Napoleon wrasse										0.21				5.18				5.4
Skipjack tuna											178.00	45.80	229.00	75.00		80.50		608.3
Other tuna											11.50	5.95	13.70	12.90		7.41		51.5
Mackerel													37.40	9.64	48.20			95.2
Billfish											87.40							87.4
Ad. coral trout	1.18		1.18	1.18	1.18	1.18				0.31								6.2
Juv. coral trout	0.12		0.12	0.12	0.12	0.12				0.03								0.6
Ad. large sharks														44.70				44.7
Juv. large sharks														4.96				5.0
Ad. small sharks														9.94				9.9
Juv. small sharks														1.10				1.1
Adult rays			6.07	6.07	6.07	6.07												24.3
Juv. rays			0.61	0.61	0.61	0.61												2.4
Ad. butterflyfish	11.20		11.20	11.20	11.20	11.20		1.00	2.00									59.0
Juv. butterflyfish	1.12		1.12	1.12	1.12	1.12			0.29									5.9
Cleaner wrasse			0.73	0.73	0.73	0.73			0.19									3.1
Ad. large pelagic			13.60	10.90	8.15	8.15									13.60			54.4
Juv. large pelagic			1.81	1.45	1.09	1.09									1.81			7.3
Ad. medium pelagic			3.02	2.42	1.81	1.81									3.02			12.1
Juv. medium pelagic			1.34	1.07	0.81	0.81									1.34			5.4
Ad. small pelagic			12.50	12.50	9.39	9.39			3.13						15.70			62.6
Juv. small pelagic			1.39	1.39	1.04	1.04			0.35						1.74			6.9
Ad. large reef assoc.	41.40		41.40	41.40	41.40	37.80			10.90					148.00				362.3
Juv. large reef assoc.	8.06		8.06	8.06	8.06	7.01			2.12					34.30				75.7
Ad. medium reef assoc.	22.80		22.80	22.80	22.80	21.10			6.01					84.60				202.9
Juv. medium reef assoc.	2.28		2.28	2.28	2.28	1.71			0.60					25.90				37.3
Ad. small reef assoc.	13.50		13.50	13.50	13.50	10.10			3.54					42.80				110.4
Juv. small reef assoc.	1.35		1.35	1.35	1.35	1.01			0.35					9.47				16.2
Ad. large demersal	9.71				9.71	7.28			2.56					9.34				38.6
Juv. large demersal	1.94				1.94	1.46			0.51					3.34				9.2
Ad. small demersal	17.40				17.40	17.40			4.59									56.8
Juv. small demersal	1.94				1.94	1.94			0.51									6.3
Ad. large planktivore	4.83		4.83	4.83	4.83	4.83			1.27									25.4
Juv. large planktivore	4.78		4.78	4.78	4.78	4.78			1.26									25.2
Ad. small planktivore	4.52		4.52	4.52	4.52	4.52			1.19									23.8
Juv. small planktivore	3.41		3.41	3.41	3.41	3.41			0.90									17.9
Ad. anchovy			79.90	63.90	47.90	47.90									116.00			355.6
Juv. anchovy			8.88	7.10	5.33	5.33									8.88			35.5
Ad. deepwater fish			4.13	4.13	4.13	4.13												16.5
Juv. deepwater fish			0.46	0.46	0.46	0.46												1.8
Ad. macro algal browsing			0.75	0.75	0.75	0.75			0.10									3.1
Juv. macro algal browsing			0.07	0.07	0.07	0.07			0.02									0.3
Ad. eroding grazers			0.25	0.25	0.25	0.25			0.03									1.0
Juv. eroding grazers			1.3E-02	1.3E-02	1.3E-02	1.3E-02			3.4E-03									0.1
Ad. scraping grazers			20.50	20.50	20.50	20.50			2.70									84.7
Juv. scraping grazers			1.99	1.99	1.99	1.99			0.52									8.5
Detritivore fish			1.75	1.75	1.75	1.75			0.23									7.2
Hermatypic corals									2.00									2.0
Penacid shrimps																	695.00	695.0
Shrimps and prawns																	81.50	81.5
Squid															30.20			30.2
Octopus	4.7E-03	1.5E-02					4.9E-03		2.5E-04									0.0
Sea cucumbers	2.12	6.68					2.23		0.11									11.1
Lobsters		262.00					87.20		4.36									353.6
Large crabs		9.81					3.27		0.16									13.2
Small crabs		9.81					3.27		0.16									13.2
Giant triton		4.40					1.47		0.07									5.9
Herbivorous echinoids		9.81					3.27		0.16									13.2
Bivalves		28.30																28.3
Sessile filter feeders		4.80																4.8
Epifaunal det. inverts.		10.90					3.64		0.18									14.7
Epifaunal carn. inverts		12.80					4.27		0.21									17.3
Sum	166.0	359.0	300.0	259.0	289.0	251.0	120.0	12.0	13.0	67.0	277.0	52.0	280.0	858.0	240.0	88.0	777.0	4408.0

Table D.2.2 EwE catch matrix for 2005 Dampier St. model (kg•km⁻²)

Group	Gear type																Sum	
	Spear and harpoon	Reef gleaning	Shore gillnet	Driftnet	Permanent trap	Portable trap	Diving spear	Diving live fish	Diving cyanide	Blasfishing	Trolling	Purse seine	Pole and line	Hook and line	Lift net	Foreign fleet		Shrimp trawl
Ad. groupers	1.45				2.89		1.45	7.23	7.23	1.45				72.30				94.0
Sub. groupers	0.73				1.47		0.73	3.67	3.67	0.73				36.70				47.7
Juv. groupers	0.49				0.98					0.49				19.60				21.6
Ad. snappers	4.36		8.71		8.71		4.36			4.36				84.00				114.5
Sub. snappers	4.36		8.71		8.71		4.36			4.36				55.50				86.0
Juv. snappers	0.97		1.94		1.94		0.97			0.97				25.40				32.2
Ad. Napoleon wrasse								0.80	0.80	0.16				28.90				30.7
Sub. Napoleon wrasse								0.80	0.80	0.16				14.70				16.5
Juv. Napoleon wrasse										0.21				5.18				5.4
Skipjack tuna											178.00	45.80	229.00	75.00		80.50		608.3
Other tuna											11.50	5.95	13.70	12.90		7.41		51.5
Mackerel													37.40	9.64	48.20			95.2
Billfish											87.40							87.4
Ad. coral trout	1.18		1.18	1.18	1.18	1.18				0.31								6.2
Juv. coral trout	0.12		0.12	0.12	0.12	0.12				0.03								0.6
Ad. large sharks														44.70				44.7
Juv. large sharks														4.96				5.0
Ad. small sharks														9.94				9.9
Juv. small sharks														1.10				1.1
Adult rays			6.07	6.07	6.07	6.07												24.3
Juv. rays			0.61	0.61	0.61	0.61												2.4
Ad. butterflyfish	11.20		11.20	11.20	11.20	11.20			1.00	2.00								59.0
Juv. butterflyfish	1.12		1.12	1.12	1.12	1.12				0.29								5.9
Cleaner wrasse			0.73	0.73	0.73	0.73				0.19								3.1
Ad. large pelagic			13.60	10.90	8.15	8.15									13.60			54.4
Juv. large pelagic			1.81	1.45	1.09	1.09									1.81			7.3
Ad. medium pelagic			3.02	2.42	1.81	1.81									3.02			12.1
Juv. medium pelagic			1.34	1.07	0.81	0.81									1.34			5.4
Ad. small pelagic			12.50	12.50	9.39	9.39				3.13					15.70			62.6
Juv. small pelagic			1.39	1.39	1.04	1.04				0.35					1.74			6.9
Ad. large reef assoc.	41.40		41.40	41.40	41.40	37.80				10.90			148.00					362.3
Juv. large reef assoc.	8.06		8.06	8.06	8.06	7.01				2.12			34.30					75.7
Ad. medium reef assoc.	22.80		22.80	22.80	22.80	21.10				6.01			84.60					202.9
Juv. medium reef assoc.	2.28		2.28	2.28	2.28	1.71				0.60			25.90					37.3
Ad. small reef assoc.	13.50		13.50	13.50	13.50	10.10				3.54			42.80					110.4
Juv. small reef assoc.	1.35		1.35	1.35	1.35	1.01				0.35			9.47					16.2
Ad. large demersal	9.71				9.71	7.28				2.56			9.34					38.6
Juv. large demersal	1.94				1.94	1.46				0.51			3.34					9.2
Ad. small demersal	17.40				17.40	17.40				4.59								56.8
Juv. small demersal	1.94				1.94	1.94				0.51								6.3
Ad. large planktivore	4.83		4.83	4.83	4.83	4.83				1.27								25.4
Juv. large planktivore	4.78		4.78	4.78	4.78	4.78				1.26								25.2
Ad. small planktivore	4.52		4.52	4.52	4.52	4.52				1.19								23.8
Juv. small planktivore	3.41		3.41	3.41	3.41	3.41				0.90								17.9
Ad. anchovy			79.90	63.90	47.90	47.90									116.00			355.6
Juv. anchovy			8.88	7.10	5.33	5.33									8.88			35.5
Ad. deepwater fish			4.13	4.13	4.13	4.13												16.5
Juv. deepwater fish			0.46	0.46	0.46	0.46												1.8
Ad. macro algal browsing			0.75	0.75	0.75	0.75				0.10								3.1
Juv. macro algal browsing			0.07	0.07	0.07	0.07				0.02								0.3
Ad. eroding grazers			0.25	0.25	0.25	0.25				0.03								1.0
Juv. eroding grazers			1.3E-02	1.3E-02	1.3E-02	1.3E-02				3.4E-03								0.1
Ad. scraping grazers			20.50	20.50	20.50	20.50				2.70								84.7
Juv. scraping grazers			1.99	1.99	1.99	1.99				0.52								8.5
Detritivore fish			1.75	1.75	1.75	1.75				0.23								7.2
Hermatypic corals										2.00								2.0
Penaeid shrimps																	695.00	695.0
Shrimps and prawns																	81.50	81.5
Squid															30.20			30.2
Octopus	4.7E-03	1.5E-02					4.9E-03			2.5E-04								0.0
Sea cucumbers	2.12	6.68					2.23			0.11								11.1
Lobsters		262.00					87.20			4.36								353.6
Large crabs		9.81					3.27			0.16								13.2
Small crabs		9.81					3.27			0.16								13.2
Giant triton		4.40					1.47			0.07								5.9
Herbivorous echinoids		9.81					3.27			0.16								13.2
Bivalves		28.30																28.3
Sessile filter feeders		4.80																4.8
Epifaunal det. inverts.		10.90					3.64			0.18								14.7
Epifaunal cam. inverts		12.80					4.27			0.21								17.3
Sum	166.0	359.0	300.0	259.0	289.0	251.0	120.0	12.0	13.0	67.0	277.0	52.0	280.0	858.0	240.0	88.0	777.0	4408.0

Table D.2.3 EwE catch matrix for 2005 SE Misool model (kg·km⁻²)

Group	Gear type															Sum		
	Spear and harpoon	Reef gleaning	Shore gillnet	Driftnet	Permanent trap	Portable trap	Diving spear	Diving live fish	Diving cyanide	Blast fishing	Trotting	Purse seine	Pole and line	Hook and line	Lift net		Foreign fleet	Shrimp trawl
Ad. groupers	0.35				0.71		0.35	1.77	1.77	0.35				17.68				23.0
Sub. groupers	0.34				0.68		0.34	1.70	1.70	0.34				16.98				22.1
Juv. groupers	0.24				0.49					0.24				9.79				10.8
Ad. snappers	6.37		12.72		12.72		6.37			6.37				122.67				167.2
Sub. snappers	6.60		13.18		13.18		6.60			6.60				83.96				130.1
Juv. snappers	1.41		2.83		2.83		1.41			1.41				37.09				47.0
Ad. Napoleon wrasse								4.27	4.27	0.86				154.69				164.1
Sub. Napoleon wrasse								4.23	4.23	0.85				77.98				87.3
Juv. Napoleon wrasse										0.55				13.72				14.3
Skipjack tuna											411.96	106.00	529.99	173.58		186.31		1407.8
Other tuna											7.44	3.85	8.86	8.35		4.79		33.3
Mackerel												127.27	32.80		164.02			324.1
Billfish										119.70								119.7
Ad. coral trout	4.20		4.20	4.20	4.20	4.20				1.10								22.1
Juv. coral trout	0.50		0.50	0.50	0.50	0.50				0.13								2.6
Ad. large sharks														216.23				216.2
Juv. large sharks														23.99				24.0
Ad. small sharks														26.34				26.3
Juv. small sharks														2.91				2.9
Adult rays			14.05	14.05	14.05	14.05												56.2
Juv. rays			1.40	1.40	1.40	1.40												5.6
Ad. butterflyfish	4.16		4.16	4.16	4.16	4.16			0.37	0.74								21.9
Juv. butterflyfish	0.45		0.45	0.45	0.45	0.45				0.12								2.4
Cleaner wrasse			0.27	0.27	0.27	0.27				0.07								1.1
Ad. large pelagic			96.36	77.23	57.75	57.75									96.36			385.5
Juv. large pelagic			4.18	3.35	2.52	2.52									4.18			16.7
Ad. medium pelagic			16.53	13.25	9.91	9.91									16.53			66.1
Juv. medium pelagic			7.33	5.85	4.41	4.41									7.33			29.3
Ad. small pelagic			77.54	77.54	58.25	58.25				19.42					97.39			388.4
Juv. small pelagic			8.63	8.63	6.45	6.45				2.16					10.80			43.1
Ad. large reef assoc.	120.88		120.88	120.88	120.88	110.37				31.83			432.12					1057.8
Juv. large reef assoc.	23.53		23.53	23.53	23.53	20.47				6.19			100.15					221.0
Ad. medium reef assoc.	14.30		14.30	14.30	14.30	13.23				3.77			53.05					127.2
Juv. medium reef assoc.	1.43		1.43	1.43	1.43	1.07				0.38			16.24					23.4
Ad. small reef assoc.	8.44		8.44	8.44	8.44	6.31				2.21			26.75					69.0
Juv. small reef assoc.	0.29		0.29	0.29	0.29	0.22				0.08			2.05					3.5
Ad. large demersal	22.47				22.47	16.85				5.92				21.62				89.3
Juv. large demersal	4.49				4.49	3.38				1.18				7.73				21.3
Ad. small demersal	14.26				14.26	14.26				3.76								46.5
Juv. small demersal	1.59				1.59	1.59				0.42								5.2
Ad. large planktivore	5.16		5.16	5.16	5.16	5.16				1.36								27.2
Juv. large planktivore	5.11		5.11	5.11	5.11	5.11				1.35								26.9
Ad. small planktivore	7.34		7.34	7.34	7.34	7.34				1.93								38.6
Juv. small planktivore	5.54		5.54	5.54	5.54	5.54				1.46								29.2
Ad. anchovy			308.08	246.38	184.69	184.69									447.27			1371.1
Juv. anchovy			34.24	27.38	20.55	20.55									34.24			137.0
Ad. deepwater fish			6.89	6.89	6.89	6.89												27.5
Juv. deepwater fish			0.77	0.77	0.77	0.77												3.1
Ad. macro algal browsing			2.88	2.88	2.88	2.88				0.38								11.9
Juv. macro algal browsing			0.28	0.28	0.28	0.28				0.07								1.2
Ad. eroding grazers			0.15	0.15	0.15	0.15				0.02								0.6
Juv. eroding grazers			0.01	0.01	0.01	0.01				0.00								0.0
Ad. scraping grazers			88.67	88.67	88.67	88.67				11.68								366.4
Juv. scraping grazers			8.61	8.61	8.61	8.61				2.25								36.7
Detritivore fish			0.39	0.39	0.39	0.39				0.05								1.6
Hermatypic corals										5.30								5.3
Penaeid shrimps																	1608.48	1608.5
Shrimps and prawns																	188.62	188.6
Squid															69.89			69.9
Octopus	1.1E-02	3.4E-02					1.1E-02			5.7E-04								0.1
Sea cucumbers	4.91	15.46					5.16			0.26								25.8
Lobsters		606.36					201.81			10.09								818.3
Large crabs		22.70					7.57			0.38								30.7
Small crabs		22.70					7.57			0.38								30.7
Giant trion		10.18					3.40			0.17								13.8
Herbivorous echinoids		22.70					7.57			0.38								30.7
Bivalves		65.50																65.5
Sessile filter feeders		11.11																11.1
Epifaunal det. inverts.		25.23					8.42			0.42								34.1
Epifaunal cam. inverts.		29.62					9.88			0.49								40.0
Sum	264.4	831.6	907.3	785.3	743.6	689.1	266.5	12.0	12.3	135.5	539.1	109.8	666.1	1678.5	948.0	191.1	1797.1	10577.3

Table D.2.4 EwE catch matrix for 2005 Kofiau model (kg•km⁻²)

Group	Gear type														Sum			
	Spear and harpoon	Reef gleaning	Shore gillnet	Driftnet	Permanent trap	Portable trap	Diving spear	Diving live fish	Diving cyanide	Blast fishing	Trotting	Purse seine	Pole and line	Hook and line		Lift net	Foreign fleet	Shrimp trawl
Ad. groupers	1.80				3.58		1.80	8.96	8.96	1.80				89.60				116.5
Sub. groupers	1.72				3.45		1.72	8.60	8.60	1.72				86.03				111.8
Juv. groupers	1.24				2.47					1.24				49.58				54.5
Ad. snappers	18.79		37.53		37.53		18.79			18.79				361.95				493.4
Sub. snappers	19.46		38.88		38.88		19.46			19.46				247.75				383.9
Juv. snappers	4.17		8.36		8.36		4.17			4.17				109.43				138.7
Ad. Napoleon wrasse								0.11	0.11	0.02				3.99				4.2
Sub. Napoleon wrasse								0.11	0.11	0.02				2.08				2.3
Juv. Napoleon wrasse										0.07				1.67				1.7
Skipjack tuna											309.32	79.59	397.94	130.33		139.89		1057.1
Other tuna											2.69	1.39	3.20	3.01		1.73		12.0
Mackerel													23.65	6.10	30.48			60.2
Billfish											285.00							285.0
Ad. coral trout	1.89		1.89	1.89	1.89	1.89				0.50								10.0
Juv. coral trout	0.23		0.23	0.23	0.23	0.23				0.06								1.2
Ad. large sharks														61.55				61.6
Juv. large sharks														6.83				6.8
Ad. small sharks														16.04				16.0
Juv. small sharks														1.77				1.8
Adult rays			21.10	21.10	21.10	21.10												84.4
Juv. rays			2.11	2.11	2.11	2.11												8.4
Ad. butterflyfish	2.53		2.53	2.53	2.53	2.53			0.23	0.45								13.3
Juv. butterflyfish	0.28		0.28	0.28	0.28	0.28				0.07								1.5
Cleaner wrasse			0.16	0.16	0.16	0.16				0.04								0.7
Ad. large pelagic			2.68	2.15	1.61	1.61									2.68			10.7
Juv. large pelagic			6.34	5.08	3.82	3.82									6.34			25.4
Ad. medium pelagic			6.90	5.53	4.14	4.14									6.90			27.6
Juv. medium pelagic			3.06	2.44	1.84	1.84									3.06			12.2
Ad. small pelagic			3.75	3.75	2.82	2.82				0.94					4.71			18.8
Juv. small pelagic			0.42	0.42	0.31	0.31				0.10					0.52			2.1
Ad. large reef assoc.	4.62		4.62	4.62	4.62	4.21				1.22			16.50					40.4
Juv. large reef assoc.	0.90		0.90	0.90	0.90	0.78				0.24			3.82					8.4
Ad. medium reef assoc.	0.54		0.54	0.54	0.54	0.50				0.14			2.01					4.8
Juv. medium reef assoc.	0.05		0.05	0.05	0.05	0.04				0.01			0.61					0.9
Ad. small reef assoc.	5.14		5.14	5.14	5.14	3.84				1.35			16.29					42.0
Juv. small reef assoc.	0.18		0.18	0.18	0.18	0.13				0.05			1.25					2.1
Ad. large demersal	16.87				16.87	12.65				4.45				16.23				67.1
Juv. large demersal	6.74				6.74	5.07				1.78				11.61				31.9
Ad. small demersal	9.02				9.02	9.02				2.38								29.4
Juv. small demersal	2.01				2.01	2.01				0.53								6.6
Ad. large planktivore	7.51		7.51	7.51	7.51	7.51				1.97								39.5
Juv. large planktivore	7.43		7.43	7.43	7.43	7.43				1.96								39.1
Ad. small planktivore	6.41		6.41	6.41	6.41	6.41				1.69								33.7
Juv. small planktivore	4.83		4.83	4.83	4.83	4.83				1.27								25.4
Ad. anchovy			60.45	48.34	36.24	36.24									87.76			269.0
Juv. anchovy			6.72	5.37	4.03	4.03									6.72			26.9
Ad. deepwater fish			0.31	0.31	0.31	0.31												1.2
Juv. deepwater fish			0.03	0.03	0.03	0.03												0.1
Ad. macro algal browsing			0.57	0.57	0.57	0.57				0.07								2.3
Juv. macro algal browsing			0.05	0.05	0.05	0.05				0.01								0.2
Ad. eroding grazers			0.07	0.07	0.07	0.07				0.01								0.3
Juv. eroding grazers			0.00	0.00	0.00	0.00				0.00								0.0
Ad. scraping grazers			42.47	42.47	42.47	42.47				5.59								175.5
Juv. scraping grazers			4.12	4.12	4.12	4.12				1.08								17.6
Detritivore fish			0.58	0.58	0.58	0.58				0.08								2.4
Hermatypic corals										3.23								3.2
Penaeid shrimps																	2415.47	2415.5
Shrimps and prawns																	283.25	283.3
Squid																		105.0
Octopus	1.6E-02	5.1E-02					1.7E-02			8.5E-04					104.96			8.5E-02
Sea cucumbers	7.37	23.22					7.75			0.39								38.7
Lobsters		45.53					15.15			0.76								61.4
Large crabs		34.09					11.36			0.57								46.0
Small crabs		34.09					11.36			0.57								46.0
Giant triton		15.29					5.11			0.25								20.7
Herbivorous echinoids		34.09					11.36			0.57								46.0
Bivalves		98.36																98.4
Sessile filter feeders		16.68																16.7
Epifaunal det. inverts.		37.88					12.65			0.63								51.2
Epifaunal carn. inverts.		44.49					14.84			0.74								60.1
Sum	131.7	383.8	289.2	187.2	297.8	195.8	135.6	17.8	18.0	83.0	597.0	81.0	424.8	1246.0	254.1	141.6	2698.7	7183.1

Table D.2.5 IUU catch for Raja Ampat (kg•km⁻²)

Group name	Spear and harpoon	Reef gleaning	Shore gillnet	Driftnet	Permanent trap	Portable trap	Diving spear	Diving live fish	Diving cyanide	Blast fishing	Trotling	Purse seine	Pole and line	Hook and line	Lift net	Foreign fleet	Shrimp trawl	IUU total
Ad. groupers	1.1				2.1		1.1	5.3	5.3	1.1				53.2				69.1
Sub. groupers	0.5				1.1		0.5	2.7	2.7	0.5				27.0				35.1
Juv. groupers	0.4				0.7					0.4				14.4				15.8
Ad. snappers	3.2		6.4		6.4		3.2			3.2				61.7				84.2
Sub. snappers	3.2		6.4		6.4		3.2			3.2				40.8				63.2
Juv. snappers	0.7		1.4		1.4		0.7			0.7				18.6				23.6
Ad. Napoleon wrasse								0.6	0.6	0.1				21.3				22.6
Sub. Napoleon wrasse								0.6	0.6	0.1				10.8				12.1
Juv. Napoleon wrasse										0.1				2.6				2.7
Skipjack tuna											76.0	19.6	98.1	32.1		34.5		260.2
Other tuna											4.9	2.5	5.8	5.5		3.2		22.0
Mackerel											16.0	4.1	20.6			7.3		48.0
Billfish											37.4							37.4
Ad. coral trout	0.9		0.9	0.9	0.9	0.9				0.2								4.6
Juv. coral trout	0.1		0.1	0.1	0.1	0.1				0.0								0.5
Ad. large sharks														19.4				19.4
Juv. large sharks														2.2				2.2
Ad. small sharks														4.3				4.3
Juv. small sharks														0.5				0.5
Adult rays			1.3	1.3	1.3	1.3												5.3
Juv. rays			0.1	0.1	0.1	0.1												0.5
Ad. butterflyfish	8.2		8.2	8.2	8.2	8.2				2.2								43.3
Juv. butterflyfish	0.8		0.8	0.8	0.8	0.8				0.2								4.3
Cleaner wrasse			0.5	0.5	0.5	0.5				0.1								2.3
Ad. large pelagic			5.8	4.7	3.5	3.5								5.8				23.3
Juv. large pelagic			0.8	0.6	0.5	0.5								0.8				3.1
Ad. medium pelagic			1.3	1.0	0.8	0.8								1.3				5.2
Juv. medium pelagic			0.6	0.5	0.3	0.3								0.6				2.3
Ad. small pelagic			5.8	5.8	4.3	4.3				1.4				7.2				28.8
Juv. small pelagic			0.6	0.6	0.5	0.5				0.2				0.8				3.2
Ad. large reef assoc.	30.5		30.5	30.5	30.5	27.8				8.0				108.5				266.1
Juv. large reef assoc.	5.9		5.9	5.9	5.9	5.2				1.6				25.3				55.7
Ad. medium reef assoc.	16.8		16.8	16.8	16.8	15.5				4.4				62.2				149.3
Juv. medium reef assoc.	1.7		1.7	1.7	1.7	1.3				0.4				19.1				27.5
Ad. small reef assoc.	9.9		9.9	9.9	9.9	7.4				2.6				31.5				81.1
Juv. small reef assoc.	1.0		1.0	1.0	1.0	0.7				0.3				7.0				11.9
Ad. large demersal	4.9				4.9	3.6				1.3				4.7				19.3
Juv. large demersal	1.0				1.0	0.7				0.3				1.7				4.6
Ad. small demersal	8.7				8.7	8.7				2.3								28.4
Juv. small demersal	1.0				1.0	1.0				0.3								3.2
Ad. large planktivore	1.0		1.0	1.0	1.0	1.0				0.3								5.4
Juv. large planktivore	4.4		4.4	4.4	4.4	4.4				1.2								23.2
Ad. small planktivore	2.1		2.1	2.1	2.1	2.1				0.5								10.9
Juv. small planktivore	3.1		3.1	3.1	3.1	3.1				0.8								16.5
Ad. anchovy			73.6	58.9	44.1	44.1								106.9				327.6
Juv. anchovy			8.2	6.5	4.9	4.9								8.2				32.7
Ad. deepwater fish			2.1	2.1	2.1	2.1												8.3
Juv. deepwater fish			0.2	0.2	0.2	0.2												0.9
Ad. macro algal browsing			0.5	0.5	0.5	0.5				0.1								2.3
Juv. macro algal browsing			0.1	0.1	0.1	0.1				0.0								0.2
Ad. eroding grazers			0.2	0.2	0.2	0.2				0.0								0.8
Juv. eroding grazers			6.4E-03	6.4E-03	6.4E-03	6.4E-03				1.7E-03								2.7E-02
Ad. scraping grazers			15.1	15.1	15.1	15.1				2.0								62.2
Juv. scraping grazers			1.5	1.5	1.5	1.5				0.4								6.2
Detritivore fish			1.3	1.3	1.3	1.3				0.2								5.3
Hermatypic corals										1.0								1.0
Penaeid shrimps																	550.2	550.2
Shrimps and prawns																	64.5	64.5
Squid															23.9			23.9
Octopus	2.3E-03	7.4E-03					2.5E-03			1.2E-04								1.2E-02
Sea cucumbers	0.9	2.8					0.9			0.0								4.7
Lobsters		97.4					32.5			1.6								131.5
Large crabs		7.8					2.6			0.1								10.5
Small crabs		7.8					2.6			0.1								10.5
Giant triton		1.8					0.6			0.0								2.5
Herbivorous echinoids		7.8					2.6			0.1								10.5
Bivalves		22.4																22.4
Sessile filter feeders		3.8																3.8
Epifaunal det. inverts.		8.7					2.9			0.1								11.7
Epifaunal carn. inverts		10.1					3.4			0.2								13.7
Sum	111.9	170.4	220.1	187.8	201.9	174.3	56.8	9.2	9.2	44.0	134.3	26.3	124.6	574.1	155.5	44.9	614.7	2859.9

D.3. TROPHIC INTERACTION MATRICES

Table D.3.1 Functional group diet composition. Raja Ampat 1990, Raja Ampat 2005, Kofiau Is., Dampier St., SE Misool

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
Mysticetae	Juv. medium pelagic	1.65	1.70	0.50	1.00	1.70	Crocodiles	Epifaunal carn. inverts	13.07	13.10	13.07	13.07	13.10
	Juv. small pelagic	4.53	4.50	0.01	4.54	4.50		Infauanal inverts.	13.07	13.10	22.22	22.22	13.10
	Squid	13.40	13.40	11.32	10.75	13.40		Jellyfish and hydroids	20.29	20.20	20.29	20.29	20.30
	Octopus			2.84	2.69			Birds	6.06	6.11	6.05	6.05	6.10
	Carn. zooplankton	20.00	20.00	21.11	20.05	20.00		Reef assoc. turtles	1.21	1.20	1.21	1.21	1.20
	Large herb. zooplankton	40.21	40.20	21.23	20.16	40.20		Green turtles	1.21	1.20	1.21	1.21	1.20
Pisc. odontocetae	Small herb. zooplankton	20.21	20.20	42.98	40.81	20.20	Oceanic turtles	1.21	1.20	1.21	1.21	1.20	
	Skipjack tuna	2.38	2.47	3.09	2.38	2.30	Juv. large pelagic	5.49	5.51	5.48	5.48	5.50	
	Ad. large pelagic	0.70	0.72	1.25	0.70	0.70	Juv. small pelagic	12.11	12.11	12.10	12.10	12.10	
	Juv. large pelagic	1.50	1.55	0.03	0.30	1.50	Juv. large planktivore	12.11	12.11	12.10	12.10	12.10	
	Ad. medium pelagic	0.10	0.10	0.17	0.10	0.10	Juv. small planktivore	12.11	12.11	12.10	12.10	12.10	
	Juv. medium pelagic	1.00	1.03	0.51	1.00	1.00	Penaeid shrimps	12.11	12.11	12.10	12.10	12.10	
	Ad. small pelagic	2.00	2.06	< 1E-2	2.00	2.00	Lobsters	8.02	8.01	5.61	5.61	8.00	
	Juv. small pelagic	20.00	20.61	0.37	19.98	20.00	Large crabs	3.35	3.30	3.01	3.01	3.30	
	Ad. large demersal	0.50	0.52	< 1E-2	0.35	0.50	Bivalves			0.34	0.33		
	Ad. small demersal	10.00	10.30	0.09	5.00	5.00	Ad. groupers	0.20	0.20	< 1E-2	0.18	0.20	
	Ad. large planktivore			22.91	12.93		Sub. groupers	0.01	0.01	0.02	0.01	0.01	
	Juv. large planktivore	23.37	24.11	41.41	23.35	28.40	Juv. groupers	< 1E-2	0.10	0.10	0.10	0.05	
	Juv. small planktivore	14.77	15.25	0.42	15.16	14.80	Ad. snappers	0.10	0.01	0.02	0.01	0.01	
	Ad. deepwater fish	10.00	7.16	5.50	3.10	10.00	Sub. snappers	0.19	0.10	0.14	0.05	0.05	
Squid	13.68	14.12	19.40	10.93	13.70	Juv. snappers		0.81					
Octopus			4.84	2.73		Juv. large sharks						5.00	
Deep. odontocetae	Ad. large pelagic	0.50	0.50	0.51	0.51	0.50	Ad. butterflyfish	0.60	0.20	0.07	2.02	2.00	
	Juv. large pelagic	0.50	0.50	0.10	0.10	0.50	Juv. butterflyfish	< 1E-2	0.60	< 1E-2	0.25	0.30	
	Juv. large demersal	3.00	3.03	1.52	1.52	2.00	Cleaner wrasse	0.05	0.05	< 1E-2	0.20	0.20	
	Juv. deepwater fish	9.70	8.82	3.94	3.94	9.70	Juv. medium pelagic	0.10					
	Squid	25.58	25.85	20.80	20.80	26.60	Ad. large reef assoc.	3.00	1.51	2.03	0.71	9.90	
	Octopus	9.70	9.79	15.05	15.05	9.70	Juv. large reef assoc.	1.00	1.01	1.23	0.43	11.90	
	Epifaunal det. inverts.	15.24	15.35	10.84	10.84	15.20	Ad. medium reef assoc.	5.00	9.67	1.75	0.61	5.50	
	Epifaunal carn. inverts	29.09	29.38	29.56	29.56	29.10	Juv. medium reef assoc.	1.00	5.04	0.24	0.35	4.10	
	Infauanal inverts.			4.65	4.65		Ad. small reef assoc.	3.00	1.41	< 1E-2	10.60	1.40	
	Sea grass	100.00	100.00	100.00	100.00	100.00	Juv. small reef assoc.	2.00					
Dugongs	Mackerel	0.18	0.20	0.20	0.27	0.20	Ad. large demersal	0.20	0.20	0.02	< 1E-2	0.04	
	Ad. small pelagic	0.10					Ad. small demersal	2.00	0.50	0.02	0.01	0.50	
	Juv. small pelagic	0.10	0.70	1.98	1.42	0.90	Ad. large planktivore	4.00	2.52	8.68	3.03	3.00	
	Ad. small planktivore		0.20			0.50	Juv. large planktivore			0.14	0.05		
	Juv. small planktivore	0.60	0.50	0.63	5.39	0.50	Ad. small planktivore	0.10	1.01	< 1E-2	0.05	2.40	
	Ad. anchovy	3.00	3.00	1.00	20.57		Ad. anchovy	2.50	4.03	2.36	1.43	0.60	
	Juv. anchovy	0.50	7.00	17.58	12.59	25.50	Juv. anchovy	2.00	2.92	5.79	2.02	2.90	
	Bivalves	7.00					Ad. deepwater fish	4.00	0.70	0.45	0.15	1.00	
	Sessile filter feeders	1.50	2.00	6.30	4.52	2.00	Juv. deepwater fish	1.00	0.91	0.59	0.20	1.00	
	Epifaunal det. inverts.	0.10	0.10	4.55	3.25	0.50	Ad. macro algal browsing	0.20	0.71	0.05	0.11	2.10	
Birds	Epifaunal carn. inverts	14.90	5.00	18.57	13.30	5.00	Juv. macro algal browsing		4.03				
	Infauanal inverts.	13.01	1.00	3.52	2.52	1.00	Ad. eroding grazers	0.50	0.10	0.09	6.06	0.08	
	Jellyfish and hydroids		0.50			0.50	Juv. eroding grazers			0.26	0.71		
	Fishery discards	0.10	0.10	4.90	7.00	0.30	Ad. scraping grazers	2.20	2.01	7.09	8.00	14.00	
	Penaeid shrimps	4.43	4.41	5.32	5.32	4.40	Juv. scraping grazers		5.04		38.43	0.40	
	Shrimps and prawns	4.43	4.41	3.01	3.01	4.40	Detritivore fish	0.05	0.01	< 1E-2	0.28	0.10	
	Octopus			0.53	0.53		Penaeid shrimps	1.00	8.06	10.44	3.63	5.60	
	Sea cucumbers	11.08	11.12	11.08	11.08	11.10	Shrimps and prawns	1.00	8.66	5.91	2.06	4.60	
	Large crabs	0.24	0.20	0.21	0.21	0.20	Squid	0.23	0.10	0.33	0.11	0.10	
	Small crabs	0.23	0.20	0.20	0.20	0.20	Octopus	0.14	0.10	1.51	0.53	0.10	
Herbivorous echinoids	3.50	3.51	2.80	2.80	3.50	Lobsters	0.10	0.30	0.09	0.04	0.30		
Reef assoc. turtles	Bivalves			0.76	0.76		Large crabs	0.20	0.81	0.26	0.09	0.30	
	Sessile filter feeders	60.58	60.72	48.46	48.46	60.80	Small crabs	1.00	1.11	1.23	0.43	1.10	
	Epifaunal det. inverts.	4.43	4.41	3.10	3.10	4.40	Giant triton	0.01	0.10	0.12	0.04	0.40	
	Epifaunal carn. inverts	5.54	5.51	5.54	5.54	5.50	Bivalves	0.14	0.20	0.69	0.24	0.10	
	Infauanal inverts.	5.54	5.51	18.99	18.99	5.50	Epifaunal det. inverts.	3.00	1.01	1.41	0.49	3.80	
	Jellyfish and hydroids	8.00	8.01	8.00	8.00	8.00	Epifaunal carn. inverts	17.90	9.97	13.30	4.57	4.50	
	Carn. zooplankton	1.02	1.00	1.02	1.02	1.00	Infauanal inverts.	15.81	13.09	15.14	5.26	4.00	
	Large herb. zooplankton	1.02	1.00	0.51	0.51	1.00	Carn. zooplankton	11.47	11.08	18.38	6.39	6.40	
	Small herb. zooplankton			0.51	0.51		Ad. groupers	0.13	0.10	0.13	0.11	0.10	
	Macro algae	38.85	38.84	38.84	38.84	38.80	Sub. groupers	0.06	0.05	0.06	0.05	0.05	
Green turtles	Sea grass	51.11	51.15	51.12	51.11	51.20	Juv. groupers	0.05	0.20	0.25	0.20	0.10	
	Sea cucumbers	13.07	13.10	13.07	13.07	13.10	Ad. snappers	0.01	0.01	0.01	0.01	< 1E-2	
	Large crabs	0.62	0.60	0.55	0.55	0.60	Sub. snappers	0.24	0.10	0.12	0.10	0.10	
	Small crabs	0.68	0.70	0.58	0.58	0.70	Juv. snappers		0.10				
	Bivalves			0.16	0.16		Ad. butterflyfish	1.00	0.40	< 1E-2	2.00	1.90	
	Sessile filter feeders	26.14	26.10	20.91	20.91	26.10	Juv. butterflyfish	0.23	0.10	0.25	0.20	0.20	
	Epifaunal det. inverts.	13.07	13.10	9.15	9.15	13.10	Cleaner wrasse	0.27	0.20	< 1E-2	0.24	0.20	

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Ad. large reef assoc.	3.97	3.54	1.70	1.40	3.30		Bivalves			0.44	0.40	
	Juv. large reef assoc.	2.27	3.03	2.15	1.78	24.30		Epifaunal det. inverts.	7.01	5.03	0.77	0.70	4.10
	Ad. medium reef assoc.	4.53	7.28	0.92	0.75	6.90		Epifaunal carn. inverts	5.55	5.64	1.10	1.00	5.80
	Juv. medium reef assoc.	20.60	18.09	1.17	0.70	7.50		Infaunal inverts.	9.00	8.76	1.10	1.00	5.50
	Ad. small reef assoc.	0.71	0.61	0.76	0.63	0.60		Carn. zooplankton	15.93	6.84	11.02	10.01	5.30
	Juv. small reef assoc.	4.08	3.03	6.07	5.00	5.70		Large herb. zooplankton			11.02	10.01	
	Ad. large demersal	0.02	0.02	0.01	0.01	0.02		Small herb. zooplankton			11.02	10.01	
	Ad. small demersal	1.50	1.41	0.01	0.01	1.20		Phytoplankton			5.50	5.00	
	Ad. large planktivore	3.74	6.06	3.65	3.00	3.10	Ad. snappers	Ad. groupers	0.25	0.20	< 1E-2	0.24	0.10
	Juv. large planktivore			0.31	0.25			Sub. groupers	0.01	0.05	< 1E-2	0.05	0.01
	Ad. small planktivore	1.31	1.21	0.08	0.25	1.10		Juv. groupers	0.01	0.10	< 1E-2	0.10	0.01
	Ad. anchovy	2.00	1.31	5.53	2.60	1.20		Ad. snappers	0.20	0.10	1.04	0.50	0.50
	Juv. anchovy	1.00	5.36	6.58	5.43	5.10		Sub. snappers	0.30	0.30	0.86	0.20	0.20
	Ad. deepwater fish	3.42	1.60	1.06	0.87	2.80		Juv. snappers	0.12	0.20	0.30	0.07	0.40
	Juv. deepwater fish	3.73	0.91	1.59	1.32	3.10		Juv. Napoleon wrasse	0.10	0.05	< 1E-2	< 1E-2	0.05
	Ad. macro algal browsing	0.10	0.71	0.11	0.09	0.09		Skipjack tuna	0.05	0.05	0.22	0.05	0.05
	Ad. eroding grazers	1.16	0.02	0.02	0.02	0.02		Other tuna	0.59	0.30	< 1E-2	0.27	0.10
	Juv. eroding grazers			0.12	0.80			Mackerel	0.42	0.40	< 1E-2	0.40	0.20
	Ad. scraping grazers	3.00	4.95	6.07	5.00	4.80		Billfish	0.09	0.09	0.40	0.09	0.09
	Juv. scraping grazers			34.18	44.76			Juv. coral trout	0.01	0.01	0.22	0.05	0.80
	Detritivore fish	0.15	0.05	< 1E-2	0.13	0.05		Juv. rays	0.09	0.09	0.19	0.09	0.09
	Penaeid shrimps	7.25	6.47	4.26	3.50	6.10		Ad. butterflyfish	0.30	0.50	0.05	2.88	0.50
	Shrimps and prawns	2.91	2.53	2.07	1.71	2.40		Juv. butterflyfish	0.01	0.01	0.02	1.00	0.90
	Squid	0.19	0.10	0.17	0.14	0.20		Cleaner wrasse	0.01	0.20	< 1E-2	0.20	0.10
	Octopus	0.19	0.20	0.61	0.51	0.20		Ad. large pelagic	0.60	0.02	0.08	0.02	0.02
	Lobsters	0.13	0.10	0.09	0.08	0.10		Juv. large pelagic	0.10	0.20	< 1E-2	0.01	0.20
	Large crabs	0.14	0.10	0.13	0.11	0.10		Ad. medium pelagic	0.05	0.05	0.01	0.01	0.05
	Small crabs	0.43	0.40	0.39	0.32	0.40		Juv. medium pelagic	0.30				
	Giant triton	0.06	0.10	0.09	0.08	0.30		Ad. small pelagic	1.03	0.60	< 1E-2	0.05	0.60
	Bivalves	0.76	0.71	0.93	0.76	0.70		Ad. large reef assoc.	5.00	4.03	0.01	3.50	4.70
	Epifaunal det. inverts.	3.59	2.45	1.28	1.05	3.00		Juv. large reef assoc.	1.00	3.02	0.08	1.52	8.30
	Epifaunal carn. inverts	7.38	8.08	7.93	6.51	6.20		Ad. medium reef assoc.	3.00	3.43	5.21	1.82	2.40
	Infaunal inverts.	7.55	7.98	3.06	2.52	2.00		Juv. medium reef assoc.	5.42	4.13	0.01	1.20	1.70
	Carn. zooplankton	10.17	10.31	6.07	5.00	4.80		Ad. small reef assoc.	2.14	2.11	< 1E-2	2.08	2.10
Juv. groupers	Ad. groupers	0.03	0.03	0.03	0.03	0.03		Juv. small reef assoc.	3.00	0.07	0.30	0.07	0.07
	Sub. groupers	0.10	0.10	< 1E-2	0.10	0.10		Ad. large demersal	0.09	0.09	< 1E-2	< 1E-2	0.09
	Juv. groupers	0.10	0.10	0.11	0.10	0.10		Juv. large demersal	0.07	0.07	0.11	0.02	0.07
	Ad. snappers	0.05	0.05	0.05	0.05	0.05		Ad. small demersal	0.57	0.60	< 1E-2	0.08	0.20
	Sub. snappers	0.10	0.10	0.11	0.10	0.10		Juv. small demersal	0.07	0.07	0.03	0.03	0.07
	Ad. butterflyfish	1.80	0.81	< 1E-2	1.72	1.90		Ad. large planktivore	3.52	5.34	1.62	3.00	3.40
	Juv. butterflyfish	0.10	0.05	0.11	0.10	0.10		Juv. large planktivore	0.08	0.07	2.48	0.57	0.07
	Cleaner wrasse	0.42	0.40	0.44	0.40	0.40		Ad. small planktivore	< 1E-2	3.72	0.03	0.50	1.00
	Ad. large reef assoc.	3.45	3.42	2.54	2.31	3.50		Juv. small planktivore	0.11	0.10	< 1E-2	0.11	0.10
	Juv. large reef assoc.	5.00	10.07	1.87	1.70	11.00		Ad. anchovy	1.00	8.06	0.22	1.68	0.80
	Ad. medium reef assoc.	2.10	2.11	1.65	1.51	2.20		Juv. anchovy	1.00	3.42	0.03	3.51	3.40
	Juv. medium reef assoc.	8.56	8.66	6.31	5.73	8.90		Ad. deepwater fish	3.67	1.00	0.40	1.07	0.50
	Ad. small reef assoc.	1.05	1.11	1.10	1.00	1.10		Juv. deepwater fish	5.15	0.91	0.03	1.43	0.50
	Juv. small reef assoc.	6.00	6.04	10.53	9.56	10.30		Ad. macro algal browsing	0.06	2.62	0.11	0.05	0.06
	Ad. large demersal	0.02	0.02	0.01	0.01	0.02		Juv. macro algal browsing	0.05	0.20	0.11	0.03	0.05
	Ad. small demersal	1.85	1.81	< 1E-2	< 1E-2	1.90		Ad. eroding grazers	0.02	0.02	< 1E-2	< 1E-2	3.60
	Ad. large planktivore	4.25	4.23	4.47	4.06	4.30		Juv. eroding grazers	0.10	0.02	0.08	4.10	0.02
	Juv. large planktivore			0.45	0.41			Ad. scraping grazers	1.00	2.01	13.48	27.91	19.50
	Ad. small planktivore	0.86	0.91	0.11	0.41	0.90		Juv. scraping grazers	0.08	0.07		10.81	0.30
	Ad. anchovy	1.50	2.11	5.33	4.85	2.20		Detritivore fish	< 1E-2	0.01	< 1E-2	0.47	0.05
	Juv. anchovy	2.00	10.47	8.81	8.01	10.80		Penaeid shrimps	14.31	5.44	< 1E-2	3.13	2.60
	Ad. deepwater fish	1.33	0.91	0.42	0.38	1.30		Shrimps and prawns	2.68	4.84		1.77	2.60
	Juv. deepwater fish	6.37	2.72	2.68	2.44	3.10		Squid	1.00	4.03	6.94	1.60	2.00
	Ad. macro algal browsing	0.02	1.11	0.02	0.02	0.02		Octopus	0.12	0.20	3.13	0.83	0.10
	Juv. eroding grazers			1.10	8.01			Sea cucumbers	0.06	0.06	0.44	0.05	0.05
	Ad. scraping grazers	4.47	4.53	2.19	2.00	4.70		Lobsters	0.10	0.30	0.02	0.11	0.30
	Juv. scraping grazers		2.01	3.30	3.00			Large crabs	0.50	0.40	1.53	0.35	0.40
	Detritivore fish	0.13	0.10	0.13	0.12	0.10		Small crabs	1.03	5.04	7.34	1.70	6.00
	Penaeid shrimps	1.06	1.11	0.22	0.20	1.10		Crown of thorns	0.05	0.04	0.19	0.04	0.04
	Shrimps and prawns	1.33	1.31	0.95	0.86	1.30		Giant triton	0.20	0.20	0.02	0.16	0.20
	Squid	5.00	4.73	0.99	0.90	4.90		Herbivorous echinoids	0.06	1.41	0.19	0.04	0.05
	Octopus			0.61	0.55			Bivalves	1.54	1.61	8.50	1.95	1.60
	Lobsters	0.10	0.10	0.07	0.07	0.10		Sessile filter feeders	8.19	9.06	0.35	6.37	8.00
	Large crabs	0.10	0.10	0.10	0.09	0.10		Epifaunal det. inverts.	3.00	2.81	3.01	0.70	2.80
	Small crabs	3.00	2.32	0.99	0.90	2.40		Epifaunal carn. inverts	3.66	3.32	4.28	1.00	8.30
	Giant triton	0.26	0.10	0.22	0.20	0.30		Infaunal inverts.	6.77	6.67	20.15	4.64	3.40

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	
Sub. snappers	Jellyfish and hydroids	1.26	0.70	1.19	0.27	0.30	Ad. Napoleon wrasse	Sub. snappers	0.47	0.40	2.33	0.43	0.40	
	Carn. zooplankton	6.52	2.42	9.65	2.22	2.00		Juv. snappers	0.80					0.70
	Large herb. zooplankton	3.00	1.01	1.27	0.29	0.60		Juv. coral trout						0.60
	Small herb. zooplankton	0.95	1.61	3.67	0.84	0.50		Ad. butterflyfish	< 1E-2	1.21	0.16	1.25	0.60	
	Ad. groupers	0.02	0.02	0.06	0.02	0.02		Juv. butterflyfish	0.01	0.30	0.01	0.30	1.00	
	Sub. groupers	0.05	0.10	< 1E-2	0.10	0.01		Cleaner wrasse	0.07	0.07	< 1E-2	0.07	0.07	
	Ad. snappers	0.10	0.10	0.29	0.10	0.10		Ad. large reef assoc.	3.63	3.52	0.02	1.00	3.50	
	Sub. snappers	0.50	0.10	1.41	0.51	0.50		Juv. large reef assoc.	1.03	3.52	0.14	1.26	3.50	
	Juv. snappers	1.14	0.50	0.26	0.09	0.09		Ad. medium reef assoc.	1.50	0.10	0.69	0.08	0.10	
	Juv. Napoleon wrasse	0.07	0.07	< 1E-2	< 1E-2	0.07		Juv. medium reef assoc.	0.51	0.50	< 1E-2	0.35	0.50	
	Other tuna	0.20	0.04	< 1E-2	0.04	0.04		Ad. small reef assoc.	0.80	0.80	< 1E-2	0.79	0.80	
	Mackerel	0.10	0.20	< 1E-2	0.17	0.20		Juv. small reef assoc.	3.85	1.00	2.00	5.90	1.00	
	Juv. coral trout	0.01	0.01	0.06	0.02	0.20		Ad. large demersal	0.02	0.02	< 1E-2	0.01	0.02	
	Juv. rays	0.16	0.10	0.12	0.08	0.01		Ad. small demersal	0.32	0.30	< 1E-2	0.01	0.20	
	Ad. butterflyfish	0.50	0.80	0.32	1.36	0.60		Ad. large planktivore	0.94	0.91	2.12	0.93	0.90	
	Juv. butterflyfish	0.01	0.40	0.01	0.40	1.10		Juv. large planktivore			2.37	0.52		
	Cleaner wrasse	0.09	0.09	< 1E-2	0.09	0.09		Ad. small planktivore	1.06	1.01	< 1E-2	0.52	1.00	
	Ad. large pelagic	0.85	< 1E-2	0.01	< 1E-2	< 1E-2		Ad. anchovy	0.10	3.11	0.46	0.05	0.10	
	Juv. large pelagic	0.01	0.01	< 1E-2	0.01	0.01		Juv. anchovy	2.00	0.10	1.00	0.11	0.10	
	Ad. medium pelagic	0.10	0.10	0.03	0.01	0.10		Ad. deepwater fish	1.11	0.77	0.75	0.33	0.50	
	Juv. medium pelagic	0.10						Juv. deepwater fish	0.95	0.82	0.01	0.37	0.50	
	Ad. small pelagic	0.50	0.50	0.01	0.05	1.10		Ad. macro algal browsing	0.03	0.03	0.02	0.03	0.03	
	Ad. large reef assoc.	4.53	5.02	1.46	3.21	4.50		Ad. eroding grazers	0.01	0.01	0.09	0.01	0.01	
	Juv. large reef assoc.	2.00	4.32	0.01	0.82	4.30		Ad. scraping grazers	0.01	2.92	4.54	1.00	8.70	
	Ad. medium reef assoc.	2.00	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Detritivore fish	< 1E-2	0.10	< 1E-2	0.13	0.05	
	Juv. medium reef assoc.	0.96	1.00	1.88	0.68	1.00		Penaeid shrimps	7.75	4.63	4.53	0.50	4.60	
	Ad. small reef assoc.	1.61	5.02	1.13	1.63	0.80		Shrimps and prawns	2.00	5.73		0.50	5.70	
	Juv. small reef assoc.	9.38	2.01	1.59	15.81	2.00		Octopus			0.20	0.69		
	Ad. large demersal	0.03	0.03	0.01	0.02	0.03		Large crabs	0.11	0.10	0.89	0.10	0.10	
	Juv. large demersal	0.09	0.09	0.09	0.03	0.09		Small crabs	0.48	0.50	3.67	0.40	0.40	
Ad. small demersal	1.17	1.21	< 1E-2	0.09	0.30	Bivalves			0.75	0.08				
Juv. small demersal	0.09	0.09	0.04	0.03	0.09	Epifaunal det. inverts.		0.50						
Ad. large planktivore	3.52	4.02	1.24	3.56	3.50	Epifaunal carn. inverts		0.10						
Juv. large planktivore	0.10	0.09	1.50	1.09	0.09	Infaunal inverts.	4.89	15.67						
Ad. small planktivore	0.10	2.51	< 1E-2	1.00	1.00	Carn. zooplankton	65.47	51.12	21.72	57.15	64.80			
Juv. small planktivore	0.94	0.90	0.04	0.95	5.00	Large herb. zooplankton			3.36	10.00				
Ad. anchovy	1.00	4.02	1.38	0.50	1.00	Small herb. zooplankton			0.71	10.00				
Juv. anchovy	1.00	1.00	< 1E-2	1.11	1.00	Phytoplankton			46.96	5.00				
Ad. deepwater fish	3.00	0.70	0.22	0.97	0.50	Ad. groupers	0.13	0.10	0.13	0.13	0.10			
Juv. deepwater fish	3.37	0.90	0.02	1.29	0.20	Sub. groupers	0.10	0.50	0.49	0.50	0.10			
Ad. macro algal browsing	0.02	4.52	0.04	0.02	0.02	Juv. groupers	0.02	0.10	0.13	0.13	0.10			
Juv. macro algal browsing	0.05	0.05		1.52	0.05	Ad. snappers	0.50	0.60	0.98	0.99	1.00			
Ad. eroding grazers	< 1E-2	< 1E-2	0.01	< 1E-2	< 1E-2	Sub. snappers	1.56	1.61	1.52	1.55	1.60			
Juv. eroding grazers	0.10	0.02	0.12	0.04	0.02	Juv. snappers	0.61	0.50	0.13	0.13	4.10			
Ad. scraping grazers	1.00	4.32	7.18	18.16		Ad. Napoleon wrasse	0.10	0.30	0.19	0.40	0.60			
Juv. scraping grazers	0.09	0.60			6.20	Sub. Napoleon wrasse	1.00	0.60	0.63	0.64	0.60			
Detritivore fish	< 1E-2	0.10	< 1E-2	0.97	0.05	Juv. Napoleon wrasse	0.50	0.10	0.13	0.13	0.10			
Penaeid shrimps	7.19	10.14	7.29	7.92	7.20	Juv. coral trout	0.01	0.01	0.32	0.13				
Shrimps and prawns	3.19	3.21	1.50	2.19	3.20	Juv. rays	0.13	0.10	0.13	0.13	0.20			
Squid	2.00	2.21	4.45	1.60	2.00	Ad. butterflyfish	0.77	0.80	0.75	0.76	0.80			
Octopus	0.14	0.20	2.58	0.93	6.00	Juv. butterflyfish	0.10	1.11	1.12	1.14	1.10			
Sea cucumbers	0.07	0.07	0.19	0.07	0.07	Ad. large reef assoc.	0.64	0.60	0.44	0.44	0.60			
Lobsters	0.21	0.20	0.01	0.15	0.20	Juv. large reef assoc.	0.77	1.51	0.51	0.52	0.80			
Large crabs	0.18	0.20	0.46	0.17	0.20	Ad. medium reef assoc.	1.00	0.80	0.56	0.57	0.80			
Small crabs	0.55	0.60	1.30	0.47	0.60	Juv. medium reef assoc.	4.84	0.03	0.02	0.02	0.03			
Crown of thorns	0.05	0.05	0.14	0.05	0.05	Ad. small reef assoc.	2.64	2.62	2.57	2.62	2.60			
Giant triton	0.20	0.50	0.03	0.10	0.20	Juv. small reef assoc.	3.00	0.10	0.13	0.13	0.10			
Herbivorous echinoids	0.04	0.04	0.10	0.04	0.04	Ad. large demersal	0.28	0.30	0.19	0.19	0.30			
Bivalves	1.85	1.81	5.57	2.02	1.80	Juv. large demersal	0.13	0.10	0.04	0.04	0.10			
Sessile filter feeders	9.73	9.74	0.27	7.87	9.70	Ad. small demersal	8.00	6.44	1.88	1.91	2.40			
Epifaunal det. inverts.	3.02	3.01	5.93	2.14	3.00	Juv. small demersal	0.13	0.10	0.05	0.05	0.10			
Epifaunal carn. inverts	6.81	6.83	19.05	6.89	13.10	Ad. large planktivore	3.19	3.22	3.11	3.17	3.20			
Infaunal inverts.	10.61	6.03	17.37	6.28	12.10	Juv. large planktivore	0.13	0.10	3.25	3.31	0.10			
Jellyfish and hydroids	0.34	0.40	0.93	0.34	0.30	Ad. small planktivore	5.00	6.44	1.57	3.18	6.30			
Carn. zooplankton	7.32	3.21	7.71	2.75	2.80	Juv. small planktivore	0.13	0.10	0.13	0.13	0.10			
Large herb. zooplankton	0.67	0.70	0.93	0.34	0.70	Ad. anchovy		1.61	1.43	1.46				
Small herb. zooplankton	0.67	5.02	3.35	1.02	0.70	Juv. anchovy	1.00	3.02	2.93	2.98	3.00			
Ad. groupers	0.01	0.02	< 1E-2	0.02	0.02	Ad. deepwater fish	1.28	0.91	0.38	0.38	1.30			
Sub. groupers	0.01	0.05	< 1E-2	0.05	0.01	Juv. deepwater fish	2.69	1.18	0.40	0.51	1.30			
Ad. snappers	0.05	0.05	0.47	0.05	0.05	Ad. macro algal browsing	2.56	2.62	2.51	2.55	2.60			

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
Sub. Napoleon wrasse	Juv. macro algal browsing	0.10	0.10	0.05	0.05	0.10	Skipjack tuna	Ad. groupers	0.01	0.01	< 1E-2	0.01	0.01
	Ad. eroding grazers	1.00	0.10	0.13	0.13	0.10		Sub. groupers	0.10	0.40	0.34	0.37	0.10
	Juv. eroding grazers	0.03	0.03	0.08	0.08	0.03		Ad. snappers	0.20	0.40	0.34	0.37	0.40
	Ad. scraping grazers	0.64	0.60	0.62	0.63	1.00		Sub. snappers	0.64	0.40	0.34	0.37	0.40
	Juv. scraping grazers	0.14	0.20	9.67	6.53	9.50		Ad. Napoleon wrasse	0.30	0.15	0.18	0.37	0.40
	Detritivore fish	< 1E-2	0.50	0.75	0.77	0.50		Sub. Napoleon wrasse	0.37	0.40	0.34	0.37	0.40
	Squid	1.00	9.64	2.00	2.04	2.60		Ad. butterflyfish	0.31	0.30	0.29	0.31	0.30
	Octopus	2.56	2.62	3.00	3.05	2.60		Juv. butterflyfish	0.10	0.30	0.29	0.31	0.30
	Sea cucumbers	3.00	2.62	2.51	2.55	2.60		Ad. medium reef assoc.	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Lobsters	0.40	0.91	0.59	0.60	0.90		Ad. small reef assoc.	1.34	1.30	1.23	1.34	1.30
	Large crabs	0.34	0.30	0.30	0.31	0.30		Ad. small demersal	0.86	0.60	0.17	0.18	0.60
	Small crabs	2.59	2.62	2.16	2.19	2.60		Juv. large planktivore			0.19	0.21	
	Crown of thorns	1.00	8.25	7.98	8.12	8.10		Ad. small planktivore	0.42	0.40	0.10	0.21	0.40
	Giant triton	0.20	0.30	2.02	2.06	1.00		Ad. deepwater fish	0.31	0.21	0.08	0.09	0.30
	Herbivorous echinoids	0.85	5.73	10.00	10.18	5.90		Juv. deepwater fish	0.73	0.63	0.27	0.29	0.70
	Bivalves	5.14	5.13	8.43	8.57	5.10		Ad. macro algal browsing	0.12	0.10	0.11	0.12	0.10
	Sessile filter feeders	7.05	7.04	5.50	5.60	6.90		Ad. eroding grazers	0.02	0.02	0.02	0.02	0.02
	Epifaunal det. inverts.	3.46	2.62	1.75	1.78	2.60		Ad. scraping grazers	0.10	0.10	0.09	0.10	0.10
	Epifaunal carn. inverts	2.56	2.61	2.51	2.55	2.60		Juv. scraping grazers			9.18	1.08	
	Infauanal inverts.	9.40	2.62	4.63	4.71	2.60		Detritivore fish	0.10	0.10	0.09	0.10	0.40
	Carn. zooplankton	10.53	7.23	6.60	6.61	6.30		Squid	1.22	1.20	0.90	0.98	1.20
	Ad. groupers	0.14	0.10	0.16	0.15	0.10		Octopus	2.44	2.40	2.47	2.69	2.40
	Sub. groupers	0.02	0.10	0.12	0.11	0.05		Sea cucumbers	3.00	6.10	5.62	6.11	6.10
	Juv. groupers	< 1E-2	0.09	0.11	0.10	0.01		Lobsters	0.30	0.70	0.45	0.49	0.70
	Ad. snappers	0.10	0.40	0.47	0.44	0.40		Large crabs	0.36	0.40	0.29	0.32	0.40
	Sub. snappers	0.50	0.80	1.13	1.05	1.00		Small crabs	1.00	6.10	4.78	5.19	6.10
	Juv. snappers	0.26	0.30	0.11	0.10	0.09		Crown of thorns	2.00	5.00	4.58	4.98	5.00
	Ad. Napoleon wrasse	0.30	0.15	0.15	0.22	0.20		Giant triton	0.50	1.70	1.22	1.33	1.70
	Sub. Napoleon wrasse	1.29	0.70	0.23	0.22	0.70		Herbivorous echinoids	2.00	7.61	3.67	4.00	7.60
	Juv. Napoleon wrasse	0.09	0.09	0.03	0.10	0.09		Bivalves	6.09	6.10	0.92	1.00	6.10
	Juv. coral trout	0.01	0.02	0.10	0.02	0.02		Sessile filter feeders	6.77	6.61	0.92	1.00	6.60
	Juv. rays	0.12	0.09	0.11	0.10	0.09		Epifaunal det. inverts.	6.00	9.71	6.29	6.84	9.70
	Ad. butterflyfish	0.37	0.80	0.94	0.88	0.80		Epifaunal carn. inverts	9.91	9.71	8.98	9.77	9.70
Juv. butterflyfish	< 1E-2	0.60	0.73	0.69	0.60	Infauanal inverts.	15.49	9.71	12.88	14.02	9.70		
Juv. large reef assoc.	0.30	6.42	0.17	0.16	0.09	Carn. zooplankton	13.00	10.11	9.20	10.01	9.80		
Ad. medium reef assoc.	0.58	0.60	0.50	0.48	0.60	Large herb. zooplankton	11.00	2.40	9.20	10.01	2.40		
Juv. medium reef assoc.	5.00	3.01	0.02	0.02	0.02	Small herb. zooplankton	7.00	2.40	9.20	10.01	2.40		
Ad. small reef assoc.	3.62	3.21	3.74	3.51	3.20	Phytoplankton			4.77	5.01			
Juv. small reef assoc.	1.25	0.09	0.11	0.10	0.09	Detritus	5.90	6.20			6.20		
Juv. large demersal	0.12	0.09	0.03	0.03	0.09	Skipjack tuna	3.00	0.70	0.38	0.69	1.50		
Ad. small demersal	3.00	2.01	0.90	3.38	1.00	Other tuna	1.53	1.51	< 1E-2	1.00	0.30		
Juv. small demersal	0.09	0.09	0.04	0.04	0.09	Mackerel	0.20	0.20	0.10	0.20	0.20		
Juv. large planktivore	0.09	0.09	2.71	2.55	0.09	Ad. large pelagic	0.01	0.01	< 1E-2	0.01	0.01		
Ad. small planktivore	1.00	4.52	0.51	2.46	2.00	Juv. large pelagic	0.02	0.02	0.02	0.02	0.02		
Juv. small planktivore	0.10	0.09	0.10	0.09	0.09	Ad. medium pelagic	0.10	0.10	< 1E-2	< 1E-2	< 1E-2		
Ad. deepwater fish	0.68	0.49	0.24	0.22	0.70	Juv. medium pelagic	< 1E-2	0.40	0.10	< 1E-2	0.40		
Juv. deepwater fish	0.68	0.63	0.32	0.30	0.70	Ad. small pelagic	0.02	0.02	0.02	0.02	0.02		
Ad. macro algal browsing	0.27	0.40	0.31	0.29	0.30	Juv. small pelagic	2.00	0.40	0.20	0.38	0.40		
Juv. macro algal browsing	0.10	0.10	0.03	0.03	0.05	Ad. large planktivore	0.09	0.20	6.18	11.90	0.09		
Ad. eroding grazers	0.03	0.03	0.03	0.03	0.03	Juv. large planktivore	0.50	3.22	3.34	3.22	3.20		
Juv. eroding grazers	0.02	0.02	0.05	0.05	0.02	Ad. small planktivore	0.12	0.10	0.03	0.06	0.10		
Ad. scraping grazers	0.14	0.10	0.97	0.91	0.10	Juv. small planktivore	0.10	1.01	0.02	1.00	1.00		
Juv. scraping grazers	0.10	4.21			17.90	Ad. anchovy	2.00	8.03	4.76	0.05	11.40		
Detritivore fish	0.01	0.10	0.13	0.12	0.10	Juv. anchovy	0.10	0.10	1.14	1.10	0.10		
Squid	1.50	2.71	2.52	2.37	2.70	Ad. deepwater fish	0.10	0.70	0.75	0.72	1.00		
Octopus	2.72	3.81	3.79	3.56	2.70	Juv. deepwater fish	0.10	0.91	0.42	0.40	1.00		
Sea cucumbers	2.00	5.42	6.32	5.93	5.40	Penaeid shrimps	1.48	3.43	1.57	1.51	1.50		
Lobsters	0.02	0.40	0.31	0.29	0.40	Shrimps and prawns	0.15	0.10	0.11	0.10	0.10		
Large crabs	0.60	0.60	0.60	0.56	0.60	Squid	0.06	0.06	0.05	0.05	0.06		
Small crabs	1.00	5.42	5.38	5.04	5.40	Octopus	0.24	0.20	0.28	0.27	0.20		
Crown of thorns	0.10	2.81	3.31	3.11	2.80	Lobsters	0.02	0.02	< 1E-2	0.01	0.02		
Giant triton	0.30	0.50	0.03	1.60	0.10	Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Herbivorous echinoids	1.00	2.01	12.66	11.87	4.00	Small crabs	0.01	0.01	< 1E-2	< 1E-2	0.01		
Bivalves	8.15	8.14	14.09	13.22	8.10	Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Sessile filter feeders	7.47	7.53	6.96	6.53	7.50	Bivalves	0.50	0.20	0.25	0.24	0.20		
Epifaunal det. inverts.	3.00	5.42	4.42	4.15	5.40	Epifaunal det. inverts.	0.30	0.30	0.22	0.21	0.30		
Epifaunal carn. inverts	6.00	5.41	6.32	5.93	5.40	Epifaunal carn. inverts	0.33	0.30	0.33	0.32	0.30		
Infauanal inverts.	11.57	12.23	9.98	9.35	11.00	Infauanal inverts.	2.00	0.30	0.43	0.41	0.30		
Carn. zooplankton	10.00	7.02	8.02	7.53	7.10	Carn. zooplankton	3.68	0.20	0.18	0.18	0.20		
Large herb. zooplankton	10.00					Large herb. zooplankton	1.08	0.20	0.10	0.09	0.20		

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool		
Other tuna	Small herb. zooplankton	0.24	0.20	0.33	0.32	0.20	Billfish	Ad. small planktivore	0.29	0.30	0.07	0.14	0.30		
	Skipjack tuna	2.00						Juv. small planktivore	4.09	4.10	0.17	4.09	4.10		
	Other tuna	2.00	0.10	0.10	0.12	0.10		Ad. anchovy	8.00	10.00	7.32	3.72	10.00		
	Juv. large sharks	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. anchovy	4.00	7.60	9.15	8.58	7.60		
	Juv. small sharks	0.04	0.05	0.09	0.05	0.05		Ad. deepwater fish	0.03	0.02	< 1E-2	< 1E-2	0.03		
	Juv. rays	0.01	0.01	< 1E-2	0.01	0.01		Juv. deepwater fish	2.00	0.18	0.06	0.07	0.20		
	Ad. large pelagic	0.10	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. macro algal browsing	0.03	0.03	0.04	0.03	0.03		
	Juv. large pelagic	0.05	0.01	< 1E-2	0.01	0.01		Ad. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
	Ad. medium pelagic	0.10	0.10	0.02	0.02	0.02		Ad. scraping grazers	0.12	0.10	0.11	0.11	0.40		
	Juv. medium pelagic	0.05	0.10	0.17	0.05	0.10		Juv. scraping grazers			4.57	0.61			
	Ad. small pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Detritivore fish	0.02	0.02	0.03	0.02	0.02		
	Juv. small pelagic	0.11	0.10	0.80	0.10	0.10		Penaeid shrimps			0.02	0.02			
	Juv. medium reef assoc.	2.71						Shrimps and prawns	0.08	0.08	0.06	0.05	0.08		
	Ad. large planktivore	0.01	0.01	8.31	9.49	0.01		Squid	3.70	0.10	0.09	0.09	0.10		
	Juv. large planktivore	0.10	3.70	3.28	3.75	3.70		Octopus			0.03	0.03			
	Ad. small planktivore	0.07	0.07	0.02	0.04	0.07		Carn. zooplankton	7.00		0.03	0.03			
	Juv. small planktivore	1.00	1.00	0.88	1.00	1.00		Large herb. zooplankton	5.00						
	Ad. anchovy	2.00	9.01	8.77	< 1E-2	10.00		Skipjack tuna	5.00	4.30	2.82	4.26	5.10		
	Juv. anchovy	0.01	0.01	4.39	1.01	0.01		Other tuna	7.53	2.50	< 1E-2	2.49	0.70		
	Ad. deepwater fish	1.00	0.35	0.13	0.15	0.50		Mackerel	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
	Juv. deepwater fish	0.10	0.08	0.03	0.04	0.09		Billfish	2.00	0.30	0.30	0.29	0.30		
	Anemonies	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. large pelagic	0.10	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
	Penaeid shrimps	1.23	0.30	0.25	0.29	0.30		Ad. medium pelagic	0.60	0.03	< 1E-2	0.01	0.03		
	Shrimps and prawns	0.05	0.05	0.03	0.04	0.05		Ad. small pelagic	0.10	0.01	< 1E-2	0.01	0.01		
	Squid	0.05	0.05	0.03	0.04	0.05		Juv. small pelagic	0.20	0.20	1.00	0.20	0.20		
	Octopus	0.07	0.07	0.07	0.08	0.07		Ad. large planktivore	0.05	0.10	6.06	5.90	1.10		
	Sea cucumbers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. small planktivore	0.10	0.10	0.04	4.00	0.10		
	Lobsters	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. small planktivore	2.00	2.00	0.08	2.00	2.00		
	Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. anchovy	5.00	10.01	2.35	0.05	10.00		
	Small crabs	0.01	0.01	< 1E-2	0.01	0.01		Juv. anchovy	0.20	0.10	4.71	1.10	0.10		
	Crown of thorns	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. deepwater fish	8.00	0.01	< 1E-2	< 1E-2	0.02		
	Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. deepwater fish	8.00	0.99	0.45	0.43	1.10		
	Herbivorous echinoids	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Penaeid shrimps	1.07		< 1E-2	< 1E-2			
	Bivalves	0.07	0.07	0.06	0.07	0.07		Shrimps and prawns	4.00	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
	Sessile filter feeders	0.90	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Squid	0.12	0.10	0.09	0.09	0.10		
	Epifaunal det. inverts.	0.13	0.10	0.08	0.09	0.10		Octopus			0.03	0.02			
	Epifaunal carn. inverts.	0.23	0.20	0.20	0.23	0.20		Lobsters	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
	Infaunal inverts.	4.78	0.30	0.26	0.30	0.30		Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
	Jellyfish and hydroids	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Small crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
	Carn. zooplankton	9.64	8.61	7.55	8.63	8.60		Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
	Large herb. zooplankton	3.51	3.50	1.54	1.75	3.50		Bivalves			< 1E-2	< 1E-2			
	Small herb. zooplankton	0.44	0.40	1.92	2.19	0.40		Epifaunal det. inverts.	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
	Macro algae	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Epifaunal carn. inverts.	0.02	0.02	0.02	0.02	0.02		
	Sea grass	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Infaunal inverts.	0.02	0.02	0.02	0.02	0.02		
	Mackerel	Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2		< 1E-2	Ad. coral trout	Ad. groupers	0.11	0.10	0.13	0.11	0.10
		Sub. groupers	0.01	0.01	< 1E-2	0.01		0.01		Sub. groupers	0.20	0.20	< 1E-2	0.19	0.01
		Ad. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2		< 1E-2		Ad. snappers	0.68	0.71	0.80	0.66	0.70
Sub. snappers		0.03	0.03	0.03	0.03	0.03	Sub. snappers	2.93		2.93	3.45	2.84	2.90		
Ad. Napoleon wrasse		0.30	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. snappers						3.50		
Sub. Napoleon wrasse		0.01	0.01	< 1E-2	0.01	0.01	Ad. Napoleon wrasse	0.11		0.15	0.01	< 1E-2	0.10		
Other tuna		0.57	0.60	0.18	0.57	0.30	Sub. Napoleon wrasse	0.11		0.10	0.06	0.05	0.10		
Mackerel		0.89	0.90	0.46	0.89	0.90	Ad. butterflyfish	1.00		3.83	0.14	3.71	0.90		
Ad. butterflyfish		< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. butterflyfish	0.50		2.83	0.03	2.71	4.10		
Juv. butterflyfish		0.40	0.40	0.39	0.40	0.40	Cleaner wrasse	0.18		0.20	0.21	0.17	0.10		
Cleaner wrasse		0.01	0.01	< 1E-2	0.01	0.01	Juv. medium pelagic	1.80							
Ad. large pelagic		0.14	0.10	0.14	0.14	0.10	Ad. large reef assoc.	20.28		20.48	5.58	13.75	15.00		
Juv. large pelagic		0.13	0.10	0.13	0.13	0.10	Juv. large reef assoc.	15.00		19.07	7.82	6.46	18.90		
Ad. medium pelagic		0.05	0.05	0.05	0.05	0.05	Ad. medium reef assoc.	0.70		0.71	0.62	0.51	0.70		
Juv. medium pelagic		0.29	0.30	0.18	0.29	0.30	Ad. small reef assoc.	6.21		2.32	2.69	2.21	2.30		
Ad. small pelagic		0.72	0.70	< 1E-2	0.72	0.70	Juv. small reef assoc.	6.79		10.90	12.69	10.48	1.00		
Juv. small pelagic		1.09	1.10	2.00	1.09	1.10	Ad. large demersal	0.36		0.40	0.07	0.24	0.20		
Ad. large reef assoc.		0.29	0.30	0.19	0.20	0.30	Ad. small demersal	0.57		0.61	0.20	0.17	0.30		
Juv. large reef assoc.		1.72	1.70	0.58	0.60	1.70	Ad. large planktivore	3.27		3.33	3.84	3.17	3.30		
Ad. medium reef assoc.		< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. large planktivore				1.33	1.09			
Juv. medium reef assoc.		0.17	0.20	0.11	0.12	0.20	Ad. small planktivore	2.26		2.32			1.00		
Ad. small reef assoc.		0.20	0.20	0.19	0.20	0.20	Ad. anchovy	3.28		0.50	1.88	1.55	0.80		
Ad. large demersal		< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. anchovy	3.27		3.33	3.89	3.21	3.30		
Ad. small demersal		0.06	0.06	0.02	0.02	0.06	Ad. deepwater fish	3.04		2.10	1.07	0.88	0.50		
Ad. large planktivore		0.03	0.03	0.03	0.03	0.03	Juv. deepwater fish	3.04		2.73	1.43	1.18	0.50		
Juv. large planktivore				6.06	6.24		Ad. macro algal browsing	0.11		0.10	0.13	0.11	0.10		

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	
Juv. coral trout	Ad. eroding grazers	0.05	0.05	0.05	0.04	0.05	Juv. large sharks	Juv. small sharks	5.00	0.10	0.19	0.10	0.10	
	Ad. scraping grazers	11.72	11.81	17.80	14.68	33.30		Whale shark	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. scraping grazers			26.93	22.21			Manta ray	0.02	0.02	0.02	0.02	0.02	0.02
	Detritivore fish	< 1E-2	1.82	< 1E-2	1.70	0.05		Adult rays	0.50	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Penaeid shrimps	1.01	1.01	1.43	1.18	1.00		Juv. rays	0.50					
	Shrimps and prawns	1.01	1.01	0.81	0.67	1.00		Ad. butterflyfish	0.41	0.40	0.37	0.40	0.40	0.40
	Squid	2.30	2.32	2.14	1.78	2.20		Juv. butterflyfish	0.37	0.40	0.33	0.36	0.40	0.40
	Octopus			0.68	0.56			Cleaner wrasse	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2	0.01
	Lobsters	0.16	0.20	0.13	0.11	0.20		Ad. large pelagic	0.04	0.03	0.03	0.03	0.03	0.03
	Large crabs	0.03	0.03	0.03	0.02	0.03		Ad. medium pelagic	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2	0.01
	Small crabs	0.09	0.09	0.09	0.07	0.09		Ad. small pelagic	0.03	0.03	0.03	0.03	0.03	0.03
	Giant triton	0.19	0.20	0.18	0.15	0.20		Ad. large reef assoc.	3.08	4.07	5.57	2.11	3.10	3.10
	Bivalves			0.06	0.05			Juv. large reef assoc.	5.47	5.45	1.74	1.88	5.50	5.50
	Epifaunal det. inverts.	0.45	0.50	0.37	0.31	0.50		Ad. medium reef assoc.	< 1E-2	4.96	2.78	< 1E-2	< 1E-2	< 1E-2
	Epifaunal carn. inverts	4.98	0.50	0.53	0.44	0.50		Ad. small reef assoc.	0.22	0.20	1.96	2.11	0.20	0.20
	Infaunal inverts.	1.45	0.50	0.69	0.57	0.50		Ad. large demersal	0.05	0.05	0.03	0.03	0.05	0.05
	Ad. groupers	0.01	0.01	0.01	0.01	< 1E-2		Ad. small demersal	0.05	0.05	< 1E-2	0.01	0.05	0.05
	Sub. groupers	0.15	0.10	0.19	0.15	0.05		Ad. large planktivore	0.76	0.79	0.70	0.75	0.80	0.80
	Ad. snappers	0.15	0.10	0.19	0.15	0.10		Juv. large planktivore			0.15	0.16	0.16	0.16
	Sub. snappers	0.30	0.30	0.39	0.30	0.30		Ad. small planktivore	0.32	0.30	0.07	0.16	0.30	0.30
	Juv. snappers					0.20		Ad. anchovy	0.07	0.07	0.20	0.22	0.07	0.07
	Ad. butterflyfish	0.15	0.10	0.19	0.15	0.10		Juv. anchovy	0.46	0.50	0.43	0.46	0.50	0.50
	Juv. butterflyfish	1.00	10.10	0.03	15.00	1.00		Ad. deepwater fish	0.90	0.62	0.24	0.26	0.90	0.90
	Cleaner wrasse	1.09	1.12	1.40	1.09	0.30		Juv. deepwater fish	0.46	0.45	0.17	0.18	0.50	0.50
	Ad. large reef assoc.	0.15	0.10	0.14	0.11	0.10		Ad. macro algal browsing	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. large reef assoc.	33.21	33.66	14.91	11.62	32.90		Ad. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. medium reef assoc.	< 1E-2	5.15	< 1E-2	< 1E-2	< 1E-2		Ad. scraping grazers	1.37	1.39	1.24	1.34	1.40	1.40
	Juv. medium reef assoc.	7.30	7.40	6.57	5.11	7.20		Juv. scraping grazers			4.84	5.22	5.22	5.22
	Ad. small reef assoc.	2.02	2.03	2.59	2.02	2.00		Detritivore fish	0.08	0.07	0.06	0.07	0.08	0.08
	Ad. large demersal	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Anemonies	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. small demersal	2.00	2.03	0.38	0.60	1.00		Penaeid shrimps			0.03	0.03	0.03	0.03
	Ad. large planktivore	3.54	3.55	4.54	3.54	3.50		Shrimps and prawns	0.14	0.10	0.08	0.09	0.10	0.10
	Juv. large planktivore			3.28	2.56			Squid	2.85	2.88	2.08	2.24	2.90	2.90
	Ad. small planktivore	5.12	5.17	< 1E-2	2.56	1.00		Octopus	0.39	0.40	0.89	0.96	0.40	0.40
	Ad. anchovy	0.74	0.71	8.36	6.51	0.70		Sea cucumbers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. anchovy	15.00	13.49	17.14	13.36	13.20		Lobsters	0.04	0.04	0.03	0.03	0.04	0.04
	Ad. deepwater fish	1.33	0.92	0.51	0.40	1.30		Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. deepwater fish	6.50	5.39	3.02	2.35	0.50		Small crabs	0.01	0.01	< 1E-2	0.01	0.01	0.01
	Ad. macro algal browsing	0.10	0.10	0.19	0.15	0.10		Crown of thorns	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. macro algal browsing	6.53	6.59	1.40	3.27	7.40		Giant triton	0.10	0.10	0.07	0.08	0.10	0.10
	Ad. eroding grazers	0.10	0.06	0.08	0.06	0.06		Herbivorous echinoids	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. eroding grazers	5.00		0.52	3.27			Bivalves	0.12	0.10	0.13	0.14	0.10	0.10
	Ad. scraping grazers	0.12	0.10	1.15	0.12			Sessile filter feeders	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. scraping grazers			30.59	23.82	25.30		Epifaunal det. inverts.	0.23	0.20	0.15	0.16	0.20	0.20
	Detritivore fish	0.13	0.10	0.16	0.12	0.10		Epifaunal carn. inverts	0.23	0.20	0.21	0.23	0.20	0.20
Penaeid shrimps			0.19	0.15		Infaunal inverts.	0.23	0.20	0.27	0.29	0.20	0.20		
Shrimps and prawns	3.00	0.71	0.64	0.50	0.70	Jellyfish and hydroids	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Squid	3.67	0.91	0.89	0.70	0.90	Carn. zooplankton	0.16	0.20	0.15	0.16	0.20	0.20		
Octopus			0.34	0.26		Large herb. zooplankton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Mysticetae	0.02	0.02	0.02	0.02	0.02	Small herb. zooplankton	< 1E-2	< 1E-2	< 1E-2	0.01	< 1E-2	< 1E-2		
Pisc. odontocetae	0.02	0.02	0.02	0.02	0.02	Macro algae	0.16	0.20	0.15	0.16	0.20	0.20		
Deep. odontocetae	0.02	0.02	0.02	0.02	0.02	Sea grass	0.16	0.20	0.15	0.16	0.20	0.20		
Birds	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Fishery discards	< 1E-2	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Reef assoc. turtles	0.11	0.10	0.10	0.11	0.10	Detritus	0.03	0.03	0.03	0.03	0.03	0.03		
Green turtles	0.11	0.10	0.10	0.11	0.10	Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Oceanic turtles	0.11	0.10	0.10	0.11	0.10	Sub. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Crocodyles	0.11	0.10	0.10	0.11	0.05	Ad. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Ad. groupers	0.02	0.02	0.02	0.02	0.02	Sub. snappers	0.04	0.04	0.04	0.04	0.04	0.04		
Sub. groupers	0.09	0.09	0.08	0.09	0.09	Ad. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Ad. snappers	0.07	0.07	0.06	0.07	0.07	Sub. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Sub. snappers	0.30	0.30	0.27	0.29	0.30	Ad. large sharks		1.00						
Ad. Napoleon wrasse	1.00	0.03	0.02	0.02	0.02	Juv. large sharks		1.00						
Sub. Napoleon wrasse	0.05	0.05	0.05	0.05	0.05	Ad. small sharks	0.04	0.08	0.04	0.04	0.04	0.04		
Skipjack tuna	0.02	0.02	0.02	0.02	0.02	Juv. small sharks	2.00	0.04	0.10	0.05	0.05	0.05		
Other tuna	0.23	0.20	0.09	0.23	0.20	Ad. butterflyfish	0.02	0.02	0.02	0.02	0.02	0.02		
Mackerel	0.16	0.20	0.15	0.16	0.20	Juv. butterflyfish	0.50	0.50	0.49	0.50	0.50	0.50		
Billfish	4.00	0.09	0.08	0.09	0.09	Cleaner wrasse	0.02	0.02	0.02	0.02	0.02	0.02		
Ad. large sharks	0.01	2.01	< 1E-2	< 1E-2	0.01	Ad. large reef assoc.	2.84	2.00	1.94	0.04	0.06	0.06		
Juv. large sharks	1.00	1.00	0.93	0.10	0.10	Juv. large reef assoc.	6.97	7.01	2.38	2.44	7.00	7.00		
Ad. small sharks	< 1E-2	4.97	< 1E-2	< 1E-2	< 1E-2	Ad. medium reef assoc.	< 1E-2	4.00	< 1E-2	< 1E-2	< 1E-2	< 1E-2		

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Juv. medium reef assoc.	2.00	2.00	1.36	1.40	2.00		Billfish	0.87	0.90	0.83	0.85	0.90
	Ad. small reef assoc.	0.31	0.30	0.30	0.31	0.30		Ad. coral trout	0.06	0.06	0.06	0.06	0.06
	Ad. large demersal	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. large sharks		0.50			
	Juv. large demersal	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. large sharks	0.31	0.30	0.78	0.30	0.30
	Ad. small demersal	0.06	0.06	0.02	0.02	0.06		Ad. small sharks	0.20	0.30	0.24	0.25	0.30
	Ad. large planktivore	0.10	0.10	0.10	0.10	0.10		Juv. small sharks	5.00		1.95		
	Juv. large planktivore	1.97	2.00	1.94	1.99	2.00		Juv. butterflyfish	0.50	0.50	0.48	0.49	0.50
	Ad. small planktivore	0.04	0.04	< 1E-2	0.02	0.04		Ad. large pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. small planktivore	0.81	0.80	0.10	0.81	0.80		Ad. medium pelagic	0.01	0.01	< 1E-2	< 1E-2	0.01
	Ad. anchovy	0.06	0.06	0.45	0.46	0.06		Ad. small pelagic	0.13	0.10	0.13	0.13	0.10
	Juv. anchovy	0.94	0.90	0.92	0.94	0.90		Juv. small pelagic	4.69	4.69	4.49	4.60	4.70
	Ad. deepwater fish	0.02	0.01	< 1E-2	< 1E-2	0.02		Ad. large planktivore	0.04	0.04	0.04	0.04	0.04
	Juv. deepwater fish	0.25	0.18	0.10	0.10	0.20		Juv. large planktivore	6.27	6.29	6.04	6.19	6.30
	Ad. macro algal browsing	0.03	0.03	0.03	0.02	0.03		Ad. small planktivore	0.07	0.07	0.02	0.03	0.07
	Juv. macro algal browsing	1.00	1.00	0.49	0.50	1.00		Juv. small planktivore	1.77	1.80	1.70	1.74	1.80
	Ad. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. anchovy	0.25	0.30	1.29	1.32	0.30
	Juv. eroding grazers			0.49	0.50			Juv. anchovy	2.75	2.80	2.66	2.73	2.80
	Ad. scraping grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. deepwater fish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. scraping grazers	1.98	2.00	7.91	6.95	2.00		Juv. deepwater fish	0.13	0.09	0.05	0.05	0.10
	Detritivore fish	0.02	0.02	0.02	0.02	0.02		Penaeid shrimps			< 1E-2	< 1E-2	
	Penaeid shrimps	0.33	0.30	0.39	0.40	0.30		Shrimps and prawns	0.02	0.02	< 1E-2	0.01	0.02
	Shrimps and prawns	0.33	0.30	0.22	0.23	0.30		Octopus			< 1E-2	< 1E-2	
	Squid	0.08	0.08	0.07	0.07	0.08		Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Octopus	0.06	0.06	0.12	0.12	0.06		Small crabs	0.12	0.10	0.10	0.10	0.10
	Lobsters	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Bivalves			0.02	0.02	
	Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Epifaunal det. inverts.	0.02	0.02	< 1E-2	0.01	0.02
	Small crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Epifaunal carn. inverts	0.02	0.02	0.02	0.02	0.02
	Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Infaunal inverts.	0.02	0.02	0.03	0.03	0.02
	Bivalves	0.06	0.06	0.07	0.06	0.06	Whale shark	Skipjack tuna	0.10	0.10	0.10	0.10	0.10
	Epifaunal det. inverts.	0.08	0.08	0.06	0.06	0.08		Other tuna	1.51	1.51	1.52	1.51	1.50
	Epifaunal carn. inverts	0.08	0.08	0.08	0.08	0.08		Mackerel	0.89	0.90	0.89	0.89	0.90
	Infaunal inverts.	0.08	0.08	0.11	0.11	0.08		Ad. medium pelagic	0.01	0.01	0.01	0.01	0.01
	Carn. zooplankton	1.79	1.80	1.74	1.79	1.80		Ad. small pelagic	0.44	0.40	0.44	0.44	0.40
	Large herb. zooplankton	0.02	0.02	< 1E-2	0.01	0.02		Juv. large planktivore			0.85	0.85	
	Small herb. zooplankton	0.02	0.02	0.03	0.03	0.02		Ad. small planktivore	1.69	1.71	0.43	0.85	1.70
Ad. small sharks	Skipjack tuna	0.24	0.20	0.23	0.24	0.20		Ad. anchovy	0.10	0.10			0.10
	Other tuna	2.36	2.43	< 1E-2	2.35	2.40		Juv. anchovy			0.01	0.01	
	Mackerel	1.79	1.82	1.70	1.78	1.80		Ad. deepwater fish	0.76	0.56	0.23	0.23	0.80
	Billfish	1.07	1.11	1.02	1.06	1.10		Juv. deepwater fish	0.30	0.27	0.12	0.12	0.30
	Ad. large sharks		1.00					Penaeid shrimps			0.06	0.06	
	Juv. large sharks	2.00	1.00	4.63	1.99	2.00		Shrimps and prawns	0.30	0.30	0.20	0.20	0.30
	Juv. small sharks	5.00		4.63				Squid	5.52	5.52	4.43	4.41	5.50
	Ad. large pelagic	0.24	0.20	0.23	0.24	0.20		Octopus			1.14	1.14	
	Ad. medium pelagic	0.01	0.01	< 1E-2	0.01	0.01		Jellyfish and hydroids	1.09	1.10	1.09	1.09	1.10
	Ad. small pelagic	0.86	0.91	0.82	0.86	0.90		Carn. zooplankton	1.33	1.30	1.34	1.33	1.30
	Juv. small pelagic	0.51	0.51	0.48	0.51	0.50		Large herb. zooplankton	0.65	0.60	0.32	0.32	0.60
	Ad. small reef assoc.			0.03	0.03			Small herb. zooplankton	1.33	1.30	1.66	1.65	1.30
	Ad. large demersal	0.21	0.20	0.14	0.15	0.20		Phytoplankton	4.03	4.01	4.92	4.90	4.00
	Ad. large planktivore	0.05	0.05	0.05	0.05	0.05	Manta ray	Ad. medium pelagic	0.01	0.01	0.01	0.01	0.01
	Juv. large planktivore			1.22	1.28			Ad. small pelagic	0.51	0.50	0.51	0.51	0.50
	Ad. small planktivore	2.57	2.63	0.61	1.28	2.60		Ad. large planktivore	0.25	0.30	0.25	0.25	0.30
	Ad. anchovy	0.35	0.30	2.16	2.26	0.30		Juv. large planktivore			0.80	0.80	
	Juv. anchovy	4.63	4.65	4.43	4.64	4.60		Ad. small planktivore	1.59	1.60	0.40	0.80	1.60
	Ad. deepwater fish	0.38	0.28	0.11	0.11	0.40		Ad. anchovy	2.00	2.00	< 1E-2	< 1E-2	2.00
	Juv. deepwater fish	2.22	2.00	0.84	0.88	2.20		Juv. anchovy	0.01	< 1E-2	0.21	0.21	< 1E-2
	Penaeid shrimps	0.11	0.10	0.13	0.13	0.10		Penaeid shrimps	2.25	2.20	2.50	2.49	2.20
	Shrimps and prawns	0.14	0.10	0.09	0.09	0.10		Shrimps and prawns	1.25	1.20	0.85	0.85	1.20
	Squid	0.51	0.51	0.39	0.41	0.50		Squid	2.25	2.20	1.81	1.80	2.20
	Octopus	0.80	0.81	0.87	0.92	0.80		Octopus			0.60	0.60	
	Lobsters	0.08	0.08	0.06	0.06	0.08		Jellyfish and hydroids	2.49	2.50	2.50	2.49	2.50
	Large crabs	0.02	0.02	0.02	0.02	0.02		Carn. zooplankton	2.49	2.50	2.50	2.49	2.50
	Small crabs	0.05	0.05	0.04	0.04	0.05		Large herb. zooplankton	1.18	1.20	0.59	0.59	1.20
	Giant triton	0.10	0.10	0.07	0.08	0.10		Small herb. zooplankton	2.49	2.50	3.10	3.09	2.50
	Bivalves			0.03	0.03			Phytoplankton	1.25	1.20	3.05	3.04	1.20
	Epifaunal det. inverts.	0.24	0.20	0.16	0.17	0.20	Adult rays	Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Epifaunal carn. inverts	0.24	0.20	0.23	0.24	0.20		Sub. groupers	0.02	0.02	0.02	0.02	0.02
	Infaunal inverts.	0.24	0.20	0.30	0.31	0.20		Ad. snappers	0.02	0.02	0.02	0.02	0.02
Juv. small sharks	Skipjack tuna	0.21	0.20	0.20	0.21	0.20		Sub. snappers	0.02	0.02	0.02	0.02	0.02
	Other tuna	1.17	1.20	1.12	1.15	1.20		Ad. butterflyfish	0.02	0.02	0.02	0.02	0.02
	Mackerel	0.31	0.30	0.29	0.30	0.30		Juv. butterflyfish	0.02	0.02	0.02	0.02	0.02

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Cleaner wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Soft corals	0.50	0.50	0.22	0.22	0.50
	Ad. large reef assoc.	0.12	< 1E-2	0.10	0.08	0.10		Anemonies	0.50	0.50	< 1E-2	< 1E-2	0.50
	Juv. large reef assoc.	0.14	0.10	0.05	0.05	0.10		Pennaeid shrimps	0.87	0.90	0.89	0.89	0.90
	Ad. medium reef assoc.	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Shrimps and prawns	0.10	0.10	0.07	0.07	0.10
	Ad. small reef assoc.	0.02	0.02	0.04	0.04	0.02		Squid	0.50	0.50	0.40	0.40	0.50
	Ad. large demersal	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Octopus	0.56	0.60	0.67	0.67	0.60
	Ad. small demersal	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Sea cucumbers	0.07	0.07	0.07	0.07	0.07
	Ad. large planktivore	0.02	0.02	0.02	0.02	0.02		Lobsters	0.02	0.01	< 1E-2	< 1E-2	0.01
	Juv. large planktivore			< 1E-2	< 1E-2			Large crabs	0.02	0.02	0.02	0.02	0.02
	Ad. small planktivore	0.02	0.02	< 1E-2	< 1E-2	0.02		Small crabs	0.40	0.40	0.34	0.34	0.40
	Ad. anchovy	< 1E-2	< 1E-2	< 1E-2	0.01	< 1E-2		Crown of thorns	0.08	0.05	0.05	0.05	0.20
	Juv. anchovy	0.02	0.02	0.02	0.02	0.02		Giant triton	0.04	0.04	0.03	0.03	0.04
	Ad. deepwater fish	0.02	0.02	< 1E-2	< 1E-2	0.02		Herbivorous echinoids	0.10	0.10	0.08	0.08	0.10
	Juv. deepwater fish	0.02	0.02	0.11	0.11	0.02		Bivalves	1.00	0.80	0.93	0.93	0.80
	Ad. macro algal browsing	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Sessile filter feeders	12.42	12.40	4.80	4.80	12.40
	Ad. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Epifaunal det. inverts.	0.87	0.90	0.28	0.28	0.90
	Ad. scraping grazers	0.08	0.08	0.08	0.08	0.08		Epifaunal carn. inverts	8.00	8.00	8.00	8.00	8.00
	Juv. scraping grazers			2.91	0.05			Infauanal inverts.	18.00	18.00	19.32	19.32	18.00
	Detritivore fish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Jellyfish and hydroids	0.50	0.50	0.50	0.50	0.50
	Pennaeid shrimps	1.59	1.60	2.16	2.22	1.60		Carn. zooplankton	10.64	10.60	10.64	10.64	10.50
	Shrimps and prawns	1.00	3.10	2.08	2.14	3.10		Large herb. zooplankton	1.07	1.00	0.52	0.52	1.00
	Squid	0.01	0.01	< 1E-2	0.01	0.01		Small herb. zooplankton	9.85	9.90	10.37	10.37	9.90
	Octopus	< 1E-2	< 1E-2	0.37	0.38	< 1E-2		Phytoplankton	9.64	9.60	9.64	9.64	9.60
	Lobsters	0.07	0.07	0.05	0.05	0.07		Macro algae	15.00	15.00	15.39	15.39	15.00
	Large crabs	0.09	0.09	0.08	0.08	0.09		Sea grass	2.96	3.00	2.96	2.96	3.00
	Small crabs	0.08	0.08	0.07	0.07	0.08		Fishery discards	< 1E-2	0.01	< 1E-2	< 1E-2	< 1E-2
	Giant triton	0.08	0.08	0.07	0.07	0.08		Detritus	1.69	3.70	3.67	3.67	3.70
	Bivalves	6.30	6.30	6.15	6.33	6.30	Juv. butterflyfish	Juv. groupers	0.01	0.01	0.01	0.01	0.01
	Epifaunal det. inverts.	2.38	2.50	1.62	1.67	2.40		Juv. snappers	0.01	0.01	0.01	0.01	0.01
	Epifaunal carn. inverts	2.38	2.40	2.31	2.38	2.40		Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Infauanal inverts.	2.38	2.40	3.00	3.09	2.40		Juv. coral trout	< 1E-2	< 1E-2	0.10	0.10	< 1E-2
	Carn. zooplankton	3.06	0.90	0.88	0.91	0.90		Juv. rays	0.01	0.01	0.01	0.01	0.01
Juv. rays	Ad. small reef assoc.	0.27	0.30	0.26	0.27	0.30		Juv. butterflyfish	0.03	0.03	0.03	0.03	0.03
	Ad. small demersal	0.64	0.60	0.19	0.19	0.60		Juv. large reef assoc.	0.01	0.01	< 1E-2	< 1E-2	0.01
	Juv. deepwater fish			0.31	0.32			Juv. medium reef assoc.	3.70	3.70	2.59	2.59	2.00
	Juv. scraping grazers			2.92	0.13			Juv. small reef assoc.	0.13	0.20	0.21	0.21	0.20
	Pennaeid shrimps	0.50	0.50	0.58	0.60	0.50		Juv. large demersal	0.01	0.01	< 1E-2	< 1E-2	0.01
	Shrimps and prawns	0.51	0.50	0.34	0.35	0.50		Juv. small demersal	0.01	0.01	< 1E-2	< 1E-2	0.01
	Octopus	1.92	1.90	1.93	1.99	1.90		Juv. large planktivore	3.02	3.00	3.02	3.02	3.00
	Sea cucumbers	1.28	1.30	1.24	1.28	1.30		Juv. small planktivore	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Lobsters	0.10	0.10	0.07	0.07	0.10		Juv. macro algal browsing	0.01	0.01	< 1E-2	< 1E-2	0.01
	Large crabs	0.08	0.08	0.07	0.07	0.08		Juv. eroding grazers	< 1E-2	< 1E-2	0.01	0.01	< 1E-2
	Small crabs	0.13	0.10	0.11	0.11	0.10		Juv. scraping grazers	2.15	3.10	2.78	2.78	3.80
	Crown of thorns	0.11	0.10	0.11	0.11	0.10		Azooxanthellate corals	0.32	0.30	0.13	0.13	0.30
	Herbivorous echinoids	0.82	0.80	0.64	0.66	0.80		Hermatypic corals	0.02	0.02	< 1E-2	< 1E-2	0.02
	Bivalves			0.19	0.19			Non reef building corals	0.32	0.30	0.09	0.09	0.30
	Sessile filter feeders	1.28	1.30	1.00	1.03	1.30		Soft corals	0.32	0.30	0.14	0.14	0.30
	Epifaunal det. inverts.	4.64	4.60	3.16	3.25	4.60		Anemonies	0.01	0.01	< 1E-2	< 1E-2	0.01
	Epifaunal carn. inverts	3.85	3.90	3.74	3.85	3.90		Pennaeid shrimps			0.02	0.02	
	Infauanal inverts.	3.85	3.90	5.35	5.50	3.90		Shrimps and prawns	0.12	0.10	0.08	0.08	0.10
Ad. butterflyfish	Juv. groupers	0.03	0.06	0.06	0.06	0.06		Squid	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. snappers	0.06	0.06	0.06	0.06	0.06		Octopus	0.57	0.60	0.59	0.59	0.60
	Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Sea cucumbers	0.02	0.02	0.02	0.02	0.02
	Juv. coral trout	< 1E-2	< 1E-2	0.20	0.20	< 1E-2		Lobsters	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. rays	0.04	0.04	0.04	0.04	0.04		Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. butterflyfish	0.06	0.06	0.06	0.06	0.06		Small crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Cleaner wrasse			0.10	0.10			Crown of thorns	0.02	0.02	0.02	0.02	0.02
	Juv. large reef assoc.	0.06	0.06	3.00	3.00	0.06		Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. medium reef assoc.	1.00	1.00	0.70	0.70	1.00		Herbivorous echinoids	0.01	0.01	< 1E-2	< 1E-2	0.01
	Juv. small reef assoc.	1.80	0.01	0.01	0.01	0.01		Bivalves	0.58	0.60	0.58	0.58	0.60
	Juv. large demersal	0.06	0.06	0.02	0.02	0.06		Sessile filter feeders	0.84	0.80	0.67	0.67	0.80
	Juv. small demersal	0.06	0.06	0.02	0.02	0.06		Epifaunal det. inverts.	0.10	0.10	0.07	0.07	0.10
	Juv. large planktivore	0.06	0.06	0.06	0.06	0.06		Epifaunal carn. inverts	11.47	11.50	11.46	11.46	11.50
	Juv. small planktivore	0.03	0.03	0.02	0.02	0.03		Infauanal inverts.	23.96	24.00	24.13	24.13	24.00
	Juv. macro algal browsing	0.14	0.10	0.07	0.07	0.10		Jellyfish and hydroids	0.15	0.20	0.15	0.15	0.20
	Juv. eroding grazers	0.01	0.01	0.08	0.08	0.01		Carn. zooplankton	2.53	2.50	2.53	2.53	2.50
	Juv. scraping grazers	0.06	0.10	5.23	5.23	0.06		Large herb. zooplankton	1.96	2.00	0.98	0.98	2.00
	Azooxanthellate corals	0.50	0.50	0.20	0.20	0.50		Small herb. zooplankton	1.50	1.50	2.48	2.48	1.50
	Hermatypic corals	0.13	0.10	0.04	0.04	0.10		Phytoplankton	25.00	24.00	24.97	24.97	25.00
	Non reef building corals	0.50	0.50	0.14	0.14	0.50		Macro algae	14.26	14.20	15.29	15.29	14.20

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
Cleaner wrasse	Sea grass	6.80	6.80	6.79	6.79	6.80	Juv. large pelagic	Ad. macro algal browsing	0.17	0.20	0.17	0.17	0.20
	Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. eroding grazers	0.02	0.02	0.02	0.01	0.02
	Sub. groupers	0.15	0.20	0.15	0.15	0.20		Ad. scraping grazers	0.20	0.20	0.20	0.20	0.20
	Ad. butterflyfish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. scraping grazers			7.67	3.40	
	Juv. butterflyfish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Detritivore fish	0.10	0.10	0.10	0.10	0.10
	Ad. large reef assoc.	0.36	0.40	0.25	0.25	0.40		Penaeid shrimps			6.22	2.47	
	Juv. large reef assoc.	0.36	0.40	0.13	0.13	0.40		Shrimps and prawns	10.00	12.54	8.62	8.41	12.40
	Ad. medium reef assoc.	0.10	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Squid	0.24	0.20	0.20	0.19	0.20
	Ad. small reef assoc.	3.17	3.20	3.19	3.17	3.20		Octopus	1.32	1.32	2.92	2.85	1.30
	Juv. small reef assoc.	3.00	5.00	5.03	5.00	5.00		Lobsters	0.03	0.03	0.02	0.02	0.03
	Ad. large demersal	0.10	0.10	0.07	0.07	0.10		Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. small demersal	0.29	0.30	0.09	0.09	0.30		Small crabs	0.02	0.02	0.02	0.02	0.02
	Ad. large planktivore	0.29	0.30	0.29	0.29	0.30		Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. large planktivore			1.07	1.06			Bivalves	0.05	0.05	0.10	0.06	0.05
	Ad. small planktivore	2.12	2.10	0.53	1.06	2.10		Epifaunal det. inverts.	0.48	0.51	0.34	0.34	0.50
	Ad. anchovy	0.87	0.90	0.14	0.14	0.90		Epifaunal carn. inverts	0.60	0.61	0.61	0.60	0.60
	Juv. anchovy	0.29	0.30	0.38	0.38	0.30		Infauanal inverts.	0.60	0.61	0.76	0.74	0.60
	Ad. deepwater fish	0.51	0.35	0.15	0.15	0.50		Carn. zooplankton	1.34	1.42	1.48	1.44	1.40
	Juv. deepwater fish	0.51	0.45	0.20	0.20	0.50		Large herb. zooplankton	1.00	0.71	0.37	0.36	0.70
	Ad. scraping grazers	0.12	0.10	0.12	0.12	0.10		Small herb. zooplankton	1.32	1.32	1.72	1.68	1.30
Juv. scraping grazers			21.71	21.60		Macro algae	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Detritivore fish	0.05	0.05	0.05	0.05	0.05	Sea grass	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Azooxanthellate corals	14.56	14.61	5.89	5.86	14.60	Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Hermatypic corals	4.44	4.40	1.43	1.42	4.40	Sub. groupers	0.01	0.01	< 1E-2	< 1E-2	0.01		
Non reef building corals	11.78	11.80	3.32	3.30	11.80	Ad. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Soft corals			0.47	0.47		Sub. snappers	0.06	0.06	0.06	0.06	0.06		
Epifaunal det. inverts.	12.46	10.60	7.43	7.39	10.60	Skipjack tuna	0.11	0.10	0.11	0.10	0.10		
Epifaunal carn. inverts	22.23	22.21	22.35	22.23	22.00	Other tuna	2.28	2.30	< 1E-2	2.15	2.30		
Infauanal inverts.	22.23	22.21	25.54	25.40	22.20	Mackerel	1.48	1.50	1.42	1.39	1.50		
Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Billfish	0.91	0.90	0.88	0.86	0.90		
Sub. groupers	0.05	0.05	0.05	0.05	0.05	Ad. butterflyfish	0.11	0.10	0.11	0.10	0.10		
Ad. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. butterflyfish	2.00	2.00	1.92	1.88	2.00		
Sub. snappers	0.12	0.10	0.12	0.12	0.10	Cleaner wrasse	0.06	0.06	0.06	0.06	0.06		
Ad. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Ad. large pelagic	0.04	0.04	0.04	0.04	0.04		
Sub. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Ad. medium pelagic	0.64	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Skipjack tuna	10.00	0.20	0.25	0.24	0.20	Ad. small pelagic	0.47	0.50	0.45	0.44	0.50		
Other tuna	6.71	6.78	< 1E-2	6.71	4.00	Juv. small pelagic	0.40	0.40	0.39	0.38	0.40		
Mackerel	2.04	2.02	2.09	2.04	2.00	Ad. large reef assoc.	0.23	0.20	0.16	0.15	0.20		
Billfish	1.32	1.32	1.35	1.32	1.30	Juv. large reef assoc.	21.71	21.72	7.33	7.16	21.70		
Ad. large sharks	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Ad. medium reef assoc.	0.10	0.10	< 1E-2	< 1E-2	< 1E-2		
Juv. large sharks	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. medium reef assoc.	1.00	1.60	1.10	1.08	1.60		
Ad. small sharks	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Ad. small reef assoc.	0.49	0.50	0.47	0.46	0.50		
Juv. small sharks	< 1E-2	< 1E-2	0.10	< 1E-2	< 1E-2	Juv. small reef assoc.	2.05	3.40	3.29	3.21	3.40		
Adult rays	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Ad. large demersal	0.01	0.01	< 1E-2	< 1E-2	0.01		
Juv. rays	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. large demersal	0.57	0.60	0.18	0.17	0.60		
Ad. butterflyfish	0.01	0.01	< 1E-2	0.01	0.01	Ad. small demersal	0.23	0.20	0.07	0.07	0.20		
Juv. butterflyfish	1.50	2.33	2.33	2.28	2.30	Ad. large planktivore	0.28	0.30	0.27	0.26	0.30		
Cleaner wrasse	0.06	0.06	0.06	0.06	0.06	Ad. small planktivore	0.60	0.60	0.15	0.28	0.60		
Ad. large pelagic	0.55	0.05	0.05	0.05	0.05	Juv. small planktivore	2.73	2.70	2.63	2.57	2.70		
Juv. large pelagic	0.27	0.30	0.28	0.27	0.30	Ad. anchovy	8.18	8.21	20.94	20.46	8.20		
Ad. medium pelagic	2.00	0.20	0.20	0.20	0.20	Juv. anchovy	44.32	44.35	43.54	42.54	44.30		
Juv. medium pelagic	< 1E-2	< 1E-2	0.19	< 1E-2	< 1E-2	Ad. deepwater fish	0.11	0.07	0.03	0.03	0.10		
Ad. small pelagic	10.00	1.01	1.05	1.03	1.00	Juv. deepwater fish	0.57	0.54	0.22	0.21	0.60		
Juv. small pelagic	1.20	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Ad. macro algal browsing	0.05	0.05	0.04	0.04	0.05		
Ad. large reef assoc.	0.60	0.61	0.43	0.42	0.60	Ad. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Juv. large reef assoc.	9.59	9.71	3.44	3.36	9.60	Ad. scraping grazers	0.09	0.09	0.09	0.09	0.09		
Ad. medium reef assoc.	0.10	0.10	< 1E-2	< 1E-2	< 1E-2	Juv. scraping grazers	2.50	2.50	9.86	9.63	2.50		
Juv. medium reef assoc.	0.65	0.61	0.47	0.46	0.60	Detritivore fish	0.05	0.05	0.05	0.04	0.05		
Ad. small reef assoc.	2.00	2.02	2.04	2.00	2.00	Penaeid shrimps			< 1E-2	< 1E-2			
Juv. small reef assoc.	1.80	1.62	1.60	1.56	1.60	Shrimps and prawns	0.01	0.01	< 1E-2	< 1E-2	0.01		
Ad. large demersal	0.01	0.01	< 1E-2	< 1E-2	0.01	Squid	0.12	0.10	0.09	0.09	0.10		
Ad. small demersal	0.24	0.20	0.08	0.07	0.20	Octopus			0.02	0.02			
Ad. large planktivore	0.30	0.30	0.31	0.30	0.30	Lobsters	0.02	0.02	0.02	0.02	0.02		
Juv. large planktivore	< 1E-2	< 1E-2	9.47	9.24	< 1E-2	Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Ad. small planktivore	0.24	0.20	0.06	0.12	0.20	Small crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Juv. small planktivore	4.56	4.65	0.95	4.56	4.60	Giant triton	0.03	0.03	0.02	0.02	0.03		
Ad. anchovy	5.02	5.06	3.67	3.58	7.70	Bivalves			< 1E-2	< 1E-2			
Juv. anchovy	6.88	7.38	8.02	7.82	7.30	Epifaunal det. inverts.	3.63	2.30	1.59	1.56	2.40		
Ad. deepwater fish	0.60	0.42	0.18	0.18	0.60	Epifaunal carn. inverts	0.07	0.07	0.07	0.07	0.07		
Juv. deepwater fish	7.32	6.65	3.00	2.93	7.30	Infauanal inverts.	0.07	0.07	0.75	0.74	0.07		

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	
Ad. medium pelagic	Carn. zooplankton	1.60	1.60	1.54	1.51	1.60	Ad. large reef assoc.	Juv. rays	0.04	0.04	0.04	0.04	0.04	
	Other tuna	2.09	2.11	1.50	2.00	2.10		Juv. large pelagic	0.02	0.02	0.02	0.02	0.02	
	Mackerel	1.58	1.60	2.28	1.51	1.60		Juv. medium pelagic	0.01	0.01	0.10	0.01	0.01	
	Billfish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. small pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. butterflyfish	0.33	0.30	0.47	0.32	0.30		Juv. large planktivore	0.05	0.05	0.04	0.04	0.05	
	Ad. large pelagic	0.09	0.09	0.13	0.09	0.09		Juv. small planktivore	0.02	0.02	0.02	0.02	0.02	
	Juv. large pelagic	0.42	0.40	0.61	0.40	0.40		Ad. anchovy			< 1E-2	< 1E-2		
	Ad. medium pelagic	1.00	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. anchovy	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2	
	Juv. medium pelagic	0.08	0.08	0.12	0.08	0.08		Juv. deepwater fish	0.05	0.04	0.02	0.02	0.05	
	Ad. small pelagic	8.00	3.51	0.63	3.33	3.50		Penaeid shrimps			< 1E-2	< 1E-2		
	Juv. small pelagic	19.63	19.65	0.29	18.77	19.60		Shrimps and prawns	0.05	0.05	0.03	0.03	0.05	
	Ad. large planktivore	0.13	0.10	0.19	0.12	0.10		Squid	0.06	0.06	0.05	0.05	0.06	
	Juv. large planktivore			0.44	0.29			Octopus				0.02	0.02	
	Ad. small planktivore	0.62	0.60	0.22	0.29	0.60		Lobsters	0.03	0.03	0.02	0.02	0.03	
	Juv. small planktivore	11.77	11.84	0.71	11.26	11.80		Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	
	Ad. anchovy	14.65	14.75	27.53	18.33	14.70		Small crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	
	Juv. anchovy	34.48	39.24	58.29	38.82	39.10		Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	
	Ad. deepwater fish	0.52	0.35	0.22	0.15	0.50		Bivalves			< 1E-2	< 1E-2		
	Juv. deepwater fish	1.70	1.54	0.98	0.65	1.70		Epifaunal det. inverts.	0.10	0.10	0.07	0.07	0.10	
	Penaeid shrimps			0.30	0.20			Epifaunal carn. inverts	0.03	0.03	0.03	0.03	0.03	
	Shrimps and prawns	1.05	1.10	1.03	0.68	1.10		Infaunal inverts.	0.51	0.50	0.54	0.54	0.50	
	Squid	0.02	0.02	0.02	0.01	0.02		Jellyfish and hydroids	0.05	0.05	0.05	0.05	0.05	
	Octopus			0.19	0.12			Carn. zooplankton	20.00	49.19	49.15	49.17	49.20	
	Lobsters	0.14	0.10	0.14	0.09	0.10		Large herb. zooplankton	30.17	1.00	0.50	0.50	1.00	
	Large crabs	0.27	0.30	0.34	0.23	0.30		Small herb. zooplankton	48.71	48.69	49.19	49.21	48.70	
	Small crabs	0.70	0.70	0.86	0.57	0.70		Phytoplankton			0.03	0.03		
	Giant triton	0.17	0.20	0.19	0.13	0.20		Juv. large sharks	0.20	0.05	0.70	0.19	0.20	
	Bivalves			0.24	0.16			Juv. small sharks	0.10	0.30	0.30	0.30	0.04	
	Epifaunal det. inverts.	0.39	0.40	0.40	0.26	0.40		Juv. rays	0.01	0.01	< 1E-2	< 1E-2	0.01	
	Epifaunal carn. inverts	0.16	0.40	0.57	0.38	0.40		Cleaner wrasse	0.07	0.07	0.07	0.07	0.01	
	Infaunal inverts.	0.01	0.60	1.11	0.74	0.70		Juv. large pelagic	0.03	0.03	0.03	0.03	0.03	
	Juv. medium pelagic	Other tuna	0.22	0.20	0.22	0.22		0.20	Juv. medium pelagic	0.04	0.04	0.04	0.04	0.04
		Mackerel	0.22	0.20	0.22	0.22		0.20	Juv. small pelagic	0.16	0.06	0.06	0.06	0.30
Juv. large sharks		0.22	0.20	0.22	0.22	0.20	Juv. large planktivore	0.31	0.30	0.30	0.30	0.30		
Juv. small sharks		0.22	0.20	0.50	0.22	0.20	Juv. small planktivore	0.17	0.20	0.16	0.16	0.20		
Juv. rays		0.01	0.01	0.01	0.01	0.01	Ad. anchovy			0.50	0.50			
Juv. butterflyfish		0.31	0.30	0.31	0.31	0.30	Juv. anchovy	0.10	5.10	4.97	4.98	5.20		
Ad. large pelagic		0.01	0.01	0.01	0.01	0.01	Juv. deepwater fish	0.72	0.54	0.24	0.24	0.10		
Juv. large pelagic		0.09	0.09	0.09	0.09	0.09	Penaeid shrimps			< 1E-2	< 1E-2			
Ad. medium pelagic		< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Shrimps and prawns	0.04	0.04	0.03	0.03	0.04		
Juv. medium pelagic		0.03	0.03	0.10	0.03	0.03	Squid	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Ad. small pelagic		1.20	1.21	0.60	1.20	1.20	Octopus			< 1E-2	< 1E-2			
Juv. small pelagic		0.08	0.08	0.08	0.08	0.08	Lobsters	0.02	0.02	0.01	0.01	0.02		
Ad. large planktivore		0.11	0.10	0.11	0.11	0.10	Large crabs	0.01	0.01	< 1E-2	< 1E-2	0.01		
Juv. large planktivore		0.22	0.20	0.29	0.29	0.20	Small crabs	0.02	0.01	< 1E-2	< 1E-2	0.01		
Ad. small planktivore		0.14	0.10	0.04	0.07	0.10	Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Juv. small planktivore		0.22	0.20	0.22	0.22	0.20	Bivalves			< 1E-2	< 1E-2			
Ad. anchovy		11.88	11.95	0.16	0.16	11.90	Epifaunal det. inverts.	0.08	0.08	0.05	0.05	0.08		
Juv. anchovy		0.32	0.30	1.51	1.51	0.30	Epifaunal carn. inverts	0.07	0.07	0.07	0.07	0.07		
Ad. deepwater fish		0.27	0.21	0.08	0.08	0.30	Infaunal inverts.	0.21	0.20	0.22	0.22	0.20		
Juv. deepwater fish		1.03	0.90	0.41	0.41	1.00	Jellyfish and hydroids	0.16	0.20	0.16	0.16	0.20		
Penaeid shrimps				< 1E-2	< 1E-2		Carn. zooplankton	15.13	10.21	9.95	9.96	10.20		
Shrimps and prawns		0.04	0.04	0.03	0.03	0.04	Large herb. zooplankton	9.27	9.21	6.95	6.96	9.20		
Squid		0.22	0.20	0.17	0.17	0.20	Small herb. zooplankton	20.87	21.01	24.75	24.78	20.80		
Octopus				0.05	0.05		Phytoplankton	52.21	52.24	50.39	50.84	52.70		
Lobsters		0.07	0.07	0.05	0.05	0.07	Ad. groupers	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Large crabs		0.01	0.01	0.01	0.01	0.01	Sub. groupers	< 1E-2	< 1E-2	< 1E-2	0.30	< 1E-2		
Small crabs		0.01	0.01	< 1E-2	< 1E-2	0.01	Juv. groupers	< 1E-2	< 1E-2	< 1E-2	0.20	< 1E-2		
Giant triton		< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Ad. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Bivalves				< 1E-2	< 1E-2		Sub. snappers	0.01	< 1E-2	0.50	0.50	0.01		
Epifaunal det. inverts.		0.11	0.10	0.08	0.08	0.10	Juv. snappers	0.10	0.10	1.94	1.00	0.01		
Epifaunal carn. inverts		0.22	0.20	0.22	0.22	0.20	Ad. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Infaunal inverts.		0.22	0.20	0.25	0.25	0.20	Sub. Napoleon wrasse	0.01	< 1E-2	0.04	< 1E-2	0.01		
Jellyfish and hydroids		1.30	1.31	1.31	1.30	1.30	Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Carn. zooplankton	27.00	27.12	27.10	27.01	27.10	Skipjack tuna	2.00	0.05	0.05	0.05	0.05			
Large herb. zooplankton	27.00	27.12	13.53	13.50	27.10	Other tuna	1.64	0.05	< 1E-2	0.05	0.01			
Small herb. zooplankton	16.20	16.27	29.80	29.71	16.20	Mackerel	0.05	0.05	0.05	0.05	0.05			
Phytoplankton	10.80	10.85	22.21	22.14	10.80	Billfish	0.05	0.05	0.05	0.05	0.05			
Ad. small pelagic	Juv. large sharks	0.04	0.04	0.04	0.04	0.04	Ad. coral trout	0.02	0.02	0.02	0.02	0.01		
	Juv. small sharks	0.04	0.04	< 1E-2	0.04	0.04	Juv. coral trout	< 1E-2	< 1E-2			< 1E-2		

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Ad. large sharks	< 1E-2	< 1E-2	< 1E-2	0.01	0.01		Juv. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. large sharks	< 1E-2	< 1E-2	0.80	< 1E-2	< 1E-2		Ad. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. small sharks	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Sub. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Adult rays	0.04	0.10	0.05	0.05	0.10		Juv. snappers	< 1E-2	< 1E-2	1.40	< 1E-2	< 1E-2
	Juv. rays	0.05	0.02	0.02	0.02	0.01		Ad. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. butterflyfish	0.10	0.05	0.10	0.10	0.10		Sub. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. butterflyfish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	0.30		Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Cleaner wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. coral trout	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. large pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. small sharks	0.05	0.02	0.02	0.02	0.01
	Juv. large pelagic	0.01	< 1E-2	< 1E-2	< 1E-2	0.01		Juv. rays	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. medium pelagic	0.03	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. butterflyfish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. medium pelagic	0.09						Juv. butterflyfish	0.02	0.02	0.02	0.02	
	Ad. small pelagic	0.10	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Cleaner wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. large reef assoc.	1.50	0.20	0.97	0.35	1.50		Juv. small pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. large reef assoc.	0.13	0.50	0.35	0.35	1.00		Ad. large reef assoc.	0.02	0.02	0.93	0.01	0.02
	Ad. medium reef assoc.	2.00	2.98	1.50	1.50	0.50		Juv. large reef assoc.	0.20	0.20	0.34	0.36	1.00
	Juv. medium reef assoc.	1.00	0.99	5.93	1.40	0.20		Ad. medium reef assoc.	0.10	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. small reef assoc.	2.10	0.20	0.60	0.60	0.60		Juv. medium reef assoc.	2.00	1.98	2.82	1.43	0.10
	Juv. small reef assoc.	0.50	0.20	0.20	0.20	0.20		Ad. small reef assoc.	0.10	< 1E-2	< 1E-2	0.01	0.01
	Ad. large demersal	0.10	0.05	< 1E-2	< 1E-2	0.01		Juv. small reef assoc.	1.00	0.10	0.09	0.10	0.10
	Juv. large demersal	0.01	< 1E-2	< 1E-2	< 1E-2	0.01		Ad. large demersal	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. small demersal	0.30	0.10	< 1E-2	0.01	0.05		Juv. large demersal	0.01	< 1E-2	< 1E-2	< 1E-2	0.01
	Juv. small demersal	0.50	0.20	< 1E-2	0.07	0.10		Ad. small demersal	0.20	0.02	< 1E-2	0.03	0.02
	Ad. large planktivore	1.00	1.19	1.65	1.60	1.60		Juv. small demersal	0.20	0.20	0.03	0.03	0.10
	Juv. large planktivore	0.20	0.20	0.25	0.25	0.20		Ad. large planktivore	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. small planktivore	0.10	0.10	< 1E-2	0.05	0.10		Juv. large planktivore	0.40	0.99	0.85	1.79	1.80
	Juv. small planktivore	0.11	0.20	0.03	0.11	0.10		Ad. small planktivore	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. anchovy	1.00	1.09	1.47	0.12	1.00		Juv. small planktivore	0.30	0.30	< 1E-2	0.31	0.30
	Juv. anchovy	0.01	0.99	0.01	0.35			Ad. anchovy	0.10	0.10	1.41	0.05	0.10
	Ad. deepwater fish	0.50	0.14	0.06	0.06	0.10		Juv. anchovy	0.10	0.99	2.82	0.11	0.10
	Juv. deepwater fish	0.20	0.09	0.04	0.04	0.05		Ad. deepwater fish	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. macro algal browsing	0.08	0.07	0.03	0.08	0.08		Juv. deepwater fish	0.10	0.09	0.04	0.04	0.01
	Juv. macro algal browsing	0.05	0.40	0.10	0.03	0.05		Ad. macro algal browsing	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. eroding grazers	< 1E-2	< 1E-2	0.49	< 1E-2	< 1E-2		Juv. macro algal browsing	0.20	0.40	0.09	0.05	0.10
	Juv. eroding grazers	0.20	0.06	0.09	0.09	0.06		Ad. eroding grazers	0.01	< 1E-2	0.28	< 1E-2	< 1E-2
	Ad. scraping grazers	0.20	0.20	0.20	0.20	0.20		Juv. eroding grazers	0.01	< 1E-2	0.05	0.05	< 1E-2
	Juv. scraping grazers	0.32	7.95	10.78	15.58	10.40		Ad. scraping grazers	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Detritivore fish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. scraping grazers	0.38	0.40			
	Azooxanthellate corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Detritivore fish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Hermatypic corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Azooxanthellate corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Non reef building corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Hermatypic corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Soft corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Non reef building corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Anemonies	0.01	< 1E-2	< 1E-2	< 1E-2	0.01		Soft corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Penaeid shrimps			0.60	0.60			Anemonies	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Shrimps and prawns	1.00	2.97	2.04	2.04	3.00		Penaeid shrimps			0.02	0.02	
	Squid	0.30	0.30	0.28	0.28	0.40		Shrimps and prawns	0.10	0.10	0.07	0.07	0.10
	Octopus	2.00	1.39	0.06	1.80	1.40		Squid	0.50	0.10	0.38	0.41	0.10
	Sea cucumbers	0.50	0.50	0.45	0.45	0.50		Octopus	0.40	0.40	0.41	0.43	0.30
	Lobsters	0.05	0.02	< 1E-2	0.01	0.02		Sea cucumbers	0.09	0.08	0.07	0.08	0.08
	Large crabs	0.05	0.15	0.18	0.18	0.20		Lobsters	0.01	< 1E-2	< 1E-2	< 1E-2	0.01
	Small crabs	0.20	0.20	0.17	0.17	0.20		Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Crown of thorns	0.08	0.10	0.18	0.35	0.40		Small crabs	0.08	0.08	0.07	0.07	0.08
	Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Crown of thorns	0.01	< 1E-2	< 1E-2	0.01	0.01
	Herbivorous echinoids	0.20	0.10	0.12	0.12	0.20		Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Bivalves	2.30	2.38	2.38	2.38	2.30		Herbivorous echinoids	0.01	< 1E-2	< 1E-2	< 1E-2	0.01
	Sessile filter feeders	2.50	2.97	1.60	1.60	3.00		Bivalves	3.11	2.28	2.24	2.37	2.30
	Epifaunal det. inverts.	0.20	0.20	0.35	0.35	0.20		Sessile filter feeders	0.82	0.79	0.63	0.67	0.80
	Epifaunal carn. inverts	4.10	5.94	4.00	4.00	6.00		Epifaunal det. inverts.	0.15	0.20	0.13	0.14	0.20
	Infauanal inverts.	14.90	16.30	21.46	21.42	20.70		Epifaunal carn. inverts	5.00	6.23	6.01	6.37	4.20
	Jellyfish and hydroids	0.10	0.10	0.06	0.06	0.06		Infauanal inverts.	30.22	30.23	29.15	30.89	30.00
	Carn. zooplankton	4.04	2.08	1.37	1.37	1.40		Jellyfish and hydroids	1.09	0.10	0.08	0.09	0.09
	Large herb. zooplankton	5.87	5.76	1.01	1.00	2.00		Carn. zooplankton	13.13	13.40	13.04	13.82	13.50
	Small herb. zooplankton	11.70	9.11	7.27	9.18	9.20		Large herb. zooplankton	11.72	6.94	3.48	3.70	4.20
	Phytoplankton		0.60			0.40		Small herb. zooplankton	11.20	12.60	15.75	16.68	15.80
	Macro algae	12.00	9.54	10.46	9.47	9.50		Phytoplankton	0.83	1.09	0.80	0.85	5.90
	Sea grass	11.12	9.05	9.11	9.10	9.10		Macro algae	7.50	10.23	9.63	9.70	9.50
	Fishery discards	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Sea grass	8.48	9.26	6.77	9.16	9.00
	Detritus	10.32	11.59	8.40	8.60	10.90		Ad. medium reef assoc.	Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Juv. large reef assoc.	Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Sub. groupers	< 1E-2	< 1E-2	< 1E-2	0.01	0.01
	Sub. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. groupers	< 1E-2	< 1E-2	< 1E-2	0.01	0.01

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
Ad. snappers		0.02	0.02	0.02	0.02	0.02		Large herb. zooplankton	9.55	2.68	1.34	1.39	2.70
Sub. snappers		0.02	0.02	0.02	0.02	0.02		Small herb. zooplankton	11.01	7.93	6.18	6.40	5.00
Juv. snappers		0.02	0.08	1.86	0.08	0.40		Phytoplankton	2.96	1.98	1.99	2.06	2.00
Ad. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Macro algae	8.75	8.52	8.53	8.83	8.60
Sub. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Sea grass	11.70	9.32	9.33	9.66	9.40
Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Fishery discards		0.08	< 1E-2	< 1E-2	< 1E-2
Skipjack tuna	0.01	< 1E-2	< 1E-2	0.01	0.01		Juv. medium reef assoc.	Detritus	8.49	6.74	2.72	4.66	8.10
Other tuna	0.01	< 1E-2	< 1E-2	0.01	0.01		Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Mackerel	0.01	< 1E-2	< 1E-2	0.01	0.01		Sub. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Billfish	0.01	< 1E-2	< 1E-2	0.01	0.01		Juv. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Juv. coral trout	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. snappers	0.01	0.01	1.47	< 1E-2	0.01	
Ad. large sharks	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Juv. large sharks						0.10	Juv. coral trout	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Ad. small sharks	< 1E-2	< 1E-2	< 1E-2	0.01	0.01		Juv. rays	< 1E-2	0.01	0.02	< 1E-2	0.01	
Adult rays	0.01	< 1E-2	< 1E-2	< 1E-2	0.01		Juv. butterflyfish	< 1E-2	0.01	0.02	< 1E-2	0.01	
Juv. rays	0.01	< 1E-2	0.05	0.05	0.10		Juv. large reef assoc.	0.05	0.20	0.12	0.07	0.20	
Ad. butterflyfish	0.02	0.20	0.20	0.21	0.20		Ad. medium reef assoc.	1.17	1.20	1.45	0.87	1.20	
Juv. butterflyfish	< 1E-2	0.05	0.05	0.05	0.05		Juv. medium reef assoc.	1.50	1.20	1.96	0.84	1.20	
Cleaner wrasse	< 1E-2	< 1E-2	< 1E-2	0.01	0.01		Ad. small reef assoc.	0.10	0.10	0.17	0.10	0.10	
Ad. large pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. small reef assoc.	1.00	0.10	0.17	0.10	0.10	
Juv. large pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. large demersal	0.05	0.05	0.03	0.02	0.05	
Ad. medium pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Ad. small demersal	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Ad. small pelagic	0.10	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Ad. large planktivore	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Ad. large reef assoc.	0.12	0.10	0.08	0.09	0.10		Juv. large planktivore	0.68	0.30	0.48	0.29	0.30	
Juv. large reef assoc.	0.10	0.40	0.12	0.13	0.40		Ad. small planktivore	0.02	0.02	< 1E-2	0.01	0.02	
Ad. medium reef assoc.	1.00	1.29	0.96	0.99	1.30		Juv. small planktivore	0.20	0.20	< 1E-2	0.20	0.20	
Juv. medium reef assoc.	1.00	4.26	3.72	1.44	2.00		Ad. anchovy	0.02	0.02			0.02	
Ad. small reef assoc.	2.00	0.99	0.99	1.03	1.00		Juv. anchovy			0.01	< 1E-2		
Juv. small reef assoc.	1.00	0.10	0.10	0.10	0.10		Ad. deepwater fish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Ad. large demersal	0.01	< 1E-2	< 1E-2	< 1E-2	0.01		Juv. macro algal browsing	0.10	0.10	0.08	0.05	0.10	
Juv. large demersal	0.10	0.10	0.03	0.03	0.10		Juv. eroding grazers			0.08	0.05		
Ad. small demersal	0.20	0.10	< 1E-2	0.03	0.10		Juv. scraping grazers	0.57	0.60	3.92	1.46	0.60	
Ad. large planktivore	0.10	0.06	0.06	0.06	0.06		Detritivore fish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Juv. large planktivore	0.10	0.40	0.46	0.47	0.40		Azooxanthellate corals	0.11	0.10	0.08	0.05	0.10	
Ad. small planktivore	0.01	0.20	0.02	0.08	0.20		Hermatypic corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Juv. small planktivore	0.10	0.30	0.03	0.36	0.30		Non reef building corals	0.09	0.20	0.08	0.05	0.20	
Ad. anchovy	1.00	1.98	0.03	0.03	1.00		Soft corals	0.10	0.30	0.23	0.14	0.30	
Juv. anchovy	0.50	0.99	0.01	0.16	0.06		Anemonies	< 1E-2	0.01	< 1E-2	< 1E-2	< 1E-2	0.01
Ad. deepwater fish	0.09	< 1E-2	< 1E-2	< 1E-2	0.01		Penaeid shrimps			0.03	0.02		
Juv. deepwater fish	0.05	0.09	0.04	0.04	0.10		Shrimps and prawns	0.09	0.09	0.11	0.06	0.09	
Ad. macro algal browsing	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Squid	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Juv. macro algal browsing	0.20	0.20		0.12	0.20		Octopus	0.10	0.50	0.77	0.47	0.50	
Ad. eroding grazers	0.06	< 1E-2	0.28	< 1E-2	< 1E-2	< 1E-2	Sea cucumbers	0.11	0.10	0.19	0.11	0.10	
Juv. eroding grazers	0.02	< 1E-2	0.11	0.12	< 1E-2	< 1E-2	Lobsters	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Ad. scraping grazers	0.05	0.69	0.81	0.84	0.70		Large crabs	0.01	0.01	0.02	0.01	0.01	
Juv. scraping grazers	0.35	0.99	5.59	1.19			Small crabs	0.04	0.04	0.06	0.03	0.04	
Detritivore fish	< 1E-2	< 1E-2	0.02	0.02	0.02		Crown of thorns	< 1E-2	< 1E-2	0.02	< 1E-2	< 1E-2	< 1E-2
Azooxanthellate corals	0.02	0.50	0.20	0.21	0.50		Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Hermatypic corals	0.03	0.03	< 1E-2	< 1E-2	0.03		Herbivorous echinoids	0.01	0.10	0.26	0.16	0.20	
Non reef building corals	0.08	0.59	0.17	0.18	0.60		Bivalves	0.46	0.50	0.84	0.51	0.50	
Soft corals	0.15	0.69	< 1E-2	0.31	0.70		Sessile filter feeders	0.40	0.60	0.75	0.45	0.60	
Anemonies	< 1E-2	< 1E-2	< 1E-2	< 1E-2	0.01		Epifaunal det. inverts.	0.01	0.10	0.12	0.07	0.10	
Penaeid shrimps			0.99	1.03			Epifaunal carn. inverts	0.10	1.90	3.12	1.88	1.90	
Shrimps and prawns	0.10	1.98	0.85	3.49	5.00		Infauanal inverts.	5.23	5.19	8.85	5.34	5.20	
Squid	0.01	0.50	0.40	0.41	0.50		Jellyfish and hydroids	0.39	0.40	0.27	2.00	0.40	
Octopus	0.35	0.30	1.04	1.08	0.30		Carn. zooplankton	5.61	5.59	< 1E-2	19.82	5.60	
Sea cucumbers	0.08	0.20	0.23	0.24	0.20		Large herb. zooplankton	4.55	1.90	1.21	19.82	1.90	
Lobsters	< 1E-2	< 1E-2	< 1E-2	< 1E-2	0.01		Small herb. zooplankton	3.74	3.80	28.17	16.99	3.70	
Large crabs	0.02	0.20	0.21	0.21	0.20		Phytoplankton	0.05	0.05	28.17	16.99	0.05	
Small crabs	0.05	0.40	0.96	1.00	1.20		Macro algae	33.58	33.56	5.40	2.97	33.60	
Crown of thorns	0.01	0.20	0.09	0.20	0.20		Sea grass	30.00	35.76	4.92	2.97	35.80	
Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Fishery discards	< 1E-2	0.06	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Herbivorous echinoids	0.01	0.10	0.16	0.16	0.20		Detritus	9.69	4.99	6.32	4.98	4.90	
Bivalves	2.08	3.97	4.19	4.34	4.00		Juv. groupers	< 1E-2	0.06	0.07	0.06	< 1E-2	< 1E-2
Sessile filter feeders	2.00	4.96	6.39	6.63	5.00		Juv. snappers	0.05	0.20	0.23	0.20	0.20	
Epifaunal det. inverts.	0.50	0.50	0.77	0.80	0.50		Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Epifaunal carn. inverts	6.22	9.91	14.24	14.74	14.30		Juv. coral trout	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Infauanal inverts.	13.50	13.98	13.27	13.72	11.40		Juv. rays	0.01	< 1E-2	< 1E-2	0.01	0.10	
Jellyfish and hydroids	2.00	0.50	0.49	0.51	0.50		Juv. butterflyfish	0.01	0.10	< 1E-2	0.10	0.10	
Carn. zooplankton	11.80	9.42	9.41	9.75	9.50		Juv. large reef assoc.	0.34	0.30	0.14	0.12	0.30	

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Juv. medium reef assoc.	0.07	0.03	0.99	0.02	0.03		Lobsters	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. small reef assoc.	1.20						Large crabs	< 1E-2	< 1E-2	< 1E-2	0.01	< 1E-2
	Juv. small reef assoc.	0.80	0.70	0.74	0.66	0.70		Small crabs	0.09	0.01	< 1E-2	0.01	0.01
	Juv. large demersal	0.34	0.30	0.02	0.02	0.10		Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. small demersal	0.34	0.30	0.02	0.04	0.30		Bivalves			< 1E-2	< 1E-2	
	Juv. large planktivore	0.34	0.30	0.35	0.31	0.30		Sessile filter feeders	0.20	0.70	0.82	0.80	0.70
	Juv. small planktivore	0.34	0.30	0.03	0.10	0.30		Epifaunal det. inverts.	0.10	0.20	0.17	0.16	0.20
	Juv. macro algal browsing	0.34	0.30	0.10	0.17	0.30		Epifaunal carn. inverts	2.61	1.90	2.77	2.73	1.90
	Juv. eroding grazers	< 1E-2	< 1E-2	0.13	2.98	< 1E-2		Infaunal inverts.	11.51	17.10	25.08	24.67	17.10
	Juv. scraping grazers	1.57	1.60	8.26	7.37	2.00		Jellyfish and hydroids	< 1E-2	< 1E-2	< 1E-2	0.01	< 1E-2
	Azooxanthellate corals	0.10	2.00	0.10	0.82	2.00		Carn. zooplankton	9.40	9.40	21.83	21.47	9.40
	Hermatypic corals	0.07	0.07	0.02	0.02	0.07		Large herb. zooplankton	6.70	5.00	3.64	3.58	5.00
	Non reef building corals	0.50	1.60	0.18	0.46	1.60		Small herb. zooplankton	10.09	7.60	25.46	25.05	7.60
	Soft corals	0.02	0.02	0.09	0.08	0.02		Phytoplankton	0.56		3.67	3.61	
	Anemonies	0.01	0.10	0.05	0.04	0.10		Macro algae	22.68	21.70	4.36	4.29	21.70
	Penaeid shrimps			0.58	0.52			Sea grass	19.51	14.28	4.36	4.29	14.30
	Shrimps and prawns	0.50	2.60	1.99	1.78	2.60		Fishery discards	< 1E-2	0.01	< 1E-2	< 1E-2	0.01
	Squid	0.11	0.10	0.10	0.09	0.10		Detritus	15.04	15.00	1.45	1.43	15.00
	Octopus	0.03	0.03	0.42	0.37	0.03	Ad. large demersal	Ad. groupers	0.02	0.02	0.02	0.02	0.02
	Sea cucumbers	0.03	0.03	0.04	0.03	0.03		Sub. groupers	0.10	0.10	0.10	0.10	0.10
	Lobsters	0.01	0.10	< 1E-2	< 1E-2	0.10		Ad. snappers	0.39	0.40	0.40	0.39	0.40
	Large crabs	0.10	0.20	0.18	0.16	0.20		Sub. snappers	0.39	0.40	0.40	0.39	0.40
	Small crabs	0.17	0.20	0.17	0.15	0.20		Ad. butterflyfish	1.06	1.10	1.08	1.06	1.10
	Crown of thorns	0.03	0.03	0.03	0.03	0.03		Juv. butterflyfish	0.50	1.10	1.08	1.06	1.10
	Giant triton	0.01	0.05	0.04	0.04	0.05		Cleaner wrasse	0.09	0.09	0.09	0.09	0.09
	Herbivorous echinoids	0.02	0.02	0.02	0.02	0.02		Ad. large reef assoc.	2.76	2.70	2.97	1.89	2.70
	Bivalves	0.56	0.60	0.71	0.63	0.60		Juv. large reef assoc.	2.12	2.10	0.76	0.74	2.10
	Sessile filter feeders	2.68	2.70	2.44	2.18	2.70		Ad. medium reef assoc.	2.00	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Epifaunal det. inverts.	0.01	1.00	0.54	0.49	1.00		Ad. small reef assoc.	1.81	1.80	1.86	1.81	1.80
	Epifaunal carn. inverts	5.00	12.10	6.69	5.96	12.10		Juv. small reef assoc.	3.00	1.00	1.02	1.00	1.00
	Infaunal inverts.	9.94	10.10	12.20	10.89	9.90		Ad. large demersal	0.08	0.08	0.06	0.06	0.08
	Jellyfish and hydroids	0.09	0.09	0.10	0.09	0.09		Ad. small demersal	0.87	0.90	0.27	0.26	0.90
	Carn. zooplankton	9.92	4.60	16.71	14.90	4.60		Juv. small demersal	5.00				
	Large herb. zooplankton	5.01	2.80	8.35	14.90	2.80		Ad. large planktivore	1.00	0.90	0.89	0.87	0.90
	Small herb. zooplankton	8.78	8.80	16.71	14.90	8.80		Juv. large planktivore			0.80	0.78	
	Phytoplankton	9.01	8.00	11.12	9.93	8.00		Ad. small planktivore	1.56	1.60	0.41	0.78	1.60
	Macro algae	16.83	16.80	3.33	2.98	16.80		Ad. anchovy	0.39	0.40	0.43	0.43	0.40
	Sea grass	17.85	17.93	3.33	2.98	17.90		Juv. anchovy	0.87	1.00	0.93	0.91	0.90
	Fishery discards	0.01	0.03	< 1E-2	< 1E-2	< 1E-2		Ad. deepwater fish	0.77	0.56	0.24	0.23	0.80
	Detritus	6.84	2.80	2.67	2.39	2.80		Juv. deepwater fish	0.77	0.72	0.32	0.31	0.80
Juv. small reef assoc.	Juv. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. macro algal browsing	0.01	0.01	< 1E-2	0.01	0.01
	Juv. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. scraping grazers	1.89	1.90	1.94	1.89	1.90
	Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. scraping grazers			1.00	0.87	
	Juv. rays	< 1E-2	0.01	< 1E-2	0.01	0.01		Detritivore fish	0.16	0.20	< 1E-2	3.00	0.20
	Juv. butterflyfish	< 1E-2	0.01	< 1E-2	0.01	0.01		Penaeid shrimps			15.08	14.75	
	Juv. large reef assoc.	0.01	0.30	0.17	0.17	0.30		Shrimps and prawns	40.00	73.65	51.31	50.14	73.40
	Ad. medium reef assoc.	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Octopus			9.06	8.85	
	Juv. medium reef assoc.	0.04	0.04	0.99	0.04	0.04		Lobsters	0.04	0.04	0.03	0.03	0.04
	Ad. small reef assoc.	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Large crabs	0.32	0.30	0.30	0.29	0.30
	Juv. small reef assoc.	0.50	0.02	0.03	0.03	0.02		Small crabs	1.01	1.00	0.88	0.86	1.00
	Juv. large demersal	0.01	0.01	< 1E-2	< 1E-2	0.01		Giant triton	0.05	0.05	0.04	0.04	0.05
	Ad. small demersal	0.01	0.01	< 1E-2	< 1E-2	0.01		Bivalves			0.20	0.19	
	Juv. small demersal	0.11	0.10	0.03	0.06	0.10		Epifaunal det. inverts.	0.30	0.40	0.28	0.27	0.40
	Juv. large planktivore	0.10	2.60	1.46	4.32	2.60		Epifaunal carn. inverts	0.39	0.40	0.40	0.39	0.40
	Ad. small planktivore	0.04	0.04	< 1E-2	0.03	0.04		Infaunal inverts.	10.35	5.10	5.38	5.27	5.10
	Juv. small planktivore	0.10	0.50	< 1E-2	0.14	0.50		Detritus	19.95				
	Ad. anchovy	0.10	2.00	0.71	0.70	2.00	Juv. large demersal	Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. anchovy	0.01	1.00	1.52	1.50	1.00		Sub. groupers	0.01	0.01	< 1E-2	0.01	0.01
	Ad. deepwater fish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. butterflyfish	0.05	0.05	0.05	0.05	0.05
	Juv. macro algal browsing	0.10	0.10	0.07	0.07	0.10		Juv. butterflyfish	0.05	0.05	0.05	0.05	0.05
	Juv. eroding grazers	< 1E-2	< 1E-2	0.07	0.07	< 1E-2		Ad. large reef assoc.	0.61	0.60	0.41	0.43	0.60
	Juv. scraping grazers	0.01	0.01	0.99	0.42			Juv. large reef assoc.	3.10	3.09	1.05	1.09	3.10
	Azooxanthellate corals	0.06	0.06	0.03	0.03	0.06		Ad. medium reef assoc.	2.00	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Hermatypic corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. medium reef assoc.	1.00	1.00	0.67	0.70	1.00
	Non reef building corals	0.06	0.06	0.02	0.02	0.06		Ad. small reef assoc.	0.23	0.20	0.22	0.23	0.20
	Soft corals	0.11	0.10	0.07	0.07	0.10		Juv. small reef assoc.	1.06	1.80	1.69	1.76	1.80
	Penaeid shrimps			0.03	0.03			Ad. large demersal	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Shrimps and prawns	0.09	0.09	0.09	0.09	0.09		Ad. small demersal	0.40	0.40	0.12	0.12	0.40
	Squid	0.01	0.01	< 1E-2	0.01	0.01		Ad. large planktivore	0.47	0.50	0.45	0.47	0.50
	Octopus			0.02	0.02			Juv. large planktivore			0.15	0.16	

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Ad. small planktivore	0.33	0.30	0.08	0.16	0.30		Juv. snappers	0.02	0.02	0.02	0.02	0.02
	Ad. anchovy	0.81	0.80	0.22	0.23	0.80		Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. anchovy	0.47	1.00	0.53	0.55	0.50		Juv. coral trout	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. deepwater fish	0.61	0.42	0.17	0.18	0.60		Juv. rays	< 1E-2	0.10	0.46	0.46	0.40
	Juv. deepwater fish	1.08	0.99	0.41	0.43	1.10		Juv. butterflyfish	0.02	0.10	0.12	0.12	0.10
	Ad. scraping grazers	0.55	0.50	0.53	0.55	0.50		Juv. large reef assoc.	0.60	2.01	0.80	0.80	2.00
	Juv. scraping grazers			4.82	1.15			Ad. medium reef assoc.	2.00	0.10	0.11	0.11	0.10
	Detritivore fish	0.05	0.05	0.05	0.05	0.05		Juv. medium reef assoc.	2.00	7.06	5.36	5.36	6.70
	Penaeid shrimps			0.26	0.27			Ad. small reef assoc.	1.30	1.21	1.38	1.38	1.20
	Shrimps and prawns	1.37	1.40	0.90	0.93	1.40		Juv. small reef assoc.	0.90	0.20	0.23	0.23	0.20
	Octopus			0.15	0.16			Juv. large demersal	0.30	0.30	0.11	0.11	0.30
	Lobsters	0.04	0.04	0.03	0.03	0.04		Ad. small demersal	0.50	0.02	< 1E-2	< 1E-2	0.02
	Large crabs	0.01	0.01	< 1E-2	0.01	0.01		Juv. small demersal	2.00	0.20	0.09	0.09	0.20
	Small crabs	0.05	0.05	0.05	0.05	0.05		Juv. large planktivore	0.50	2.82	3.36	3.36	2.80
	Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. small planktivore	0.70	0.30	0.09	0.09	0.30
	Bivalves	0.27	0.30	0.27	0.28	0.30		Juv. small planktivore	1.00	1.01	1.15	1.15	1.00
	Epifaunal det. inverts.	1.07	1.10	0.72	0.75	1.10		Ad. anchovy	1.00	9.76	1.28	1.28	9.70
	Epifaunal carn. inverts	13.86	13.97	13.46	13.97	14.00		Juv. anchovy	1.00	2.31	3.72	3.72	2.30
	Infaunal inverts.	12.07	13.97	13.77	14.29	14.00		Ad. deepwater fish	0.60	1.26	0.63	0.63	1.80
	Carn. zooplankton	15.71	15.67	15.14	15.71	15.70		Juv. deepwater fish	0.01	1.50	1.12	1.12	1.00
	Large herb. zooplankton	15.71	15.67	7.58	7.86	15.70		Juv. macro algal browsing	0.10	0.10	0.06	0.06	0.10
	Small herb. zooplankton	15.75	15.67	22.76	23.61	15.70		Juv. eroding grazers	< 1E-2	< 1E-2	0.06	0.06	< 1E-2
	Detritus			3.08	3.20			Juv. scraping grazers	1.07	1.11	2.12	2.12	1.10
Ad. small demersal	Juv. groupers	< 1E-2	0.07	0.08	0.07	0.07		Detritivore fish	0.02	0.05	0.05	0.05	0.05
	Juv. snappers	0.10	0.41	0.44	0.37	0.40		Penaeid shrimps			0.23	0.22	
	Juv. Napoleon wrasse	0.03	0.03	0.04	0.03	0.03		Shrimps and prawns	0.98	1.01	0.77	0.76	1.00
	Juv. coral trout	< 1E-2	0.01	0.01	0.01	0.01		Squid	0.15	0.20	0.14	0.14	0.20
	Juv. rays	0.05	< 1E-2	0.51	0.43	0.40		Octopus	2.00	1.51	1.93	1.93	1.50
	Juv. butterflyfish	0.05	0.20	0.24	0.20	0.20		Sea cucumbers	0.50	1.61	1.83	1.83	1.60
	Ad. large reef assoc.	0.72	0.71	0.60	0.50	0.70		Lobsters	0.04	0.04	0.03	0.03	0.04
	Juv. large reef assoc.	0.77	2.23	0.90	0.76	2.20		Large crabs	0.04	0.04	0.04	0.04	0.04
	Ad. medium reef assoc.	1.00	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Small crabs	0.30	0.70	0.72	0.72	0.70
	Juv. medium reef assoc.	1.00	2.33	1.93	1.62	2.30		Crown of thorns	0.16	0.20	0.19	0.19	0.20
	Ad. small reef assoc.	0.79	0.81	0.94	0.79	0.80		Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. small reef assoc.	1.00	0.41	0.48	0.40	0.40		Herbivorous echinoids	0.10	1.01	0.92	0.92	1.00
	Ad. large demersal	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Bivalves	3.45	3.92	4.80	4.80	3.90
	Juv. large demersal	2.00	1.01	0.39	0.33	0.50		Sessile filter feeders	4.81	3.02	2.81	2.81	3.00
	Ad. small demersal	1.00	2.03	0.72	0.60	1.00		Epifaunal det. inverts.	1.00	1.68	0.81	0.81	1.00
	Juv. small demersal	2.50	2.03	0.89	0.75	2.50		Epifaunal carn. inverts	12.33	12.08	13.84	13.83	12.00
	Ad. large planktivore	3.72	3.75	4.44	3.72	3.70		Infaunal inverts.	18.33	18.01	21.74	21.71	17.70
	Juv. large planktivore	0.50	1.42	2.41	2.03	1.40		Macro algae	23.71	23.43	26.88	26.85	23.30
	Ad. small planktivore	0.50	1.22	0.35	0.60	1.20		Sea grass					1.40
	Juv. small planktivore	2.50	3.04	1.79	3.00	3.00		Detritus	16.48				
	Ad. anchovy	1.00	17.35	0.42	0.35	17.20	Ad. large planktivore	Ad. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. anchovy	0.72	0.71	2.89	2.43	0.70		Sub. groupers	0.01	0.01	0.01	0.01	0.01
	Ad. deepwater fish	1.00	1.62	0.82	0.69	2.30		Juv. groupers	< 1E-2	0.01	0.01	0.01	0.01
	Juv. deepwater fish	0.10	2.29	1.18	1.00	1.00		Ad. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. macro algal browsing	3.00	2.03	1.18	1.00	3.00		Sub. snappers	0.01	0.01	0.01	0.01	0.01
	Juv. eroding grazers	0.50	0.10	1.31	1.10	0.10		Juv. snappers	0.01	0.01	0.01	0.01	0.01
	Juv. scraping grazers	1.00	0.41	2.31	1.94	0.40		Juv. Napoleon wrasse	0.01	0.01	< 1E-2	< 1E-2	0.01
	Detritivore fish	0.02	0.10	< 1E-2	14.20	0.10		Skipjack tuna	0.08	0.08	0.09	0.08	0.08
	Penaeid shrimps			1.75	1.47			Other tuna	0.91	0.90	0.01	0.01	0.10
	Shrimps and prawns	3.00	7.41	5.93	4.99	7.30		Mackerel	0.20	0.50	0.01	0.01	0.10
	Squid	1.00	1.52	1.46	1.22	1.50		Billfish	0.34	0.40	0.37	0.34	0.40
	Octopus	3.50	2.44	4.33	3.63	2.40		Juv. coral trout	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Sea cucumbers	1.35	7.41	8.74	7.34	7.30		Juv. large sharks	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Lobsters	0.05	0.10	0.09	0.08	0.10		Juv. small sharks	0.02	0.02	0.02	0.02	0.02
	Large crabs	0.70	0.10	0.10	0.09	0.10		Juv. rays	0.02	0.02	0.02	0.02	0.02
	Small crabs	0.60	2.23	2.23	1.87	2.20		Ad. butterflyfish	0.20	0.40	< 1E-2	0.40	0.40
	Crown of thorns	0.50	0.51	0.63	0.53	0.50		Juv. butterflyfish	0.03	0.10	0.11	0.10	0.10
	Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Cleaner wrasse	0.03	0.03	0.03	0.03	0.03
	Herbivorous echinoids	1.00	1.82	2.12	1.77	2.20		Ad. large pelagic	0.03	0.03	0.03	0.03	0.03
	Bivalves	2.00	1.42	2.66	2.23	1.40		Juv. large pelagic	0.03	0.02	< 1E-2	< 1E-2	0.02
	Sessile filter feeders	2.00	1.62	1.37	1.16	1.40		Ad. medium pelagic	< 1E-2	0.10	< 1E-2	< 1E-2	< 1E-2
	Epifaunal det. inverts.	4.00	1.82	1.20	1.01	1.40		Juv. medium pelagic	< 1E-2	< 1E-2	0.30	< 1E-2	< 1E-2
	Epifaunal carn. inverts	16.70	5.09	5.78	4.85	4.80		Ad. small pelagic	0.05	0.05	0.01	0.01	0.05
	Infaunal inverts.	16.61	15.02	18.49	15.52	15.10		Juv. small pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Macro algae	3.00						Ad. large reef assoc.	0.10	0.10	0.08	0.07	0.10
	Detritus	18.40	5.18	15.85	13.30	6.70		Juv. large reef assoc.	0.20	2.31	0.43	0.40	2.30
Juv. small demersal	Juv. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. medium reef assoc.	0.20	0.20	0.16	0.15	0.20

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Juv. medium reef assoc.	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. deepwater fish	0.01	0.45	0.21	0.21	0.01
	Ad. small reef assoc.	0.34	0.30	0.37	0.34	0.30		Juv. macro algal browsing	0.13	0.10	0.07	0.07	0.50
	Juv. small reef assoc.	0.30	0.50	0.54	0.50	0.50		Juv. eroding grazers	< 1E-2	< 1E-2	0.07	0.07	< 1E-2
	Ad. large demersal	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. scraping grazers	0.86	0.90	1.41	1.36	2.10
	Juv. large demersal	0.01	0.01	< 1E-2	< 1E-2	0.01		Penaeid shrimps			0.23	0.22	
	Ad. small demersal	0.11	0.10	< 1E-2	0.03	0.10		Shrimps and prawns	1.06	1.10	0.77	0.74	1.10
	Juv. small demersal	0.01	0.01	< 1E-2	< 1E-2	0.01		Squid	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. large planktivore	0.50	0.50	0.54	0.50	0.50		Octopus			0.14	0.13	
	Juv. large planktivore	< 1E-2	< 1E-2	0.26	0.24	< 1E-2		Lobsters	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. small planktivore	0.87	0.50	0.02	0.24	0.50		Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. small planktivore	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Small crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. anchovy	0.34	0.30	< 1E-2	< 1E-2	0.30		Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. anchovy	0.02	0.02	0.06	0.05	0.02		Bivalves	3.66	3.70	3.91	3.77	3.70
	Ad. deepwater fish	0.50	0.70	0.45	0.41	0.20		Epifaunal det. inverts.	0.48	0.50	0.36	0.34	0.50
	Juv. deepwater fish	0.10	0.09	0.04	0.04	0.10		Epifaunal carn. inverts	1.23	1.20	1.25	1.21	1.20
	Ad. macro algal browsing	0.02	0.02	0.02	0.01	0.02		Infaunal inverts.	10.59	10.61	11.44	11.05	10.50
	Juv. macro algal browsing	0.01	0.01	< 1E-2	< 1E-2	0.01		Jellyfish and hydroids	0.38	0.40	0.41	0.39	0.40
	Ad. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Carn. zooplankton	28.00	28.02	29.86	28.83	28.00
	Juv. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Large herb. zooplankton	17.68	13.31	7.10	6.86	13.30
	Ad. scraping grazers	0.20	1.00	2.34	2.18	1.00		Small herb. zooplankton	28.80	29.02	38.08	36.75	29.00
	Juv. scraping grazers	0.01	0.01	0.46	0.43	0.01		Phytoplankton	0.02	0.02			0.30
	Detritivore fish	0.03	0.03	0.03	0.03	0.03	Ad. small planktivore	Juv. groupers	0.01	0.01	< 1E-2	< 1E-2	0.01
	Penaeid shrimps			1.72	1.60			Juv. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Shrimps and prawns	2.50	8.04	0.65	5.44	8.00		Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Squid	0.50	1.51	1.30	1.20	1.50		Mackerel	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Octopus	0.01	0.01	1.37	1.27	0.01		Juv. coral trout	0.01	< 1E-2	< 1E-2	< 1E-2	0.01
	Sea cucumbers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. large sharks	0.42	0.05	0.38	0.38	0.40
	Lobsters	0.05	0.05	0.03	0.03	0.05		Juv. small sharks	0.30	0.20	0.27	0.27	0.30
	Large crabs	0.10	0.40	0.10	0.09	0.40		Juv. rays	0.15	< 1E-2	0.14	0.14	0.20
	Small crabs	0.05	0.05	0.04	0.04	0.05		Juv. butterflyfish	0.21	0.20	0.19	0.19	0.20
	Crown of thorns	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. large pelagic	0.18	0.20	< 1E-2	< 1E-2	0.20
	Giant triton	0.01	0.10	< 1E-2	< 1E-2	0.10		Ad. medium pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Herbivorous echinoids	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. medium pelagic	0.05	0.05	0.05	0.05	0.05
	Bivalves	0.69	0.70	0.76	0.70	0.70		Ad. small pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Sessile filter feeders	3.15	3.11	2.71	2.52	3.10		Juv. small pelagic	0.08	0.08	0.07	0.07	0.08
	Epifaunal det. inverts.	0.65	0.60	0.42	0.39	0.60		Juv. large reef assoc.	0.21	0.20	0.07	0.07	0.20
	Epifaunal carn. inverts		4.12	4.43	4.11	4.10		Juv. medium reef assoc.	0.02	0.02	0.01	0.01	0.02
	Infaunal inverts.	6.86	4.09	4.91	4.57	3.80		Juv. small reef assoc.	0.05	0.09	0.08	0.08	0.09
	Jellyfish and hydroids	3.10	2.51	0.67	2.50	1.50		Juv. large demersal	0.21	0.20	0.06	0.06	0.20
	Carn. zooplankton	23.19	23.22	24.85	23.08	23.10		Juv. small demersal	0.21	0.20	0.07	0.07	0.20
	Large herb. zooplankton	20.74	12.45	6.64	6.18	6.00		Ad. large planktivore	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Small herb. zooplankton	18.34	18.38	26.43	24.52	26.90		Juv. large planktivore	0.32	0.30	0.30	0.30	0.30
	Phytoplankton	3.70	3.52	7.96	7.40	3.50		Juv. small planktivore	0.21	0.20	0.19	0.19	0.20
	Macro algae	3.09	3.11	3.32	3.09	4.30		Ad. anchovy	< 1E-2	< 1E-2	0.19	0.19	< 1E-2
	Sea grass	3.36	3.41	3.62	3.36	3.40		Juv. anchovy	0.42	0.40	0.39	0.39	0.40
	Fishery discards	< 1E-2	0.02	< 1E-2	< 1E-2	< 1E-2		Ad. deepwater fish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Detritus	2.62	0.90	0.98	0.91	0.90		Juv. deepwater fish	0.42	0.36	0.15	0.15	0.40
Juv. large planktivore	Juv. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. macro algal browsing	0.21	0.20	0.10	0.10	0.20
	Juv. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. eroding grazers	< 1E-2	< 1E-2	0.10	0.10	< 1E-2
	Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. scraping grazers	0.76	0.80	0.82	0.82	0.80
	Juv. coral trout	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Anemonies	0.02	0.02	< 1E-2	< 1E-2	0.02
	Juv. large sharks	0.03	0.02	0.03	0.03	0.03		Penaeid shrimps			0.04	0.04	
	Juv. small sharks	0.03	0.04	0.03	0.03	0.03		Shrimps and prawns	0.21	0.20	0.13	0.13	0.20
	Juv. rays	0.01	0.01	0.01	0.01	0.01		Squid	0.11	0.10	0.08	0.08	0.10
	Juv. butterflyfish	0.01	0.01	0.01	0.01	0.01		Octopus	0.02	0.02	0.06	0.06	0.02
	Cleaner wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Sea cucumbers	0.02	0.02	0.02	0.02	0.02
	Juv. large pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Lobsters	0.05	0.05	0.03	0.03	0.05
	Juv. medium pelagic	0.01	0.01	0.10	< 1E-2	0.01		Large crabs	0.05	0.05	0.04	0.04	0.05
	Juv. small pelagic	0.09	0.09	< 1E-2	0.09	0.09		Small crabs	0.11	0.10	0.08	0.08	0.10
	Juv. large reef assoc.	0.40	1.30	0.47	0.45	1.30		Crown of thorns	0.02	0.02	0.02	0.02	0.02
	Ad. medium reef assoc.	0.20	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. medium reef assoc.	1.61	1.60	1.20	1.16	0.50		Herbivorous echinoids	0.01	0.01	0.01	0.01	0.01
	Juv. small reef assoc.	0.07	0.10	0.13	0.12	0.10		Bivalves	0.02	0.02	0.04	0.04	0.02
	Juv. large demersal	0.01	0.01	< 1E-2	< 1E-2	0.01		Sessile filter feeders	1.07	1.10	0.78	0.78	1.10
	Juv. small demersal	0.09	0.09	< 1E-2	0.03	0.09		Epifaunal det. inverts.	0.90	1.10	0.58	0.58	0.90
	Juv. large planktivore	1.00	4.00	0.71	4.12	4.00		Epifaunal carn. inverts	6.66	6.69	6.08	6.08	6.70
	Juv. small planktivore	0.01	0.01	0.01	0.01	0.01		Infaunal inverts.	6.66	6.69	6.52	6.52	6.70
	Ad. anchovy	2.00	2.00	0.52	0.50	2.00		Jellyfish and hydroids	0.09	0.08	0.08	0.08	0.09
	Juv. anchovy	1.00	1.00	1.28	1.24	1.00		Carn. zooplankton	28.68	28.65	27.26	27.26	28.60
	Ad. deepwater fish	0.50	0.35	0.16	0.15	0.20		Large herb. zooplankton	0.94	1.30	27.26	27.26	0.90

Table D.3.1 Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
Juv. small planktivore	Small herb. zooplankton	28.75	28.81	26.67	26.67	28.70	Juv. deepwater fish	Sub. Napoleon wrasse	0.02	0.02	0.02	0.02	0.02
	Macro algae	10.57	10.58	0.27	0.27	10.60		Skipjack tuna	2.93	2.82	2.03	2.83	2.80
	Sea grass	10.57	10.58	0.27	0.27	10.60		Other tuna	2.83	2.82	< 1E-2	1.20	0.40
	Juv. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Mackerel	1.00	1.01	< 1E-2	1.80	1.00
	Juv. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Billfish	0.10	2.82	3.74	2.83	2.80
	Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. coral trout					1.00
	Juv. coral trout	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. small sharks	< 1E-2	0.07	0.10	0.07	0.07
	Juv. large sharks	0.11	0.03	0.13	0.13	0.10		Juv. small sharks	0.30	0.20	0.26	0.20	0.30
	Juv. small sharks	0.11	0.10	0.13	0.13	0.10		Adult rays	1.00	1.01	1.05	0.80	1.60
	Juv. rays	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. butterflyfish	0.10	0.02	0.02	0.01	0.02
	Juv. butterflyfish	0.05	0.05	0.06	0.06	0.05		Juv. butterflyfish	0.20	0.30	0.40	0.30	0.60
	Juv. large pelagic	0.03	0.03	0.04	0.04	0.03		Cleaner wrasse	0.10	0.10	0.02	0.40	0.10
	Juv. medium pelagic	0.01	0.01	0.01	0.01	0.01		Ad. large pelagic	0.20	0.03	0.04	0.03	0.03
	Juv. small pelagic	0.02	0.02	0.02	0.02	0.02		Juv. large pelagic	0.20	0.10	0.01	0.01	0.10
	Juv. large reef assoc.	0.10	0.10	0.04	0.04	0.10		Ad. medium pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. medium reef assoc.	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. small pelagic	0.20	0.20	0.07	0.20	0.20
	Juv. small reef assoc.	0.01	0.02	0.02	0.02	0.02		Juv. small pelagic	0.33	0.30	0.44	0.33	0.30
	Juv. large demersal	0.01	0.01	< 1E-2	< 1E-2	0.01		Ad. large reef assoc.	6.39	2.01	1.89	1.41	2.00
	Juv. small demersal	0.10	0.10	0.04	0.04	0.10		Juv. large reef assoc.	1.00	2.41	1.09	0.83	2.40
	Juv. large planktivore	0.07	0.07	0.08	0.08	0.07		Ad. medium reef assoc.	1.00	0.50	0.52	0.39	0.50
	Juv. small planktivore	0.03	0.03	0.03	0.03	0.03		Juv. medium reef assoc.	1.00	1.01	0.93	0.70	1.00
	Ad. anchovy			0.07	0.07			Ad. small reef assoc.	0.71	0.70	0.94	0.71	0.70
	Juv. anchovy	0.11	0.10	0.14	0.14	0.10		Juv. small reef assoc.	1.01	1.01	1.31	1.00	1.00
	Juv. deepwater fish	0.12	0.09	0.05	0.05	0.10		Ad. large demersal	1.00	0.01	0.01	< 1E-2	0.01
	Juv. macro algal browsing	0.10	0.10	0.06	0.06	0.10		Ad. small demersal	3.60	0.20	0.01	0.30	1.00
	Juv. eroding grazers	< 1E-2	< 1E-2	0.06	0.06	< 1E-2		Juv. small demersal	1.00	0.20	0.10	0.08	0.20
	Juv. scraping grazers	0.10	0.10	0.18	0.18	0.10		Ad. large planktivore	0.45	0.50	0.60	0.45	0.50
	Azooxanthellate corals	0.05	0.05	0.02	0.02	0.05		Juv. large planktivore			0.68	0.51	
	Hermatypic corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Ad. small planktivore	0.80	1.01	< 1E-2	0.51	1.00
	Non reef building corals	0.03	0.03	< 1E-2	< 1E-2	0.03		Juv. small planktivore	1.00	1.01	0.01	1.00	1.00
	Soft corals	0.05	0.05	0.03	0.03	0.05		Ad. anchovy	2.00	4.32	0.25	0.19	2.50
	Penaeid shrimps			0.02	0.02			Juv. anchovy	0.50	0.40	0.85	0.65	0.40
Shrimps and prawns	0.09	0.09	0.07	0.07	0.09	Ad. deepwater fish	1.00	0.70	3.25	7.34	1.00		
Octopus			0.01	0.01		Juv. deepwater fish	0.10	1.81	1.05	0.80	2.00		
Lobsters	0.02	0.02	0.01	0.01	0.02	Ad. macro algal browsing	0.87	0.40	0.49	0.37	1.40		
Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. macro algal browsing	1.00	2.01	0.66	0.50	2.00		
Small crabs	0.02	0.02	0.02	0.02	0.02	Ad. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. eroding grazers			0.66	0.50			
Bivalves			< 1E-2	< 1E-2		Ad. scraping grazers	0.26	0.30	0.35	0.26	0.30		
Sessile filter feeders	1.45	1.40	1.38	1.38	1.40	Juv. scraping grazers			2.07	1.55			
Epifaunal det. inverts.	0.34	0.30	0.28	0.28	0.30	Detritivore fish	0.05	0.10	0.14	0.11	0.10		
Epifaunal carn. inverts	0.37	0.40	0.44	0.44	0.40	Penaeid shrimps			1.52	1.14			
Infauanal inverts.	5.85	5.91	7.43	7.43	5.90	Shrimps and prawns	1.00	6.84	5.17	3.89	6.80		
Carn. zooplankton	11.53	12.20	30.00	29.99	11.50	Squid	1.00	2.82	2.94	2.22	2.80		
Large herb. zooplankton	0.62		30.00	29.99	0.60	Octopus			1.66	1.24			
Small herb. zooplankton	14.65	14.63	19.99	19.99	14.60	Lobsters	0.10	0.10	0.09	0.07	0.10		
Phytoplankton	15.81	15.84	8.50	8.50	15.80	Large crabs	0.09	0.09	0.10	0.08	0.09		
Macro algae	28.03	28.05	0.30	0.30	28.10	Small crabs	1.00	3.12	3.49	2.62	3.10		
Sea grass	20.00	20.03	0.30	0.30	20.00	Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Ad. anchovy	Penaeid shrimps	0.01	2.10	2.95	2.15	2.10	Bivalves			0.63	0.47		
	Shrimps and prawns	0.20	0.20	0.19	0.14	0.20	Sessile filter feeders	3.13	3.12	3.31	2.50	3.10	
	Octopus			0.03	0.02		Epifaunal det. inverts.	1.00	2.92	2.74	2.06	2.90	
	Jellyfish and hydroids	0.20	0.80	0.55	0.80	0.40	Epifaunal carn. inverts	13.03	12.96	15.03	11.32	13.40	
	Carn. zooplankton	40.00	40.00	18.28	40.00	40.00	Infauanal inverts.	18.24	17.19	22.95	17.31	16.80	
	Large herb. zooplankton	6.29	3.60	2.46	1.80	3.60	Jellyfish and hydroids	11.10	9.66	3.47	15.69	9.50	
	Small herb. zooplankton	32.00	35.20	50.76	37.02	35.60	Carn. zooplankton	15.92	8.59	10.61	8.00	8.50	
	Phytoplankton	21.30	18.10	24.78	18.07	18.10	Juv. small reef assoc.	0.06	0.10	0.10	0.10	0.10	
	Juv. anchovy	Penaeid shrimps			< 1E-2	< 1E-2		Juv. small planktivore	0.10	0.10	0.10	0.10	0.10
		Shrimps and prawns	0.01	0.01	< 1E-2	< 1E-2	0.01	Ad. anchovy			0.25	0.25	
Octopus				< 1E-2	< 1E-2		Juv. anchovy	1.00	0.50	0.50	0.50	0.50	
Jellyfish and hydroids		< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Juv. deepwater fish	1.00	0.90	0.40	0.40	0.50	
Carn. zooplankton		1.24	1.18	1.24	1.24	1.20	Juv. macro algal browsing	0.05	0.05	0.03	0.03	0.05	
Large herb. zooplankton		0.90	0.90	0.45	0.45	0.90	Juv. eroding grazers			0.03	0.03		
Small herb. zooplankton		9.00	10.00	10.45	10.45	10.00	Penaeid shrimps			0.03	0.03		
Phytoplankton		88.84	87.90	87.84	87.84	87.90	Shrimps and prawns	0.14	0.10	0.09	0.09	0.10	
Ad. groupers		< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2	Squid	0.06	0.06	0.05	0.05	0.06	
Sub. groupers		0.02	0.02	0.03	0.02	0.02	Octopus			0.03	0.03		
Ad. snappers	0.02	0.02	0.02	0.02	0.02	Lobsters	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Sub. snappers	0.11	0.10	0.15	0.11	0.10	Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		
Ad. Napoleon wrasse	0.02	0.02	0.02	0.02	0.02	Small crabs	0.01	0.30	0.26	0.26	0.30		

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Epifaunal carn. inverts	2.21	2.20	2.33	2.20	2.20
	Bivalves			0.05	0.05			Infauanal inverts.	0.55	0.50	1.89	1.78	0.50
	Sessile filter feeders	0.48	0.50	0.39	0.39	0.50		Macro algae	39.32	39.30	56.75	53.57	35.30
	Epifaunal det. inverts.	0.14	0.10	0.10	0.10	0.10		Mangroves	1.10	1.10	1.17	1.10	1.10
	Epifaunal carn. inverts	9.92	10.01	9.97	9.97	10.00	Juv. eroding grazers	Azooxanthellate corals	18.49	18.50	6.99	6.99	18.50
	Infauanal inverts.	12.42	12.41	12.56	12.56	12.40		Hermatypic corals	11.10	11.10	20.98	20.98	11.10
	Jellyfish and hydroids	0.01	0.01	0.01	0.01	0.01		Non reef building corals	18.49	14.00	7.98	7.98	18.50
	Carn. zooplankton	24.00	23.98	23.99	24.00	24.00		Soft corals	18.49	16.50	4.99	4.99	18.50
	Large herb. zooplankton	2.10	15.01	7.50	7.50	15.00		Calcareous algae	0.92	0.90	0.30	0.30	0.90
	Small herb. zooplankton	30.00	30.03	37.48	37.50	30.00		Anemonies			0.02	0.02	
	Phytoplankton			0.36	0.36			Sessile filter feeders			7.10	7.10	
	Macro algae	3.75	3.50	3.46	3.46	4.00		Epifaunal det. inverts.	2.95	4.00	0.70	0.70	2.90
	Detritus	14.75						Epifaunal carn. inverts	3.70	9.10	3.69	3.69	3.70
Ad. macro algal browsing	Juv. butterflyfish	0.22	0.20	0.22	0.22	0.20		Infauanal inverts.	1.83	1.80	3.90	3.90	1.80
	Ad. large pelagic	0.02	0.02	0.02	0.02	0.02		Macro algae	24.04	24.10	43.35	43.34	24.10
	Juv. large pelagic	0.14	0.10	0.01	0.01	0.10	Ad. scraping grazers	Azooxanthellate corals	3.00	2.00	0.18	0.60	3.00
	Ad. medium pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Hermatypic corals	0.10	5.00	< 1E-2	0.20	0.10
	Ad. small pelagic	0.42	0.40	0.10	0.10	0.40		Non reef building corals	2.38	2.00	0.07	0.66	2.40
	Ad. large reef assoc.	0.54	0.50	0.38	0.38	0.50		Soft corals	0.55	1.00	0.06	0.31	0.50
	Juv. large reef assoc.	0.54	0.50	0.19	0.19	0.50		Anemonies	0.11	0.10	0.11	0.02	0.10
	Ad. medium reef assoc.	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Penaeid shrimps			0.11	0.02	
	Ad. small reef assoc.	0.57	0.60	0.58	0.57	0.60		Shrimps and prawns	0.10	0.10	0.09	0.07	0.10
	Juv. small reef assoc.	0.22	0.40	0.37	0.36	0.40		Squid	0.55	0.50	0.04	< 1E-2	0.50
	Ad. large demersal	0.02	0.02	0.01	0.01	0.02		Octopus	0.33	0.30	0.20	0.34	0.30
	Ad. small demersal	1.08	0.10	0.02	0.32	0.10		Sea cucumbers	0.11	0.10	0.58	0.11	0.10
	Ad. large planktivore	0.54	0.50	0.55	0.54	0.50		Lobsters	0.11	0.10	< 1E-2	< 1E-2	< 1E-2
	Juv. large planktivore			1.21	0.69			Large crabs	0.02	0.02	0.09	0.02	0.02
	Ad. small planktivore	1.38	1.40	< 1E-2	0.69	1.40		Small crabs	0.02	0.02	0.08	0.02	0.02
	Juv. small planktivore	2.05	3.10	0.52	2.05	1.00		Crown of thorns	0.09	0.09	< 1E-2	0.09	0.09
	Ad. anchovy	1.08	1.10	0.27	0.26	1.10		Giant triton	0.23	0.20	< 1E-2	< 1E-2	0.01
	Juv. anchovy	0.54	0.50	0.66	0.65	0.50		Herbivorous echinoids	0.11	0.10	0.45	0.09	0.10
	Juv. scraping grazers			0.36	0.35			Bivalves	1.00	1.10	0.36	1.10	1.10
	Epifaunal det. inverts.	0.87	0.90	0.62	0.61	0.90		Sessile filter feeders	0.22	0.20	0.06	0.17	0.20
	Epifaunal carn. inverts	2.16	2.20	2.20	2.16	2.20		Epifaunal det. inverts.	0.22	0.20	0.83	0.16	0.20
	Infauanal inverts.	1.08	1.10	1.36	1.34	1.10		Epifaunal carn. inverts	0.55	0.50	2.89	0.55	0.50
	Carn. zooplankton	5.40	5.40	5.50	5.40	5.40		Infauanal inverts.	0.55	0.50	3.46	0.66	0.50
	Large herb. zooplankton	5.54	5.40	2.75	2.70	5.40		Jellyfish and hydroids	0.26	0.30	0.06	0.26	0.30
	Small herb. zooplankton	5.40	5.40	8.25	8.09	5.40		Carn. zooplankton	0.66	0.70	0.53	0.10	0.70
	Phytoplankton	5.45	5.40	5.80	5.50	7.50		Large herb. zooplankton	0.32	0.30	< 1E-2	0.80	0.30
	Macro algae	53.96	54.00	55.38	54.35	54.00		Small herb. zooplankton	0.66	0.70	3.87	0.73	0.70
	Sea grass	10.79	10.76	12.66	12.43	10.80		Phytoplankton	4.77	4.81	25.15	4.76	4.90
Juv. macro algal browsing	Ad. small pelagic	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Macro algae	39.59	34.95	2.28	41.35	39.70
	Ad. small reef assoc.	0.01	0.01	0.01	0.01	0.01		Sea grass	32.74	33.85	2.36	36.19	32.70
	Juv. small reef assoc.	0.11	0.20	0.19	0.19	0.20		Fishery discards	< 1E-2	0.05	< 1E-2	< 1E-2	< 1E-2
	Ad. small demersal	0.01	0.01	< 1E-2	< 1E-2	0.01		Detritus	10.68	10.21	56.07	10.61	10.80
	Juv. small demersal	0.01	0.01	< 1E-2	< 1E-2	0.01	Juv. scraping grazers	Juv. groupers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. large planktivore			< 1E-2	< 1E-2			Juv. snappers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. small planktivore	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Juv. Napoleon wrasse	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. small planktivore	0.25	0.20		0.25	0.20		Juv. coral trout	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Ad. anchovy	< 1E-2	< 1E-2	0.06	0.06	< 1E-2		Juv. rays	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Juv. anchovy	0.13	0.10	0.13	0.13	0.10		Juv. butterflyfish	0.01	< 1E-2	< 1E-2	0.01	< 1E-2
	Juv. scraping grazers			< 1E-2	< 1E-2			Juv. large reef assoc.	0.34	0.30	< 1E-2	< 1E-2	0.03
	Epifaunal det. inverts.	0.10	0.10	0.07	0.07	0.10		Juv. medium reef assoc.	0.03	0.03	< 1E-2	0.02	0.01
	Epifaunal carn. inverts	0.08	0.08	0.08	0.08	< 1E-2		Juv. small reef assoc.	0.04	0.07	< 1E-2	0.07	0.01
	Infauanal inverts.	< 1E-2	< 1E-2	0.04	0.04	< 1E-2		Juv. large demersal	0.05	0.05	< 1E-2	< 1E-2	< 1E-2
	Carn. zooplankton	3.27	3.20	3.20	3.19	3.20		Juv. small demersal	0.11	0.10	< 1E-2	< 1E-2	< 1E-2
	Large herb. zooplankton	1.71	1.70	0.86	0.85	1.70		Juv. large planktivore	0.34	0.30	0.12	0.40	0.01
	Small herb. zooplankton	6.10	6.10	6.97	6.95	6.10		Juv. small planktivore	0.56	0.30		0.01	< 1E-2
	Phytoplankton	17.01	17.10	17.04	17.00	17.20		Juv. macro algal browsing	0.10	0.10	< 1E-2	< 1E-2	0.01
	Macro algae	53.51	53.48	53.61	53.48	53.50		Juv. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Sea grass	17.10	17.10	17.13	17.09	17.10		Juv. scraping grazers	0.34	0.60	1.23	0.34	0.30
	Mangroves	0.59	0.60	0.59	0.59	0.60		Azooxanthellate corals	0.11	0.10	0.01	0.07	0.01
Ad. eroding grazers	Azooxanthellate corals	15.46	15.50	6.35	5.99	15.50		Hermatypic corals	< 1E-2	< 1E-2	< 1E-2	0.05	< 1E-2
	Hermatypic corals	9.51	18.50	21.16	19.97	9.50		Non reef building corals	0.06	0.06	< 1E-2	0.03	0.01
	Non reef building corals	15.00	13.00	0.40	5.99	15.20		Soft corals	0.11	0.50	< 1E-2	0.05	0.01
	Soft corals	14.00	7.00	5.29	4.99	17.80		Penaeid shrimps				0.03	
	Calcareous algae	1.10	1.10	0.32	0.30	1.10		Shrimps and prawns	0.16	0.20	0.04	0.11	0.20
	Anemonies			0.05	0.05			Squid	0.06	0.06	0.03	< 1E-2	0.06
	Sessile filter feeders			2.99	2.82			Octopus	0.23	0.20	0.02	0.04	0.20
	Epifaunal det. inverts.	1.76	1.80	1.30	1.23	1.80		Sea cucumbers	0.01	0.01	0.04	0.01	0.01

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Lobsters	0.01	0.01	< 1E-2	< 1E-2	< 1E-2		Shrimps and prawns	0.10	1.00	0.11	0.68	1.50
	Large crabs	0.01	0.01	0.05	0.01	0.01		Octopus			0.18	0.12	
	Small crabs	0.02	0.02	0.05	0.01	0.02		Large crabs	0.05	0.10	0.07	0.05	0.10
	Crown of thorns	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Small crabs	0.05	0.05	0.06	0.04	0.05
	Giant triton	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Bivalves	3.00	6.70	3.86	7.76	4.00
	Herbivorous echinoids	< 1E-2	< 1E-2	0.02	< 1E-2	< 1E-2		Sessile filter feeders	0.40	0.40	0.48	0.32	0.40
	Bivalves	0.28	0.30	0.06	0.28	0.30		Epifaunal det. inverts.	0.05	0.05	0.05	0.04	0.05
	Sessile filter feeders	1.47	1.50	< 1E-2	0.16	0.30		Epifaunal carn. inverts	1.69	1.80	1.04	0.70	1.80
	Epifaunal det. inverts.	0.07	0.07	0.03	< 1E-2	0.01		Infaunal inverts.	22.84	33.20	12.38	33.29	34.10
	Epifaunal carn. inverts	0.18	0.20	0.56	0.15	0.01		Carn. zooplankton	0.97	0.90	1.37	0.92	0.90
	Infaunal inverts.	0.57	0.60	0.55	0.61	0.01		Macro algae	14.39	10.40	15.45	10.39	10.40
	Jellyfish and hydroids	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2		Sea grass	4.17	4.20	6.20	4.17	4.20
	Carn. zooplankton	6.40	6.40	0.30	2.00	2.40		Detritus	51.29	39.40	58.68	39.44	39.40
	Large herb. zooplankton	4.16	4.20	0.13	1.00	0.40	Shrimps and prawns	Sessile filter feeders	0.80	0.80	0.64	0.64	0.80
	Small herb. zooplankton	7.07	7.10	< 1E-2	9.99	14.80		Epifaunal det. inverts.	0.10	0.10	0.07	0.07	0.10
	Phytoplankton	7.23	7.20	36.17	9.99	8.10		Epifaunal carn. inverts	0.14	0.10	0.14	0.14	0.10
	Macro algae	29.76	30.10	< 1E-2	33.11	30.90		Infaunal inverts.	0.18	0.20	0.37	0.37	0.20
	Sea grass	24.45	24.50	< 1E-2	24.65	26.20		Macro algae	21.18	21.20	21.18	21.18	21.20
	Fishery discards	< 1E-2	0.05	< 1E-2	< 1E-2	< 1E-2		Sea grass	21.18	21.20	21.18	21.18	21.20
	Detritus	15.65	14.73	60.54	16.72	15.60		Detritus	56.42	56.40	56.42	56.42	56.40
Detritivore fish	Octopus	1.30	1.30	1.30	1.30	1.30	Squid	Juv. medium pelagic	0.02	0.62	0.08	0.02	0.02
	Sea cucumbers	2.60	2.60	2.60	2.60	2.60		Juv. small pelagic	0.40	0.41	< 1E-2	0.40	0.40
	Lobsters	0.98	1.00	0.69	0.69	1.00		Juv. large reef assoc.	1.00	2.00	0.15	2.83	8.10
	Large crabs	0.36	0.40	0.32	0.32	0.40		Juv. medium reef assoc.		1.00			
	Small crabs	0.34	0.30	0.29	0.29	0.30		Juv. small planktivore	1.00	1.00		1.00	1.00
	Herbivorous echinoids	4.33	4.30	3.48	3.48	4.30		Ad. anchovy			0.32	2.45	
	Bivalves	1.43	1.40	2.39	2.39	1.40		Juv. anchovy	5.00	5.00	0.04	5.00	5.00
	Sessile filter feeders	1.30	1.30	1.04	1.04	0.50		Juv. scraping grazers			11.74	2.83	
	Epifaunal det. inverts.	1.47	1.50	1.04	1.04	0.50		Penaeid shrimps	15.15	12.10	0.20	12.41	12.10
	Epifaunal carn. inverts	1.78	1.80	1.79	1.79	2.70		Shrimps and prawns	2.31	5.40	< 1E-2	0.89	1.30
	Infaunal inverts.	1.78	1.80	2.49	2.49	2.60		Squid	0.50	0.50	1.66	0.40	0.50
	Fishery discards	< 1E-2	0.05	0.03	0.05	< 1E-2		Octopus			1.06	0.26	
	Detritus	82.33	82.25	82.54	82.52	82.30		Carn. zooplankton	35.01	35.00	0.28	35.01	35.10
Azooxanthellate corals	Carn. zooplankton	9.50	9.50	9.50	9.50	9.50		Large herb. zooplankton	35.49	32.40	0.26	16.19	16.20
	Large herb. zooplankton	5.14	5.10	2.57	2.57	5.10		Small herb. zooplankton			67.12	16.19	16.20
	Small herb. zooplankton	24.39	24.40	26.96	26.96	24.40		Detritus	4.12	4.57	17.09	4.12	4.10
	Phytoplankton	48.78	48.80	48.78	48.78	48.80	Octopus	Juv. butterflyfish			0.03	5.00	
	Detritus	12.20	12.20	12.20	12.20	12.20		Juv. small pelagic					5.00
Hermatypic corals	Carn. zooplankton	9.50	9.50	9.50	9.50	9.50		Juv. large reef assoc.	0.20	1.00	0.01	0.52	1.50
	Large herb. zooplankton	5.14	5.10	2.57	2.57	5.10		Juv. deepwater fish	0.10	0.27	0.29	0.12	0.10
	Small herb. zooplankton	24.39	24.40	26.96	26.96	24.40		Juv. macro algal browsing	0.28	0.30		0.14	2.30
	Phytoplankton	48.78	48.80	48.78	48.78	48.80		Ad. eroding grazers			0.06	4.00	
	Detritus	12.20	12.20	12.20	12.20	12.20		Juv. eroding grazers			0.06	0.20	
Non reef building corals	Carn. zooplankton	9.50	9.50	9.50	9.50	9.50		Ad. scraping grazers			2.51	1.00	
	Large herb. zooplankton	5.14	5.10	2.57	2.57	5.10		Juv. scraping grazers	0.85	0.80		16.00	1.00
	Small herb. zooplankton	24.39	24.40	26.96	26.96	24.40		Detritivore fish	0.02	0.02	0.04	0.02	0.02
	Phytoplankton	48.78	48.80	48.78	48.78	48.80		Penaeid shrimps	2.00	14.98	0.07	7.07	15.40
	Detritus	12.20	12.20	12.20	12.20	12.20		Shrimps and prawns	0.35	0.60	0.60	0.24	0.40
Soft corals	Carn. zooplankton	9.50	9.50	9.50	9.50	9.50		Squid	< 1E-2	0.80	2.74	1.09	0.40
	Large herb. zooplankton	5.14	5.10	2.57	2.57	5.10		Octopus	1.00	9.00	0.65	2.31	3.00
	Small herb. zooplankton	24.39	24.40	26.96	26.96	24.40		Sea cucumbers	1.00	0.10	0.13	0.05	0.05
	Phytoplankton	48.78	48.80	48.78	48.78	48.80		Lobsters	< 1E-2	0.02	0.03	0.01	0.02
	Detritus	12.20	12.20	12.20	12.20	12.20		Large crabs	0.10	< 1E-2	0.01	< 1E-2	< 1E-2
Anemonies	Juv. large reef assoc.	6.42	6.40	2.25	2.25	6.40		Small crabs	0.50	0.10	0.21	0.09	0.10
	Juv. medium reef assoc.	0.56	0.60	0.39	0.39	0.60		Herbivorous echinoids	0.20	0.20	0.41	0.16	0.20
	Ad. small reef assoc.	2.66	2.70	2.66	2.66	2.70		Bivalves	15.00	30.65	25.76	30.76	30.70
	Juv. small reef assoc.	1.84	3.10	3.07	3.07	3.10		Sessile filter feeders	3.50	6.39	0.80	5.12	4.40
	Juv. scraping grazers			2.25	2.25			Epifaunal det. inverts.	2.00	0.50	0.88	0.35	0.50
	Small crabs	0.61	0.60	0.51	0.51	0.60		Epifaunal carn. inverts	27.35	11.60	17.59	7.00	14.10
	Bivalves			0.09	0.09			Infaunal inverts.	25.76	14.10	28.72	11.43	13.40
	Epifaunal det. inverts.	4.45	3.20	2.25	2.25	3.20		Carn. zooplankton	2.00	2.80	5.66	2.25	2.30
	Epifaunal carn. inverts	6.42	6.40	6.42	6.42	6.40		Detritus	17.80	5.76	12.74	5.08	5.10
	Infaunal inverts.			0.96	0.96		Sea cucumbers	Macro algae	40.00	40.00	40.00	40.00	40.00
	Carn. zooplankton	19.26	19.30	19.25	19.25	19.30		Detritus	60.00	60.00	60.00	60.00	60.00
	Large herb. zooplankton	19.26	19.30	9.62	9.62	19.30		Juv. scraping grazers			7.00	7.00	2.20
	Small herb. zooplankton	12.84	12.80	22.46	22.46	12.80	Lobsters	Shrimps and prawns					0.50
	Phytoplankton	12.84	12.80	14.99	14.99	12.80		Sea cucumbers		1.00			
	Detritus	12.84	12.80	12.83	12.83	12.80		Herbivorous echinoids	1.00	0.20	1.16	1.16	0.30
Penaeid shrimps	Juv. scraping grazers			0.07	0.05	2.20		Bivalves	18.86	18.90	19.15	19.15	18.90
	Penaeid shrimps	1.00	1.80		2.04	0.90		Sessile filter feeders	3.00	3.00	2.40	2.40	3.00

Table D.3.1. Cont. Functional group diet composition.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
Large crabs	Epifaunal det. inverts.	1.69	1.20	0.87	0.87	0.60	Infaunal inverts.	Epifaunal det. inverts.	0.10	0.10	0.40	0.14	0.10
	Epifaunal carn. inverts	37.73	20.00	20.00	20.00	18.20		Epifaunal carn. inverts	1.26	0.50	0.99	0.35	0.40
	Infaunal inverts.	37.72	55.70	38.70	38.70	47.80		Infaunal inverts.	66.42	75.58	54.13	75.96	75.70
	Detritus			10.72	10.72	8.50		Detritus	28.35	11.99	34.24	12.01	11.90
	Penaeid shrimps	22.00	26.40	0.10	26.66	26.40		Juv. large demersal	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Shrimps and prawns	1.24	1.20	2.34	0.84	1.20		Juv. small demersal	0.01	0.01	< 1E-2	< 1E-2	< 1E-2
	Octopus			0.41	0.15			Ad. macro algal browsing	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Small crabs	0.10	0.10	0.24	0.09	0.10		Juv. macro algal browsing	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Bivalves	39.62	39.60	6.84	39.63	39.60		Ad. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
	Epifaunal det. inverts.	0.69	0.70	1.33	0.48	0.70		Juv. eroding grazers	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2
Small crabs	Epifaunal carn. inverts	0.25	0.30	0.69	0.25	0.30	Juv. scraping grazers	0.11	0.10	0.22	0.11	0.10	
	Infaunal inverts.	9.69	5.30	15.16	5.49	5.30	Penaeid shrimps	0.01	0.01	0.02	0.01	0.01	
	Macro algae	13.21	13.20	36.45	13.21	13.20	Shrimps and prawns	< 1E-2	< 1E-2	0.01	< 1E-2	< 1E-2	
	Detritus	13.21	13.20	36.45	13.21	13.20	Octopus			< 1E-2	< 1E-2		
	Epifaunal det. inverts.	0.82	0.80	0.57	0.57	0.80	Sea cucumbers	0.01	0.01	0.02	0.01	0.03	
	Epifaunal carn. inverts	0.38	0.40	0.38	0.38	0.40	Bivalves	0.10	0.20	0.40	0.20	0.60	
	Infaunal inverts.	49.40	49.40	49.65	49.64	49.40	Epifaunal det. inverts.	< 1E-2	< 1E-2	0.01	< 1E-2	< 1E-2	
	Macro algae	6.18	6.20	6.17	6.17	6.20	Epifaunal carn. inverts	0.01	0.01	0.02	0.01	0.01	
	Sea grass	37.05	37.00	37.06	37.05	37.00	Infaunal inverts.	0.12	0.10	0.20	0.10	0.10	
	Detritus	6.18	6.20	6.17	6.17	6.20	Macro algae	22.61	16.31	< 1E-2	20.00	16.30	
Crown of thorns	Azooxanthellate corals	11.00	13.55	3.23	4.65	10.00	Sea grass	27.00	33.61	< 1E-2	29.75	33.60	
	Hermatypic corals	81.27	70.50	0.28	25.89	80.90	Detritus	50.00	49.62	99.09	49.79	49.20	
	Non reef building corals	6.20	12.31	2.93	2.11	7.60	Juv. groupers	< 1E-2	0.01	0.01	0.01	0.01	
	Soft corals		2.00	0.42	0.30		Juv. snappers	0.01	0.01	0.01	0.01	0.01	
	Calcareous algae	1.53	1.64	0.47	0.34	1.50	Juv. Napoleon wrasse	0.01	0.01			0.01	
	Anemonies			0.09	0.06		Juv. butterflyfish	0.05	0.10	0.10	0.10	0.10	
	Infaunal inverts.			92.58	66.64		Juv. large pelagic	0.04	0.04	< 1E-2	< 1E-2	0.04	
	Crown of thorns	20.00	8.40	5.88	60.00	25.00	Juv. medium pelagic	0.07	0.07	0.01	0.01	0.07	
	Bivalves	9.72	9.70	23.53	10.00	9.70	Juv. small pelagic	0.46	0.50	0.20	0.20	0.50	
	Epifaunal det. inverts.	24.10	30.70	23.53	10.00	25.70	Juv. large reef assoc.	0.11	0.10	0.04	0.04	0.10	
Herbivorous echinoids	Epifaunal carn. inverts	25.70	30.70	23.53	10.00	19.10	Juv. medium reef assoc.	0.01	< 1E-2	< 1E-2	< 1E-2	< 1E-2	
	Infaunal inverts.	20.47	20.50	23.53	10.00	20.50	Juv. small reef assoc.	0.04	0.06	0.06	0.06	0.06	
	Infaunal inverts.	0.04	0.04	0.04	0.04	0.04	Juv. large demersal	0.10	0.10	0.03	0.03	0.10	
	Macro algae	55.53	55.48	55.53	55.53	55.50	Juv. small demersal	0.33	0.30	0.12	0.12	0.30	
	Sea grass	44.43	44.48	44.43	44.43	44.40	Juv. large planktivore	0.55	0.60	0.55	0.55	0.60	
	Small herb. zooplankton	20.00	20.00	5.88	20.00	20.00	Juv. small planktivore	0.10	0.10	0.10	0.10	0.10	
	Phytoplankton	50.90	50.90	59.88	50.90	50.90	Ad. anchovy			1.83	1.83		
	Detritus	29.10	29.10	34.24	29.10	29.10	Juv. anchovy	2.50	3.71	3.74	3.74	3.70	
	Cam. zooplankton	4.58	4.60	4.58	4.58	4.60	Juv. deepwater fish	0.10	1.08	0.47	0.47	0.60	
	Large herb. zooplankton	1.99	2.00	0.99	0.99	2.00	Juv. macro algal browsing	0.10	0.10	0.05	0.05	0.10	
Sessile filter feeders	Small herb. zooplankton	20.29	20.30	21.28	21.28	20.30	Juv. eroding grazers	0.04	0.04	0.09	0.09	0.04	
	Phytoplankton	59.23	59.20	59.24	59.23	59.20	Juv. scraping grazers	0.22	0.20	0.32	0.32	0.80	
	Detritus	13.91	13.90	13.91	13.91	13.90	Jellyfish and hydroids	1.80	1.80	1.23	1.23	1.80	
	Infaunal inverts.	0.10	0.10	0.09	0.09	0.10	Cam. zooplankton	23.29	22.14	22.05	22.05	22.00	
	Macro algae	14.83	14.80	14.83	14.83	14.80	Large herb. zooplankton	24.70	24.74	12.35	12.35	24.70	
	Sea grass	14.83	14.80	14.83	14.83	14.80	Small herb. zooplankton	16.11	22.14	34.46	34.45	22.10	
	Detritus	70.25	70.30	70.25	70.25	70.30	Phytoplankton	29.25	22.04	22.16	22.16	22.10	
	Juv. large reef assoc.	0.01	0.10	0.10	0.04	0.10	Cam. zooplankton	15.00	15.30	4.28	15.00	12.00	
	Juv. small demersal	0.05	0.05	< 1E-2	0.02	< 1E-2							
	Juv. deepwater fish	< 1E-2	0.02	0.06	0.04	0.01							
Epifaunal det. inverts.	Ad. macro algal browsing	0.01	0.10	< 1E-2	0.05	0.10							
	Juv. macro algal browsing	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2							
	Ad. eroding grazers	0.10	0.30	< 1E-2	0.30	0.30							
	Juv. eroding grazers	0.10	0.30	< 1E-2	0.33	0.30							
	Juv. scraping grazers	0.80	0.80	1.01	0.84	0.80							
	Detritivore fish	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2							
	Azooxanthellate corals			< 1E-2	< 1E-2								
	Hermatypic corals	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2							
	Non reef building corals	0.16	0.10	0.12	0.04	0.20							
	Soft corals			0.02	< 1E-2								
Epifaunal carn. inverts	Penaeid shrimps			0.05	0.02								
	Shrimps and prawns	0.08	0.08	0.16	0.06	0.08							
	Octopus	0.10	0.10	0.01	0.14	0.10							
	Sea cucumbers	0.01	0.10	0.35	0.13	0.10							
	Lobsters	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2							
	Large crabs	< 1E-2	< 1E-2	< 1E-2	< 1E-2	< 1E-2							
	Small crabs	0.01	< 1E-2	0.02	< 1E-2	< 1E-2							
	Herbivorous echinoids	0.02	0.06	0.15	0.05	0.07							
	Bivalves	2.00	8.30	7.95	8.36	8.30							
	Sessile filter feeders	0.40	1.40	0.19	1.10	1.40							

Table D.3.2 Vulnerability matrices for 5 Ecosim models. Density-dependent modifiers of predation mortality set by a data fitting process.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
Mysticetæ	Juv. medium pelagic	>1E8	>1E8	>1E8	>1E8	>1E8	Crocodiles	Epifaunal carn. inverts	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. small pelagic	>1E8	>1E8	>1E8	>1E8	>1E8		Infauanal inverts.	>1E8	>1E8	>1E8	>1E8	>1E8
	Squid	>1E8	>1E8	>1E8	>1E8	>1E8		Jellyfish and hydroids	>1E8	>1E8	>1E8	>1E8	>1E8
	Octopus			2	2			Birds	1.83	2.62	1.25	2.43	1.31
	Carn. zooplankton	>1E8	>1E8	>1E8	>1E8	>1E8		Reef assoc. turtles	1.83	1	1	2.75	1.47
Pisc. odontocetæ	Large herb. zooplankton	>1E8	>1E8	>1E8	>1E8	>1E8	Green turtles	1.83	1	1.3	2.15	2.34	
	Small herb. zooplankton	>1E8	>1E8	>1E8	>1E8	>1E8	Oceanic turtles	1.83	1	1.3	2.14	2.21	
	Skipjack tuna	637721	>1E8	>1E8	>1E8	>1E8	Juv. large pelagic	1.83	1.46	1	1	1.46	
	Ad. large pelagic	637721	>1E8	>1E8	>1E8	>1E8	Juv. small pelagic	1.83	1	1	1	2.2	
	Juv. large pelagic	637721	>1E8	>1E8	>1E8	>1E8	Juv. large planktivore	1.83	3	3.75	14.9	3	
	Ad. medium pelagic	637721	>1E8	>1E8	>1E8	>1E8	Juv. small planktivore	1.83	1.31	1	1.7	1	
	Juv. medium pelagic	637721	>1E8	>1E8	>1E8	>1E8	Penaeid shrimps	1.83	13.4	1.91	6.04	1.34	
	Ad. small pelagic	637721	>1E8	>1E8	>1E8	>1E8	Lobsters	1.83	2.89	1	5.15	2.89	
	Juv. small pelagic	637721	>1E8	>1E8	>1E8	>1E8	Large crabs	1.83	1.85	4.62	4.81	1.85	
	Ad. large demersal	637721	>1E8	>1E8	>1E8	>1E8	Bivalves			2	2		
	Ad. small demersal	637721	>1E8	>1E8	>1E8	>1E8	Ad. groupers	1	1.01	182	1.1	1.01	
	Ad. large planktivore			2	2		Sub. groupers	1	6.28	2.73	6.39	6.28	
	Juv. large planktivore	637721	>1E8	>1E8	>1E8	>1E8	Juv. groupers	1	1	1	1	1.02	
	Juv. small planktivore	637721	>1E8	>1E8	>1E8	>1E8	Ad. snappers	1	14.5	16.2	5.98	14.5	
	Ad. deepwater fish	637721	>1E8	>1E8	>1E8	>1E8	Sub. snappers	1	7.32	9.24	4.03	47.6	
Squid	637721	>1E8	>1E8	>1E8	>1E8	Juv. snappers			2				
Deep. odontocetæ	Octopus			2	2		Juv. large sharks						2
	Ad. large pelagic	1102676	>1E8	>1E8	>1E8	>1E8	Ad. butterflyfish	1	4.73	5.31	1.09	1.56	
	Juv. large pelagic	1102676	>1E8	>1E8	>1E8	>1E8	Juv. butterflyfish	1	1	1.51	1	1	
	Juv. large demersal	1102676	>1E8	>1E8	>1E8	>1E8	Cleaner wrasse	1	1.6	14.3	1	1.29	
	Juv. deepwater fish	1102676	>1E8	>1E8	>1E8	>1E8	Juv. medium pelagic	1					
	Squid	1102676	>1E8	>1E8	>1E8	>1E8	Ad. large reef assoc.	1	1	1	1.25	1.46	
	Octopus	1102676	>1E8	>1E8	>1E8	>1E8	Juv. large reef assoc.	1	1	1	1	1.15	
	Epifaunal det. inverts.	1102676	>1E8	>1E8	>1E8	>1E8	Ad. medium reef assoc.	1	1	1.55	1.73	1	
	Epifaunal carn. inverts	1102676	>1E8	>1E8	>1E8	>1E8	Juv. medium reef assoc.	1	1	4.14	1.07	1	
	Infauanal inverts.			2	2		Ad. small reef assoc.	1	1	303	1	3.32	
	Dugongs	Sea grass	10.4	8.9	141	9.98	3.51	Juv. small reef assoc.	1				
		Mackerel	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. large demersal	1	1	4.64	2.28	7.65
	Birds	Ad. small pelagic	>1E8					Ad. small demersal	1	1.76	3.21	8.27	3.05
		Juv. small pelagic	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. large planktivore	1	1.43	1	1	5.25
		Ad. small planktivore			2		2	Juv. large planktivore			2	2	
Juv. small planktivore		>1E8	>1E8	>1E8	>1E8	>1E8	Ad. small planktivore	1	1	7.56	1	1	
Ad. anchovy		1.01	2	36.2	2.05		Ad. anchovy	1	1	1	1	18.2	
Juv. anchovy		>1E8	>1E8	>1E8	>1E8	>1E8	Juv. anchovy	1	2.44	1	1	8.48	
Bivalves		>1E8					Ad. deepwater fish	1	2.4	2.63	3.72	4.34	
Sessile filter feeders		>1E8	>1E8	>1E8	>1E8	>1E8	Juv. deepwater fish	1	1	1	1.14	1.76	
Epifaunal det. inverts.		>1E8	>1E8	>1E8	>1E8	>1E8	Ad. macro algal browsing	1	1	1.39	1	1	
Epifaunal carn. inverts		>1E8	>1E8	>1E8	>1E8	>1E8	Juv. macro algal browsing			2			
Infauanal inverts.		>1E8	>1E8	>1E8	>1E8	>1E8	Ad. eroding grazers	1	9.89	4.5	1	69.2	
Jellyfish and hydroids				2		2	Juv. eroding grazers			2	2		
Fishery discards		>1E8	2	2	2	2	Ad. scraping grazers	1	2.57	3.96	1.47	6.09	
Reef assoc. turtles		Penaeid shrimps	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. scraping grazers			2	2	2
		Shrimps and prawns	>1E8	>1E8	>1E8	>1E8	>1E8	Detritivore fish	1	8.06	2338	1	2.39
	Octopus			2	2		Penaeid shrimps	1	1	1	1	1.5	
	Sea cucumbers	>1E8	>1E8	>1E8	>1E8	>1E8	Shrimps and prawns	1	1	1	1	1.82	
	Large crabs	>1E8	>1E8	>1E8	>1E8	>1E8	Squid	1	3.77	1.88	1	14.3	
	Small crabs	>1E8	>1E8	>1E8	>1E8	>1E8	Octopus	1	1.85	1	1	9.23	
	Herbivorous echinoids	>1E8	>1E8	>1E8	>1E8	>1E8	Lobsters	1	1	1	1.09	4.15	
	Bivalves			2	2		Large crabs	1	1	1.97	1.01	3.91	
	Sessile filter feeders	>1E8	>1E8	>1E8	>1E8	>1E8	Small crabs	1	1.45	2.64	1.07	5.4	
	Epifaunal det. inverts.	>1E8	>1E8	>1E8	>1E8	>1E8	Giant triton	1	1	1	1	1	
	Epifaunal carn. inverts	>1E8	>1E8	>1E8	>1E8	>1E8	Bivalves	1	17	1	1	17	
	Infauanal inverts.	>1E8	>1E8	>1E8	>1E8	>1E8	Epifaunal det. inverts.	1	3.1	2.55	1.78	3	
	Jellyfish and hydroids	>1E8	>1E8	>1E8	>1E8	>1E8	Epifaunal carn. inverts	1	3.96	1	1.13	14.6	
	Green turtles	Carn. zooplankton	>1E8	>1E8	>1E8	>1E8	>1E8	Infauanal inverts.	1	1.64	1	1.08	16.4
		Large herb. zooplankton	>1E8	>1E8	>1E8	>1E8	>1E8	Carn. zooplankton	1	2.85	1	1.46	8.73
Small herb. zooplankton				2	2		Ad. groupers	1	1	1	1	1	
Macro algae		>1E8	>1E8	>1E8	>1E8	>1E8	Sub. groupers	1	1.47	1.34	1.57	1.72	
Sea grass		>1E8	>1E8	>1E8	>1E8	>1E8	Juv. groupers	1	1	1	1	1.16	
Oceanic turtles	Sea cucumbers	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. snappers	1	1	1	1	1.6	
	Large crabs	>1E8	>1E8	>1E8	>1E8	>1E8	Sub. snappers	1	1.05	2.97	1	5.8	
	Small crabs	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. snappers			2			
	Bivalves			2	2		Ad. butterflyfish	1	1	282	1	1	
	Sessile filter feeders	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. butterflyfish	1	1.06	1	1.23	6.62	
Epifaunal det. inverts.	>1E8	>1E8	>1E8	>1E8	>1E8	Cleaner wrasse	1	1	4.32	1	1.5		

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Ad. large reef assoc.	1	1	1	1	1.31		Bivalves			2	2	
	Juv. large reef assoc.	1	1	1	1	1		Epifaunal det. inverts.	1	1	1.67	1	1
	Ad. medium reef assoc.	1	1	1	1	1		Epifaunal carn. inverts	1	1	1	1	1
	Juv. medium reef assoc.	1	1	3.7	2.39	1.16		Infaunal inverts.	1	1	1	1	1
	Ad. small reef assoc.	1	1	1	1	1		Carn. zooplankton	1	1.27	1	1	2.23
	Juv. small reef assoc.	1	1	1	1	1		Large herb. zooplankton			2	2	
	Ad. large demersal	1	1	1	1	1		Small herb. zooplankton			2	2	
	Ad. small demersal	1	1	1.04	1.34	1		Phytoplankton			2	2	
	Ad. large planktivore	1	1	1	1	1.03	Ad. snappers	Ad. groupers	1.1	1.21	121	1.88	1
	Juv. large planktivore			2	2			Sub. groupers	1.1	1.27	50.6	2.35	1.12
	Ad. small planktivore	1	1	1	1	1.62		Juv. groupers	1.1	1.02	580	1.86	1.71
	Ad. anchovy	1	1	1	1	1.4		Ad. snappers	1.1	1	1	1	1
	Juv. anchovy	1	1	1	1	1		Sub. snappers	1.1	2.99	1	2.93	2.88
	Ad. deepwater fish	1	1	1	1	1		Juv. snappers	1.1	3.45	1	3.35	1
	Juv. deepwater fish	1	1	1	1	1		Juv. Napoleon wrasse	1.1	2.02	1	7.88	1.19
	Ad. macro algal browsing	1	1	1	1	2.18		Skipjack tuna	1.1	1	1	1	1
	Ad. eroding grazers	1	15.5	9.09	45.7	155		Other tuna	1.1	1	91.1	1	1
	Juv. eroding grazers			2	2			Mackerel	1.1	1.47	105	1	1.64
	Ad. scraping grazers	1	1	1.35	1	5.19		Billfish	1.1	1.46	1	1	1
	Juv. scraping grazers			2	2			Juv. coral trout	1.1	1	1	3.52	1
	Detritivore fish	1	1.01	25.6	1	3.17		Juv. rays	1.1	1.54	1	1.02	1
	Penaed shrimps	1	1	1	1	2.1		Ad. butterflyfish	1.1	1	1	1	1
	Shrimps and prawns	1	1	1	1	2.04		Juv. butterflyfish	1.1	2.23	1	1	1
	Squid	1	1	1	1	1.17		Cleaner wrasse	1.1	1	1	1	1
	Octopus	1	1	1	1	1.24		Ad. large pelagic	1.1	26.7	1	3.57	23.3
	Lobsters	1	1	1	1	2		Juv. large pelagic	1.1	1	5.26	1.56	1
	Large crabs	1	1	1	1	1.67		Ad. medium pelagic	1.1	1	1	1	1
	Small crabs	1	1	1	1	1.32		Juv. medium pelagic	1.1				
	Giant triton	1	1	1	1	1		Ad. small pelagic	1	1	305	1.84	2.29
	Bivalves	1	1	1	1	8.9		Ad. large reef assoc.	1.1	1	55	1	1
	Epifaunal det. inverts.	1	1	1	1	1		Juv. large reef assoc.	1.1	1	1.84	1	1
	Epifaunal carn. inverts	1	1	1	1	1		Ad. medium reef assoc.	1.1	1.4	1	1	1
	Infaunal inverts.	1	1	1	1	15.1		Juv. medium reef assoc.	1.7	4.17	224	4.8	1.61
Juv. groupers	Carn. zooplankton	1	1	1	1	2.22		Ad. small reef assoc.	1	1	169	1.04	1
	Ad. groupers	1	1	1	1	1		Juv. small reef assoc.	1	8.5	1	21.1	4.8
	Sub. groupers	1	1.03	72	1.02	1.03		Ad. large demersal	1.1	1	152	1.95	1
	Juv. groupers	1	1.53	1.41	1.62	1.53		Juv. large demersal	1.1	1	1	1	1
	Ad. snappers	1	1	1	1	2.8		Ad. small demersal	1.1	1	1.63	1	1
	Sub. snappers	1	1	1	1	1.92		Juv. small demersal	1.1	1	1	1	1
	Ad. butterflyfish	1	1	201	1	1		Ad. large planktivore	1.1	1	1	1.62	1
	Juv. butterflyfish	1	1	1	1	4.63		Juv. large planktivore	1.1	2.31	1	1	1.54
	Cleaner wrasse	1	1	1	1	1		Ad. small planktivore	1.1	1	1	1	1
	Ad. large reef assoc.	1	1	1	1	1		Juv. small planktivore	1.1	1.52	1	1	1
	Juv. large reef assoc.	1	1	1	1	1.05		Ad. anchovy	1.1	1	1	1	1
	Ad. medium reef assoc.	1	1	1	1	1		Juv. anchovy	1.1	1.05	10.2	1	1
	Juv. medium reef assoc.	1	1	1	1	1		Ad. deepwater fish	1.1	2.19	1	1	1.32
	Ad. small reef assoc.	1	1	1	1	1		Juv. deepwater fish	1.1	5.01	21.9	1.51	3.05
	Juv. small reef assoc.	1	1	1	1	1		Ad. macro algal browsing	1.1	1	1	1	1.49
	Ad. large demersal	1	1	1	1	1		Juv. macro algal browsing	1.1	1.72	1	1	1
	Ad. small demersal	1	1	3.34	4.04	1		Ad. eroding grazers	1.1	1.45	1.12	14.5	1
	Ad. large planktivore	1	1	1	1	1		Juv. eroding grazers	1.1	15.8	1	1	7.88
	Juv. large planktivore			2	2			Ad. scraping grazers	1.1	1.16	1	1	1
	Ad. small planktivore	1	1	1	1	1		Juv. scraping grazers	1.1	2.59	1	1	1.29
	Ad. anchovy	1	1	1	1	1		Detritivore fish	1.1	1	1	1	1
	Juv. anchovy	1	1	1	1	1		Penaed shrimps	1.76	9.5	6273	8.55	12.3
	Ad. deepwater fish	1	1	1	1	1		Shrimps and prawns	1	2.09		1.61	1.31
	Juv. deepwater fish	1	1	1	1	1		Squid	1.1	1	1	1	1
	Ad. macro algal browsing	1	1	1	1	3.2		Octopus	1.1	1	1	1	1.08
	Juv. eroding grazers			2	2			Sea cucumbers	1.1	1.91	1	1	1
	Ad. scraping grazers	1	1	3.94	1.81	5.78		Lobsters	1.1	1	1	1	1
	Juv. scraping grazers		2	2	2			Large crabs	1.1	2.01	1	1.19	1.24
	Detritivore fish	1	1	1	1	1		Small crabs	1.1	1	1	1	1
	Penaed shrimps	1	1	1	1	1.04		Crown of thorns	1.1	1.62	1	1.66	2.02
	Shrimps and prawns	1	1	1	1	1.3		Giant triton	1.1	1.6	2.42	1.05	1
	Squid	1	1	2.09	1	1		Herbivorous echinoids	1.1	1.5	1	1.08	1
	Octopus			2	2			Bivalves	1.1	2.52	1	1.01	1.44
	Lobsters	1	1	1	1	6.3		Sessile filter feeders	1	1.48	5.34	1	1
	Large crabs	1	1	1	1	1		Epifaunal det. inverts.	1.1	1.09	1	2.27	1
	Small crabs	1	1	1.49	1	1.12		Epifaunal carn. inverts	1.1	1.15	1	1.92	1
	Giant triton	1	1	1	1	1		Infaunal inverts.	1.1	1.51	1	1	1.51

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	
Sub. snappers	Jellyfish and hydroids	1.1	3.07	1	2.93	1.46	Ad. Napoleon wrasse	Sub. snappers	39146980	>1E8	>1E8	>1E8	>1E8	
	Carn. zooplankton	1.1	4.99	1	4.35	2.64		Juv. snappers	39146980					2
	Large herb. zooplankton	1.1	5.72	1	10.3	2.71		Juv. coral trout						
	Small herb. zooplankton	1.1	1.62	1	2.69	2.59		Ad. butterflyfish	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. groupers	1.09	1	1	1.05	1		Juv. butterflyfish	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Sub. groupers	1.09	1.83	79.1	3.39	2.97		Cleaner wrasse	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. snappers	1.09	1	1	1	1		Ad. large reef assoc.	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Sub. snappers	1.09	1.15	1	1.13	1.15		Juv. large reef assoc.	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. snappers	1.09	14.3	5.03	14.2	14.3		Ad. medium reef assoc.	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. Napoleon wrasse	1.09	1	1	3.13	1		Juv. medium reef assoc.	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Other tuna	1.09	1.46	14.6	1	1		Ad. small reef assoc.	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Mackerel	1.09	1	62.1	1	1		Juv. small reef assoc.	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. coral trout	1.09	1	1	5.08	1		Ad. large demersal	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. rays	1.09	1	1	1.14	4.56		Ad. small demersal	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. butterflyfish	1.09	1	1	1.44	1		Ad. large planktivore	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. butterflyfish	1.09	1	1	1	1		Juv. large planktivore				2	2	
	Cleaner wrasse	1.09	1	1.29	4	1		Ad. small planktivore	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. large pelagic	1.09	125	4.24	12.9	62.3		Ad. anchovy	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. large pelagic	1.09	1	1	1	1		Juv. anchovy	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. medium pelagic	1.09	1	1	1	1		Ad. deepwater fish	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. medium pelagic	1.09						Juv. deepwater fish	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. small pelagic	1.09	1	1	1	1		Ad. macro algal browsing	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. large reef assoc.	1.09	1	1	1	1		Ad. eroding grazers	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. large reef assoc.	1.09	1	12.2	1.03	1		Ad. scraping grazers	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. medium reef assoc.	1.09	91.7	91.7	91.7	91.7		Detritivore fish	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. medium reef assoc.	1.09	1.2	1	1	1		Penaeid shrimps	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. small reef assoc.	1.09	1	1	1	1		Shrimps and prawns	39146980	>1E8		>1E8	>1E8	>1E8
	Juv. small reef assoc.	1	1	1	1	1		Octopus				2	2	
	Ad. large demersal	1.09	1	1	1	1		Large crabs	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. large demersal	1.09	1	1	1	1		Small crabs	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. small demersal	1.09	1	2.87	1	1		Bivalves				2	2	
	Juv. small demersal	1.09	1	1	1	1		Epifaunal det. inverts.		2				
	Ad. large planktivore	1.09	1	1	1	1		Epifaunal carn. inverts.		2				
	Juv. large planktivore	1.09	1.44	1	1	1		Infaunal inverts.	39146980	>1E8				
	Ad. small planktivore	1.09	1	20.3	1	1		Carn. zooplankton	39146980	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. small planktivore	1.09	1	1	1	1		Large herb. zooplankton				2	2	
	Ad. anchovy	1.09	1	1	1	1		Small herb. zooplankton				2	2	
	Juv. anchovy	1.09	2.02	26	1	1.21		Phytoplankton				2	2	
	Ad. deepwater fish	1.09	1.05	1	1	1		Ad. groupers	32.1	92.8	464	928	30.9	
	Juv. deepwater fish	1.09	1.91	15.9	1	2.98		Sub. groupers	32.1	106	760	2500	148	
	Ad. macro algal browsing	1.09	1	1	1	1		Juv. groupers	32.1	170	893	3047	47.1	
	Juv. macro algal browsing	1.09	1		1	1		Ad. snappers	32.1	44	1143	584	81.6	
	Ad. eroding grazers	1.09	1.74	1	1.74	1.74		Sub. snappers	32.1	157	3838	2075	267	
	Juv. eroding grazers	1.09	7.18	1	9.05	7.18		Juv. snappers	32.1	1110	>1E8	9734	40.6	
	Ad. scraping grazers	1.09	1	1	1	1		Ad. Napoleon wrasse	32.1	15.9	16.6	8.08	5.39	
Juv. scraping grazers	1.09	1.44			1	Sub. Napoleon wrasse	32.1	110	104	103	110			
Detritivore fish	1.09	1	11.8	1	1	Juv. Napoleon wrasse	32.1	400	321	313	415			
Penaeid shrimps	1.87	1.59	1	1.06	1.39	Juv. coral trout	32.1	20.4	311	1440				
Shrimps and prawns	1.09	1.28	1	1	1	Juv. rays	32.1	173	495	1049	41.6			
Squid	1.09	1	1	1	1	Ad. butterflyfish	32.1	126	361	7127	118			
Octopus	1.09	1	1	1	1	Juv. butterflyfish	32.1	16.1	43.4	854	52.8			
Sea cucumbers	1.09	1.05	1	1	1	Ad. large reef assoc.	32.1	51.4	257	514	514			
Lobsters	1.09	1.12	1.11	1	1.28	Juv. large reef assoc.	32.1	66.1	441	1130	1323			
Large crabs	1.09	1	1	1	1	Ad. medium reef assoc.	32.1	143	476	700	28.6			
Small crabs	1.09	1	1	1	1	Juv. medium reef assoc.	32.1	>1E8	>1E8	>1E8	>1E8			
Crown of thorns	1.09	1	1	1	1.13	Ad. small reef assoc.	32.1	38.1	429	1185	36.4			
Giant triton	1.09	1	1.02	1	1	Juv. small reef assoc.	32.1	592	4440	>1E8	592			
Herbivorous echinoids	1.09	1.09	1	1	1	Ad. large demersal	32.1	67.3	374	224	33.7			
Bivalves	1.09	1.41	1	1	1	Juv. large demersal	32.1	50.9	509	252	25.5			
Sessile filter feeders	1.09	1	5.26	1	1	Ad. small demersal	32.1	44.7	91.1	337	59.4			
Epifaunal det. inverts.	1.09	1	1	1	1	Juv. small demersal	32.1	71.2	82.1	306	35.6			
Epifaunal carn. inverts.	1.09	1	1	1	1	Ad. large planktivore	32.1	87	641	1464	87			
Infaunal inverts.	1.09	1.39	1	1	1	Juv. large planktivore	32.1	1152	52.4	118	1152			
Jellyfish and hydroids	1.09	1	1	1	1	Ad. small planktivore	32.1	140	159	891	117			
Carn. zooplankton	1.09	2.25	1	2.3	1.23	Juv. small planktivore	32.1	100	31.4	349	100			
Large herb. zooplankton	1.09	1	1	1.15	1	Ad. anchovy		2	2	2				
Small herb. zooplankton	1.09	1	1	1	1	Juv. anchovy	32.1	94.4	183	246	94.4			
Ad. groupers	39146980	>1E8	>1E8	>1E8	>1E8	Ad. deepwater fish	32.1	50.8	572	911	25.4			
Sub. groupers	39146980	>1E8	>1E8	>1E8	>1E8	Juv. deepwater fish	32.1	170	1696	2346	84.8			
Ad. snappers	39146980	>1E8	>1E8	>1E8	>1E8	Ad. macro algal browsing	32.1	198	188	505	193			

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
Sub. Napoleon wrasse	Juv. macro algal browsing	32.1	97.6	195	567	97.6	Juv. Napoleon wrasse	Ad. groupers	1	1	1	1	1
	Ad. eroding grazers	32.1	1088	3627	>1E8	1088		Sub. groupers	1	1.67	13.3	42.3	1.82
	Juv. eroding grazers	32.1	581	145	581	581		Ad. snappers	1	1	15.5	7.94	1.03
	Ad. scraping grazers	32.1	191	7656	>1E8	510		Sub. snappers	1	3.4	85	45	5.67
	Juv. scraping grazers	32.1	67.7	21.8	212	13.5		Ad. Napoleon wrasse	1	1.16	1	1	1
	Detritivore fish	32.1	1	1	9.3	1		Sub. Napoleon wrasse	1	1	1	1	1
	Squid	32.1	14	772	443	54.9		Ad. butterflyfish	1	1.6	4.81	89	1.6
	Octopus	32.1	122	385	679	122		Juv. butterflyfish	1	1	2.14	39.7	2.57
	Sea cucumbers	32.1	126	753	884	137		Ad. medium reef assoc.	1	1	1	1	1
	Lobsters	32.1	65.2	168	492	130		Ad. small reef assoc.	1	1	5.74	14.8	1
	Large crabs	32.1	137	1716	983	172		Ad. small demersal	1	1	1.42	4.78	1
	Small crabs	32.1	129	2154	1041	136		Juv. large planktivore			2	2	
	Crown of thorns	32.1	15.9	45.3	209	30.7		Ad. small planktivore	1	2.14	2.61	14.3	1.79
	Giant triton	32.1	87.9	49.2	86.1	27.5		Ad. deepwater fish	1	1	7.4	11.4	1
	Herbivorous echinoids	32.1	19.8	74.8	73.5	19.8		Juv. deepwater fish	1	1.09	8.74	13.9	1
	Bivalves	32.1	246	447	812	246		Ad. macro algal browsing	1	2.84	2.58	6.31	2.84
	Sessile filter feeders	32.1	126	628	1107	147		Ad. eroding grazers	1	3.5	3.5	3.5	3.5
	Epifaunal det. inverts.	32.1	112	1284	1087	112		Ad. scraping grazers	1	3.2	32	32	32
	Epifaunal carn. inverts	32.1	82.3	412	558	82.3		Juv. scraping grazers			2	2	
	Infaunal inverts.	32.1	1534	767	1370	1534		Detritivore fish	1	1.65	7.19	88.9	1
	Carn. zooplankton	32.1	205	723	2495	187		Squid	1	1.7	27.2	14.2	1.85
	Ad. groupers	1	1.98	7.9	27.4	1		Octopus	1	1.57	5.77	9.28	1.57
	Sub. groupers	1	1.67	9.74	35.3	1		Sea cucumbers	1	1	4.33	4.66	1
	Juv. groupers	1	1	1	3.11	1		Lobsters	1	1	2.11	5.73	1.32
	Ad. snappers	1	1	7.52	4.13	1		Large crabs	1	1.38	24.2	12.3	1.61
	Sub. snappers	1	1.25	26.8	15.3	2.1		Small crabs	1	1	4.81	2.14	1
	Juv. snappers	1	6.98	140	84.4	11.2		Crown of thorns	1	1	2	8.6	1.26
	Ad. Napoleon wrasse	1	1.47	1	1	1		Giant triton	1	1	2.57	4.23	1
	Sub. Napoleon wrasse	1	1.87	5.71	5.99	1.87		Herbivorous echinoids	1	1	6.11	5.56	1
	Juv. Napoleon wrasse	1	1.26	3.77	1.15	1.26		Bivalves	1	2.62	78.6	78.6	2.62
	Juv. coral trout	1	1.58	15.4	132	49.1		Sessile filter feeders	1	1.63	57	75	1.9
	Juv. rays	1	2.53	7.89	19.8	1.35		Epifaunal det. inverts.	1	1	8.09	6.2	1
	Ad. butterflyfish	1	1	2.14	45.9	1		Epifaunal carn. inverts	1	1.08	5.38	7.11	1.08
	Juv. butterflyfish	1	1	1	1	1		Infaunal inverts.	1	1.71	5.68	9.61	1.71
	Juv. large reef assoc.	1	1	6.77	20.3	20.3		Carn. zooplankton	1	2.26	8.09	25.7	1.89
	Ad. medium reef assoc.	1	1.64	5.45	7.62	1		Large herb. zooplankton	1	5.39	4.6	14.6	4.49
	Juv. medium reef assoc.	1	4.41	618	618	618		Small herb. zooplankton	1	7.54	6.99	22.2	6.29
	Ad. small reef assoc.	1	1	6.25	18.8	1		Phytoplankton			2	2	
	Juv. small reef assoc.	1	4.19	36.7	114	3.67		Detritus	1	2			2
	Juv. large demersal	1	1	9.28	4.74	1		Skipjack tuna	1.25	5.3	9.81	5.44	2.49
	Ad. small demersal	1	1	1.11	1.11	1		Other tuna	1.04	1.05	1339	1.57	1.63
	Juv. small demersal	1	1	1.06	4.33	1		Mackerel	1.25	5.02	10.6	9.85	10.1
	Juv. large planktivore	1	3.06	1	1.59	3.06		Ad. large pelagic	1.25	3.53	2.61	2.48	10.6
	Ad. small planktivore	1	1	1.52	3.58	1.14		Juv. large pelagic	1.25	4.26	3.31	3.14	12.8
	Juv. small planktivore	1	1.55	1	5.78	1.55		Ad. medium pelagic	1.01	31.8	38	13.1	127
Ad. deepwater fish	1	1	7.39	12.9	1		Juv. medium pelagic	1.25	1	1	1	1	
Juv. deepwater fish	1	1.18	9.11	15.7	1		Ad. small pelagic	1.25	2.04	1	2.04	26.5	
Ad. macro algal browsing	1	2.04	2.48	7.13	2.83		Juv. small pelagic	1.01	8.68	4.65	9.01	82	
Juv. macro algal browsing	1	1.93	5.51	16.1	3.86		Ad. large planktivore	1.25	3.98	1	1	7.97	
Ad. eroding grazers	1	1.16	5.8	11.6	11.6		Juv. large planktivore	1.25	1.26	2.29	9.27	2.78	
Juv. eroding grazers	1	1.5	2.5	15	15		Ad. small planktivore	1.25	9.61	2.43	22.3	17.6	
Ad. scraping grazers	1	4.28	16.1	24	12.9		Juv. small planktivore	1.25	1	1.86	1	1	
Juv. scraping grazers	1	1	1	1	1		Ad. anchovy	1.25	1	1	198	1.61	
Detritivore fish	1	1	1	9.04	1		Juv. anchovy	1.25	13.1	1	1.31	26.3	
Squid	1	1.16	14.2	8.87	1.22		Ad. deepwater fish	1.25	1	1	1	1	
Octopus	1	1.34	5.08	9.6	2.01		Juv. deepwater fish	1.25	1	1	2.17	1	
Sea cucumbers	1	1	3.17	3.93	1		Penaeid shrimps	69.2	434	421	1314	1013	
Lobsters	1	1	1	1	1		Shrimps and prawns	1.25	13.7	11.4	35.7	27.5	
Large crabs	1	2.06	22.5	14.7	2.15		Squid	1.25	6.14	21.8	22.2	13.5	
Small crabs	1	1	5.29	2.71	1		Octopus	1.25	6.39	4.49	14.1	14.4	
Crown of thorns	1	1	1	1	1		Lobsters	1.25	9.68	4.84	20.2	96.8	
Giant triton	1	1.22	75.2	2.59	6.45		Large crabs	1.25	4.63	15.4	18.8	46.3	
Herbivorous echinoids	1	1.01	1.07	1.15	1		Small crabs	1.25	4.63	23.1	20.1	9.25	
Bivalves	1	3.08	6.84	13	3.42		Giant triton	1.25	5.3	5.3	17.5	5.3	
Sessile filter feeders	1	2.04	8.36	15.6	2.16		Bivalves	1.25	22.2	18.5	55.8	222	
Epifaunal det. inverts.	1	1	7.16	6.28	1		Epifaunal det. inverts.	1.25	3.61	10.6	15.7	9.03	
Epifaunal carn. inverts	1	1.39	5.86	8.71	1.52		Epifaunal carn. inverts	1.25	4.84	4.4	10.9	9.69	
Infaunal inverts.	1	1.49	6.78	13.3	1.87		Infaunal inverts.	1.25	15.1	21.6	65.2	151	
Carn. zooplankton	1	3.06	8.77	32.3	2.48		Carn. zooplankton	1.25	114	106	639	206	
Large herb. zooplankton	1						Large herb. zooplankton	1.25	22.6	39.8	252	40.2	

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	
Other tuna	Small herb. zooplankton	1.25	10.9	5.98	35.9	21.8	Billfish	Ad. small planktivore	1	1.52	1	2.26	1.3	
	Skipjack tuna	2						Juv. small planktivore	1	1	1.74	1	1	1
	Other tuna	22.7	426	435	379	426		Ad. anchovy	1	1	1	1.06	1	
	Juv. large sharks	22.7	31.6	316	147	316		Juv. anchovy	1	1.35	1	1	1.4	
	Juv. small sharks	22.7	31	485	60.2	194		Ad. deepwater fish	1	1.7	1.7	1.7	1	
	Juv. rays	22.7	93.8	3752	376	375		Juv. deepwater fish	1	7.39	18.5	25.7	3.7	
	Ad. large pelagic	22.7	1073	>1E8	1036	>1E8		Ad. macro algal browsing	1	1.98	1	1	1.98	
	Juv. large pelagic	22.7	377	>1E8	288	2263		Ad. eroding grazers	1	1	1	1	1	
	Ad. medium pelagic	1.01	8.35	355	3.3	142		Ad. scraping grazers	1	2.31	15.4	20.7	2.31	
	Juv. medium pelagic	22.7	20.2	436	16.1	283		Juv. scraping grazers			2	2		
	Ad. small pelagic	22.7	33.5	335	37.3	670		Detritivore fish	1	1.14	1.05	14.2	1	
	Juv. small pelagic	22.7	44.3	45.4	42.5	1018		Penaeid shrimps				2	2	
	Juv. medium reef assoc.	22.7						Shrimps and prawns	1	5.4	2.7	3.65	5.4	
	Ad. large planktivore	22.7	179	5.12	1	179		Squid	1	38.3	139	72.8	51	
	Juv. large planktivore	22.7	3.98	264	29.2	28.1		Octopus				2	2	
	Ad. small planktivore	22.7	163	1303	410	652		Carn. zooplankton	1		236	708		
	Juv. small planktivore	22.7	89.8	233	125	526		Large herb. zooplankton	1					
	Ad. anchovy	22.7	15.9	279	>1E8	107		Skipjack tuna	1.01	1	1	1	1	
	Juv. anchovy	22.7	266	8.3	2.61	266		Other tuna	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. deepwater fish	22.7	80.1	8410	640	280		Mackerel	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. deepwater fish	22.7	69.1	2073	432	207		Billfish	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Anemonies	22.7	161	161	161	161		Ad. large pelagic	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Penaeid shrimps	22.7	577	>1E8	1899	2307		Ad. medium pelagic	1.01	4.58	10.2	2.17	17	
	Shrimps and prawns	22.7	101	1015	650	1015		Ad. small pelagic	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Squid	22.7	107	5330	406	533		Juv. small pelagic	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Octopus	22.7	85.1	1703	237	1703		Ad. large planktivore	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Sea cucumbers	22.7	70.4	70.4	70.4	70.4		Ad. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Lobsters	22.7	429	429	370	429		Juv. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Large crabs	22.7	65.6	656	342	656		Ad. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Small crabs	22.7	131	1312	364	1312		Juv. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Crown of thorns	22.7	368	368	368	368		Ad. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Giant triton	22.7	53.6	536	400	536		Juv. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Herbivorous echinoids	22.7	74.9	74.9	74.9	74.9		Penaeid shrimps	2	248	248			
	Bivalves	22.7	309	309	309	309		Shrimps and prawns	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Sessile filter feeders	22.7	5275	5275	5275	5275		Squid	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Epifaunal det. inverts.	22.7	79.2	1584	289	1584		Octopus				2	2	
	Epifaunal carn. inverts	22.7	69.7	697	200	697		Lobsters	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Infaunal inverts.	22.7	3662	3662	3662	3662		Large crabs	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Jellyfish and hydroids	22.7	4.54	4.54	4.54	4.54		Small crabs	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Carn. zooplankton	22.7	125	3848	630	701		Giant triton	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Large herb. zooplankton	22.7	75.1	4595	760	427		Bivalves				2	2	
	Small herb. zooplankton	22.7	205	1172	181	821		Epifaunal det. inverts.	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Macro algae	22.7	1	1	1	1		Epifaunal carn. inverts	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Sea grass	22.7	1	1	1	1		Infaunal inverts.	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
	Mackerel	Ad. groupers	1	1	1	1		1	Ad. coral trout	Ad. groupers	1	1.6	1	1
Sub. groupers		1	2.48	8.27	24.8	1.24	Sub. groupers	1		6.16	61.6	1.83	1.03	
Ad. snappers		1	1	1	1	1	Ad. snappers	1		1	1	1	1	
Sub. snappers		1	1.98	9.9	4.12	1.98	Sub. snappers	1		1.33	1	1	1	
Ad. Napoleon wrasse		1	144	7.97	6.63	144	Juv. snappers						2	
Sub. Napoleon wrasse		1	1	1	1	1	Ad. Napoleon wrasse	1		1	1	1	1	
Other tuna		1	1	1	1	1	Sub. Napoleon wrasse	1		1	1	1	1	
Mackerel		1	1	1.93	1	1	Ad. butterflyfish	1		1	1	1	1	
Ad. butterflyfish		1	1.2	1.2	1.2	1.2	Juv. butterflyfish	1		1	1.39	1	1	
Juv. butterflyfish		1	1.55	1.16	19.5	5.3	Cleaner wrasse	1		1	1	1.08	1	
Cleaner wrasse		1	1.18	1	14.7	1.06	Juv. medium pelagic	1						
Ad. large pelagic		1	1	1	1	1.34	Ad. large reef assoc.	1		1	1	1	1	
Juv. large pelagic		1	1.1	1	1	1.61	Juv. large reef assoc.	1		1	1	1	1	
Ad. medium pelagic		1	1	1	1	1	Ad. medium reef assoc.	1		2.1	1	1	1	
Juv. medium pelagic		1	1	1	1	1.02	Ad. small reef assoc.	1		1	1	1	1	
Ad. small pelagic		1	1	172	1	1.91	Juv. small reef assoc.	1		1	1	1	1	
Juv. small pelagic		1	1	1	1	2	Ad. large demersal	1		1	1	1	1	
Ad. large reef assoc.		1	1	1	1.61	3.9	Ad. small demersal	1		1	1	1	1	
Juv. large reef assoc.		1	1.24	1.98	4.37	2.48	Ad. large planktivore	1		1	1	1	1	
Ad. medium reef assoc.		1	1	1	1	1	Juv. large planktivore					2	2	
Juv. medium reef assoc.		1	1	1.78	2.07	1	Ad. small planktivore	1		1.49				1
Ad. small reef assoc.		1	1	1.01	2.36	1	Ad. anchovy	1		19.5	1	1	1	
Ad. large demersal		1	1.2	1.2	1	1.2	Juv. anchovy	1		1.93	1	1	1	
Ad. small demersal		1	1	1	1	1	Ad. deepwater fish	1		1	1	1	1	
Ad. large planktivore		1	1.9	1.9	1.9	1.9	Juv. deepwater fish	1		1	1	1	1	
Juv. large planktivore				2	2		Ad. macro algal browsing	1		8.1	1	1	1	1

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	
Juv. coral trout	Ad. eroding grazers	1	1	1	1	1	Juv. large sharks	Juv. small sharks	1	24	6.49	19.4	4.73	
	Ad. scraping grazers	1	1.58	1	1.17	1		Whale shark	1	1	1.18	1.03	1	
	Juv. scraping grazers			2	2			Manta ray	1	1.27	1	1	1	
	Detritivore fish	1	1	1	1	1		Adult rays	1	73.5	73.5	73.5	73.5	
	Penaeid shrimps	1	1	1	1	1		Juv. rays	2					
	Shrimps and prawns	1	1	1	1	1		Ad. butterflyfish	1	1.19	1	13.1	1	
	Squid	1	1.07	1	1	1		Juv. butterflyfish	1	1.61	1	18.1	1.11	
	Octopus			2	2			Cleaner wrasse	1	1.6	1	13.7	1	
	Lobsters	1	4.3	1	1	1		Ad. large pelagic	1	1	1	1	1	
	Large crabs	1	1.1	1	1	1		Ad. medium pelagic	1	1	1	1	1	
	Small crabs	1	3.7	1	1	1		Ad. small pelagic	1	1	1	1	1	
	Giant triton	1	1.12	1	1	1		Ad. large reef assoc.	1	1	1	1.5	1	
	Bivalves			2	2			Juv. large reef assoc.	1	1.19	1.44	4.06	1	
	Epifaunal det. inverts.	1	2.4	1	1	1		Ad. medium reef assoc.	1	1	1	1	1	
	Epifaunal carn. inverts	1	6.7	1	1	1		Ad. small reef assoc.	1	1	1	1	1	
	Infaunal inverts.	1	1	1	1	1		Ad. large demersal	1	1	1	1	1	
	Ad. groupers	1	1	1	1	1		Ad. small demersal	1	1	1	1	1	
	Sub. groupers	1	14.2	1	1	1		Ad. large planktivore	1	1	1.04	2.69	1	
	Ad. snappers	1	1.1	1	1	1		Juv. large planktivore			2	2		
	Sub. snappers	1	1	1	1	1		Ad. small planktivore	1	1.53	1	2.1	1	
	Juv. snappers					2		Ad. anchovy	1	1	1	1	1	
	Ad. butterflyfish	1	2.2	1	1	1		Juv. anchovy	1	13.1	1	1.34	1	
	Juv. butterflyfish	1	1	1.74	1	1		Ad. deepwater fish	1	1	1	1.68	1	
	Cleaner wrasse	1	1	1	1	1		Juv. deepwater fish	1	1.02	1.13	2.04	1	
	Ad. large reef assoc.	1	1	1	1	1		Ad. macro algal browsing	1	1.6	1	1	1.6	
	Juv. large reef assoc.	1	1	1	1	1		Ad. eroding grazers	1	1	1	1	1	
	Ad. medium reef assoc.	1	1	1	1	1		Ad. scraping grazers	1	1.84	11.8	19.1	1.84	
	Juv. medium reef assoc.	1	1	1	1	1		Juv. scraping grazers			2	2		
	Ad. small reef assoc.	1	1	1	1	1		Detritivore fish	1	1.26	1	13.2	1	
	Ad. large demersal	1	1	1	1	1		Anemonies	1	1	1	1	1	
	Ad. small demersal	1	1	1	1	1		Penaeid shrimps			2	2		
	Ad. large planktivore	1	1	1	1	1		Shrimps and prawns	1	2.8	1.4	2.8	2.8	
	Juv. large planktivore			2	2			Squid	1	1.31	3.23	2.09	1	
	Ad. small planktivore	1	1	5.66	1	1		Octopus	1	1.04	1	1	1	
	Ad. anchovy	1	1.3	1	1	1		Sea cucumbers	1	1	1	1	1	
	Juv. anchovy	1	1.81	1	1	1		Lobsters	1	2.7	1	1.94	2.7	
	Ad. deepwater fish	1	1	1	1	1		Large crabs	1	1	1	1	1	
	Juv. deepwater fish	1	1	1	1	1		Small crabs	1	1.3	1.3	1.3	1.3	
	Ad. macro algal browsing	1	2.2	1	1	1		Crown of thorns	1	1	1	1	1	
	Juv. macro algal browsing	1	1	1	1	1		Giant triton	1	1.38	1	2.05	1	
	Ad. eroding grazers	1	1	1	1	1		Herbivorous echinoids	1	1	1	1	1	
	Juv. eroding grazers	1		1	1			Bivalves	1	1	1	1	1	
	Ad. scraping grazers	1	1.9	1	1			Sessile filter feeders	1	1	1	1	1	
	Juv. scraping grazers			2	2	2		Epifaunal det. inverts.	1	3	1.5	1.48	1	
	Detritivore fish	1	1	1	1	1		Epifaunal carn. inverts	1	1	1	1	1	
Penaeid shrimps			2	2		Infaunal inverts.	1	1	1	1	1			
Shrimps and prawns	1	7.7	1	1	1	Jellyfish and hydroids	1	1	1	1	1			
Squid	1	2.9	1	1	1	Carn. zooplankton	1	4.9	1	2.9	1			
Octopus			2	2		Large herb. zooplankton	1	1	1	1	1			
Mysticetae	1	1.75	1.46	1.34	1	Small herb. zooplankton	1	1	1	1	1			
Pisc. odontocetae	1	1.11	1	1	1	Macro algae	1	1	1	1	1			
Deep. odontocetae	1	6.4	1.28	1.36	1	Sea grass	1	1	1	1	1			
Birds	1	1	1	1	1	Fishery discards	1	2	2	2	2			
Reef assoc. turtles	1	1	1	1.04	1	Detritus	1	2	2	2	2			
Green turtles	1	1	1	1	1	Ad. groupers	1	1	1	1	1			
Oceanic turtles	1	1	1	1	1	Sub. groupers	1	2.6	2.6	2.6	1			
Crocodiles	1	1.32	1.07	1	1	Ad. snappers	1	1	1	1	1			
Ad. groupers	1	1	1	1	1	Sub. snappers	1	13.9	6.95	4.22	1			
Sub. groupers	1	6.71	6.1	23.1	1	Ad. Napoleon wrasse	1	1	1	1	1			
Ad. snappers	1	4	4	2.14	1	Sub. Napoleon wrasse	1	1	1	1	1			
Sub. snappers	1	1.49	6.61	3.83	1	Ad. large sharks			2					
Ad. Napoleon wrasse	1	14.4	2.67	2.98	3.6	Juv. large sharks			2					
Sub. Napoleon wrasse	1	1	1	1	1	Ad. small sharks	1	25.2	3.87	5.94	1.48			
Skipjack tuna	1	1	1	1	1	Juv. small sharks	1	54.6	5.61	17.1	4.28			
Other tuna	1	1	1	1	1	Ad. butterflyfish	1	4	1	4	1			
Mackerel	1	1	1	1	1	Juv. butterflyfish	1	4.65	1	20	1.35			
Billfish	1	140	69.8	59.4	6.98	Cleaner wrasse	1	3.73	1	15	1			
Ad. large sharks	1	3.6	1.2	1.02	3.6	Ad. large reef assoc.	1	2.01	1	20.1	20.1			
Juv. large sharks	1	3.38	1	8.31	8.46	Juv. large reef assoc.	1	3.51	1.48	4.48	1			
Ad. small sharks	1	1	2.9	2.9	2.9	Ad. medium reef assoc.	1	1	1	1	1			

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Juv. medium reef assoc.	1	5.51	1.41	2.13	1		Billfish	1.18	3.8	6.33	3.76	1.9
	Ad. small reef assoc.	1	1	1	2.41	1		Ad. coral trout	1.18	3	60.1	36.6	60.1
	Ad. large demersal	1	1	1	1	1		Ad. large sharks		2			
	Juv. large demersal	1	1	1	1	1		Juv. large sharks	1.18	1	1.43	2.33	13.1
	Ad. small demersal	1	4.3	1	1	1		Ad. small sharks	1.18	10	12.2	12.1	10
	Ad. large planktivore	1	3.4	1.13	3.01	1		Juv. small sharks	1.18		2.74		
	Juv. large planktivore	1	5.2	2.3	6.16	1		Juv. butterflyfish	1.18	3.75	3.44	50.9	15
	Ad. small planktivore	1	6.7	1	2.29	1		Ad. large pelagic	1.18	1.77	1.77	1	1.77
	Juv. small planktivore	1	2.81	1	1	1		Ad. medium pelagic	1.18	4.25	1.42	1	4.25
	Ad. anchovy	1	1.6	1	1	1		Ad. small pelagic	1.18	1.17	1	1	23.4
	Juv. anchovy	1	4.67	1	1.49	1		Juv. small pelagic	1.18	1.08	1	1	4.86
	Ad. deepwater fish	1	1	1	1	1		Ad. large planktivore	1.18	1	1	1	1
	Juv. deepwater fish	1	9.7	1.21	2.26	1		Juv. large planktivore	1.18	3.95	9.36	15.8	4.44
	Ad. macro algal browsing	1	7.7	1	1.04	1		Ad. small planktivore	1.18	8.02	1.15	5.9	8.02
	Juv. macro algal browsing	1	2.87	1	1.15	1		Juv. small planktivore	1.18	2.19	1	1.81	2.19
	Ad. eroding grazers	1	1	1	1	1		Ad. anchovy	1.18	4.48	1	1	4.48
	Juv. eroding grazers			2	2			Juv. anchovy	1.18	4.91	3.78	3.78	9.83
	Ad. scraping grazers	1	1.7	1.7	1.7	1.7		Ad. deepwater fish	1.18	1	1	1	1
	Juv. scraping grazers	1	4.38	1	6	2.19		Juv. deepwater fish	1.18	3.42	3.42	3.42	3.42
	Detritivore fish	1	2.75	1	14.7	1		Penaeid shrimps			2	2	
	Penaeid shrimps	1	11.8	1.07	2.11	1		Shrimps and prawns	1.18	1	1	1	1
	Shrimps and prawns	1	11.8	1.69	3.73	1		Octopus			2	2	
	Squid	1	1.81	3.02	2.31	1		Large crabs	1.18	1	1	1	1
	Octopus	1	2.9	1	1	1		Small crabs	1.18	15.1	15.1	5.39	15.1
	Lobsters	1	1	1	1	1		Bivalves			2	2	
	Large crabs	1	1	1	1	1		Epifaunal det. inverts.	1.18	1	1	1	1
	Small crabs	1	1	1	1	1		Epifaunal carn. inverts	1.18	1	1	1	1
	Giant triton	1	8.1	1.01	2.18	1		Infauanal inverts.	1.18	1	1	1	1
	Bivalves	1	1	1	1	1	Whale shark	Skipjack tuna	2.29	1	1	1	1
	Epifaunal det. inverts.	1	1.9	1.9	1.64	1		Other tuna	2.29	1	1	1	1
	Epifaunal carn. inverts	1	1	1	1	1		Mackerel	2.29	1.37	1.37	1.37	1.37
	Infauanal inverts.	1	1	1	1	1		Ad. medium pelagic	2.29	1	1	1	1
	Carn. zooplankton	1	3.17	1	3.21	1		Ad. small pelagic	2.29	1	1	1	1
	Large herb. zooplankton	1	1.3	1.3	1.3	1		Juv. large planktivore			2	2	
	Small herb. zooplankton	1	1	1	1	1		Ad. small planktivore	2.29	1	1	1	1
Ad. small sharks	Skipjack tuna	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. anchovy	2.29	1			1
	Other tuna	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. anchovy			2	2	
	Mackerel	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. deepwater fish	2.29	1	1	1	1
	Billfish	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. deepwater fish	2.29	1	1	1	1
	Ad. large sharks		2					Penaeid shrimps			2	2	
	Juv. large sharks	>1E8	>1E8	>1E8	>1E8	>1E8		Shrimps and prawns	2.29	1	1	1	1
	Juv. small sharks	>1E8		>1E8				Squid	2.29	3.89	3.89	3.89	3.89
	Ad. large pelagic	>1E8	>1E8	>1E8	>1E8	>1E8		Octopus			2	2	
	Ad. medium pelagic	>1E8	>1E8	>1E8	>1E8	>1E8		Jellyfish and hydroids	2.29	1	1	1	1
	Ad. small pelagic	>1E8	>1E8	>1E8	>1E8	>1E8		Carn. zooplankton	2.29	1	1	1	1
	Juv. small pelagic	>1E8	>1E8	>1E8	>1E8	>1E8		Large herb. zooplankton	2.29	1	1	1	1
	Ad. small reef assoc.		2		2			Small herb. zooplankton	2.29	1	1	1	1
	Ad. large demersal	>1E8	>1E8	>1E8	>1E8	>1E8		Phytoplankton	2.29	1	1	1	1
	Ad. large planktivore	>1E8	>1E8	>1E8	>1E8	>1E8	Manta ray	Ad. medium pelagic	1	1	1	1	1
	Juv. large planktivore		2		2			Ad. small pelagic	1	1.5	1	1	1.5
	Ad. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. large planktivore	1	1	1	1	1
	Ad. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. large planktivore			2	2	
	Juv. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. small planktivore	1	3.2	1	3.2	3.2
	Ad. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. anchovy	1	1	1	1	1
	Juv. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. anchovy	1	1	1	1	1
	Penaeid shrimps	>1E8	>1E8	>1E8	>1E8	>1E8		Penaeid shrimps	1	1	1	1	1
	Shrimps and prawns	>1E8	>1E8	>1E8	>1E8	>1E8		Shrimps and prawns	1	1	1	1	1
	Squid	>1E8	>1E8	>1E8	>1E8	>1E8		Squid	1	1	5.9	3.47	5.9
	Octopus	>1E8	>1E8	>1E8	>1E8	>1E8		Octopus			2	2	
	Lobsters	>1E8	>1E8	>1E8	>1E8	>1E8		Jellyfish and hydroids	1	1	1	2.04	1
	Large crabs	>1E8	>1E8	>1E8	>1E8	>1E8		Carn. zooplankton	1	1.6	1	1.6	1.6
	Small crabs	>1E8	>1E8	>1E8	>1E8	>1E8		Large herb. zooplankton	1	1	1	1	1
	Giant triton	>1E8	>1E8	>1E8	>1E8	>1E8		Small herb. zooplankton	1	1.1	1.1	1.1	1.1
	Bivalves		2		2			Phytoplankton	1	1	1	1	1
	Epifaunal det. inverts.	>1E8	>1E8	>1E8	>1E8	>1E8	Adult rays	Ad. groupers	2	1	1	1	1
	Epifaunal carn. inverts	>1E8	>1E8	>1E8	>1E8	>1E8		Sub. groupers	2	4.9	16.3	4.9	4.9
	Infauanal inverts.	>1E8	1	1	1	1		Ad. snappers	2	3.8	3.8	3.8	3.8
Juv. small sharks	Skipjack tuna	1.18	2.36	1	1	1		Sub. snappers	2	13	13	13	13
	Other tuna	1.18	1	1	1	1		Ad. butterflyfish	2	7.6	1.52	7.6	7.6
	Mackerel	1.18	2.83	3.15	2.61	2.83		Juv. butterflyfish	2	3.14	2.24	31.4	31.4

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Cleaner wrasse	2	1.06	1.51	10.6	10.6		Soft corals	1.17	1.16	2.72	1	2.33
	Ad. large reef assoc.	2	1.6	1.6	1.6	1.6		Anemonies	1.17	1.22	196	20.5	2.45
	Juv. large reef assoc.	2	4	4	4	4		Penaeid shrimps	1.17	1.71	2.25	1	1.71
	Ad. medium reef assoc.	2	1	1	1	1		Shrimps and prawns	1.17	1.37	3.42	1	1.37
	Ad. small reef assoc.	2	2.2	1.1	2.2	2.2		Squid	1.17	1.24	6.31	1	1.36
	Ad. large demersal	2	1.6	1.6	1.6	1.6		Octopus	1.17	1.01	1.27	1	1.12
	Ad. small demersal	2	1	1	1	1		Sea cucumbers	1.17	1.21	2.01	1	1.21
	Ad. large planktivore	2	1.2	1.2	1.2	1.2		Lobsters	1.17	8.89	2.22	1	8.89
	Juv. large planktivore			2	2			Large crabs	1.17	1.3	4.33	1	1.3
	Ad. small planktivore	2	5	1	5	5		Small crabs	1.17	1.19	7.2	1	1.3
	Ad. anchovy	2	1	1	1	1		Crown of thorns	1.17	1.79	1.94	1	1.02
	Juv. anchovy	2	2.2	2.2	2.2	2.2		Giant triton	1.17	1.27	2.15	1	1.39
	Ad. deepwater fish	2	1.4	1.4	1.4	1.4		Herbivorous echinoids	1.17	1.36	3.88	1	1.36
	Juv. deepwater fish	2	1.8	1	1	1.8		Bivalves	1.17	3.28	2.73	1	3.28
	Ad. macro algal browsing	2	1	1	1	1		Sessile filter feeders	1.17	1.21	4.25	1	1.33
	Ad. eroding grazers	2	1	1	1	1		Epifaunal det. inverts.	1.17	1	7.04	1	1
	Ad. scraping grazers	2	3.1	31	31	31		Epifaunal carn. inverts	1.17	1	1.32	1	1
	Juv. scraping grazers			2	2			Infaunal inverts.	1.17	1	1.2	1	1.01
	Detritivore fish	2	3.04	2.34	30.4	3.04		Jellyfish and hydroids	1.17	1	1	1	1
	Penaeid shrimps	2	3.51	2.29	6.68	5.27		Carn. zooplankton	1.17	1.27	1.5	1	1.11
	Shrimps and prawns	2	1	1.51	4.35	2.21		Large herb. zooplankton	1.17	1	2.08	1	1
	Squid	2	5.8	5.8	5.8	5.8		Small herb. zooplankton	1.17	2.01	2.29	1	1.75
	Octopus	2	1	1	1	1		Phytoplankton	1.17	1.21	1.42	1	1.03
	Lobsters	2	1.52	1.69	7.96	15.2		Macro algae	1.17	1.24	1	1	1.24
	Large crabs	2	2.9	7.25	7.38	2.9		Sea grass	1.17	1.44	2.4	1	1.44
	Small crabs	2	2.78	9.27	7.83	2.78		Fishery discards	1.17	2	2	2	2
	Giant triton	2	2.27	2.74	8.42	3.98		Detritus	1.17	2	2	2	2
	Bivalves	2	3.33	3.44	10.2	9.98	Juv. butterflyfish	Juv. groupers	2	9.78	24.5	4.05	1
	Epifaunal det. inverts.	2	1.46	4.45	6.04	2.56		Juv. snappers	2	1.26	12.6	1	1.26
	Epifaunal carn. inverts	2	1.27	1.81	4.2	2.54		Juv. Napoleon wrasse	2	1.04	1	1	1
	Infaunal inverts.	2	6.4	1.28	3.98	6.4		Juv. coral trout	2	2.8	1	1	2.8
	Carn. zooplankton	2	7.66	6.96	39.7	15.3		Juv. rays	2	1.84	1.84	1	1
Juv. rays	Ad. small reef assoc.	1	1	1	1.22	1		Juv. butterflyfish	2	2.19	1.99	2.01	2.19
	Ad. small demersal	1	1	1	1	1		Juv. large reef assoc.	2	1	1	1	1
	Juv. deepwater fish			2	2			Juv. medium reef assoc.	2	1.91	3.25	1	1
	Juv. scraping grazers			2	2			Juv. small reef assoc.	2	1	1	1	1
	Penaeid shrimps	1	1.31	1.31	1.06	13.1		Juv. large demersal	2	1	1.4	1	1
	Shrimps and prawns	1	1.35	2.25	1.89	13.5		Juv. small demersal	2	1	1	1	1
	Octopus	1	1	1	1	2.21		Juv. large planktivore	2	2.09	5.45	1	1
	Sea cucumbers	1	1	1.41	1	2.12		Juv. small planktivore	2	1	1	1	1
	Lobsters	1	1	1	1.09	8.4		Juv. macro algal browsing	2	2.2	1	1	1
	Large crabs	1	1	3.3	1.01	9.9		Juv. eroding grazers	2	3.6	1.2	1	3.6
	Small crabs	1	1.71	4.28	1.07	1.71		Juv. scraping grazers	2	1.46	4.97	1.64	1.91
	Crown of thorns	1	1	1	1.76	18		Azooxanthellate corals	2	1.77	3.73	1	1.01
	Herbivorous echinoids	1	1.07	2.37	1.15	2.14		Hermatypic corals	2	3.2	3.2	1.11	3.2
	Bivalves			2	2			Non reef building corals	2	1.75	5.37	1.25	1
	Sessile filter feeders	1	1.05	1.31	1.14	1.05		Soft corals	2	1.77	3.37	1	1.01
	Epifaunal det. inverts.	1	1	2.14	1	1.32		Anemonies	2	2.6	2.6	1	2.6
	Epifaunal carn. inverts	1	1	1	1	1.62		Penaeid shrimps			2	2	
	Infaunal inverts.	1	1	1	1	4.1		Shrimps and prawns	2	10.8	3.6	1	1.08
Ad. butterflyfish	Juv. groupers	1.17	3.79	9.48	1.63	1.15		Squid	2	1.2	1.2	1	1.2
	Juv. snappers	1.17	1.4	12.5	1	2.81		Octopus	2	1.39	1.83	1	1
	Juv. Napoleon wrasse	1.17	1	1	1	1		Sea cucumbers	2	2.4	2.4	1	1
	Juv. coral trout	1.17	2.13	1	1	42.6		Lobsters	2	1.6	1.6	1	1.6
	Juv. rays	1.17	1.1	1.56	1	1		Large crabs	2	1	1	1	1
	Juv. butterflyfish	1.17	1.63	1.61	1.61	4.88		Small crabs	2	1	1	1	1
	Cleaner wrasse			2	2			Crown of thorns	2	1.02	1.28	1	1.02
	Juv. large reef assoc.	1.17	3.51	1	1	3.51		Giant triton	2	1	1	1	1
	Juv. medium reef assoc.	1.17	1.53	2.61	1	1		Herbivorous echinoids	2	2.2	2.2	1	2.2
	Juv. small reef assoc.	1.17	36.5	122	17	36.5		Bivalves	2	1.26	3.15	1	1
	Juv. large demersal	1.17	1	1.34	1	1		Sessile filter feeders	2	1.21	2.69	1	1
	Juv. small demersal	1.17	1	1	1	1		Epifaunal det. inverts.	2	1	3.1	1	1
	Juv. large planktivore	1.17	1.81	4.53	1	1.81		Epifaunal carn. inverts	2	1	1.64	1	1
	Juv. small planktivore	1.17	1	1	1	1		Infaunal inverts.	2	1.13	1.58	1	1
	Juv. macro algal browsing	1.17	1.56	1	1	1.56		Jellyfish and hydroids	2	1	1	1	1
	Juv. eroding grazers	1.17	1	1	1	9.24		Carn. zooplankton	2	1.6	1.87	1	1
	Juv. scraping grazers	1.17	1.02	1	1	10.2		Large herb. zooplankton	2	1.02	2.52	1	1
	Azooxanthellate corals	1.17	1.16	3.02	1	2.33		Small herb. zooplankton	2	2.76	1.82	1	1
	Hermatypic corals	1.17	1.46	4.16	1	2.91		Phytoplankton	2	1.58	1.78	1	1
	Non reef building corals	1.17	1.16	4.29	1	2.33		Macro algae	2	1.59	1	1	1

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool		
Cleaner wrasse	Sea grass	2	1.48	3.17	1	1	Juv. large pelagic	Ad. macro algal browsing	2	3.36	1.64	7.92	3.36		
	Ad. groupers	3.6	1	1	1	1		Ad. eroding grazers	2	2	2	2	2		
	Sub. groupers	3.6	11.9	34	8.78	4.76		Ad. scraping grazers	2	5.52	55.2	55.2	55.2		
	Ad. butterflyfish	3.6	1.8	1.8	1.8	1.8		Juv. scraping grazers				2	2		
	Juv. butterflyfish	3.6	7.2	3.6	6.67	7.2		Detritivore fish	2	3.5	4.52	112	2.1		
	Ad. large reef assoc.	3.6	3.24	3.24	1	3.24		Penaeid shrimps				2	2		
	Juv. large reef assoc.	3.6	6.48	6.48	1.51	6.48		Shrimps and prawns	2	3.9	7.54	23.2	2.92		
	Ad. medium reef assoc.	3.6	1.44	1.44	1.44	1.44		Squid	2	3.46	17.3	17.9	3.46		
	Ad. small reef assoc.	3.6	1.44	3.92	1	1.54		Octopus	2	2.7	1.93	5.93	2.7		
	Juv. small reef assoc.	3.6	1	1.14	1	1		Lobsters	2	4	4	4	4		
	Ad. large demersal	3.6	2.59	3.7	1	1.3		Large crabs	2	1.4	1.4	1.4	1.4		
	Ad. small demersal	3.6	1.26	1	1	1		Small crabs	2	5.6	5.6	5.6	5.6		
	Ad. large planktivore	3.6	11.9	5.94	1.03	11.9		Giant triton	2	1	1	1	1		
	Juv. large planktivore			2	2			Bivalves	2	1	1	1	1		
	Ad. small planktivore	3.6	7.19	1.88	1	6.16		Epifaunal det. inverts.	2	1.46	7.3	12.7	1.46		
	Ad. anchovy	3.6	2.66	13.3	1.07	2.66		Epifaunal carn. inverts	2	4.6	4.6	4.6	4.6		
	Juv. anchovy	3.6	17.6	4.41	1	17.6		Infaunal inverts.	2	1.2	1.2	1.2	1.2		
	Ad. deepwater fish	3.6	1.94	4.86	1	1		Carn. zooplankton	2	3.15	3.78	23.1	1.89		
	Juv. deepwater fish	3.6	2.41	6.03	1	2.41		Large herb. zooplankton	2	4.23	7.69	46.2	2.12		
	Ad. scraping grazers	3.6	30.6	30.6	7.27	30.6		Small herb. zooplankton	2	6.16	5.13	31.3	3.08		
	Juv. scraping grazers			2	2			Macro algae	2	1	1	1	1		
	Detritivore fish	3.6	5.12	5.12	5.05	5.12		Sea grass	2	1	1	1	1		
	Azooxanthellate corals	3.6	5.12	8.44	2.97	10.6		Ad. groupers	1.48	1	1	1	1		
	Hermatypic corals	3.6	5.17	10.7	3.74	10.3		Sub. groupers	1.48	10.4	10.4	10.4	1.04		
	Non reef building corals	3.6	5.23	12.1	4.27	10.9		Ad. snappers	1.48	1	1	1	1		
	Soft corals			2	2			Sub. snappers	1.48	1.64	16.4	16.4	1.64		
	Epifaunal det. inverts.	3.6	3.85	10.8	1	4.33		Skipjack tuna	1.48	1.33	1	1	1		
	Epifaunal carn. inverts	3.6	3.07	3.74	1	3.83		Other tuna	1.48	1	36.1	1	1		
	Infaunal inverts.	3.6	3.89	3.24	1	3.89		Mackerel	1.48	1.71	2.46	4.93	1.17		
	Ad. large pelagic	Ad. groupers	2	1	1	1		1	Billfish	1.48	2.2	4.88	7.1	1	
		Sub. groupers	2	8.8	44	88		2.93	Ad. butterflyfish	1.48	1.76	1.96	17.6	1.76	
		Ad. snappers	2	1	1	1		1	Juv. butterflyfish	1.48	2.65	2.75	96	6.31	
Sub. snappers		2	5.52	27.6	32.7	5.52	Cleaner wrasse	1.48	2.04	2.06	72.4	1.33			
Ad. Napoleon wrasse		2	1	1	1	1	Ad. large pelagic	1.48	1.27	1.16	1.24	1.27			
Sub. Napoleon wrasse		2	1	1	1	1	Ad. medium pelagic	1.48	304	304	304	304			
Skipjack tuna		2	20.9	41.8	42	10.5	Ad. small pelagic	1.48	1	1	1.02	2.34			
Other tuna		2	1	178	1	1	Juv. small pelagic	1.48	1	1	1.08	2.75			
Mackerel		2	3	3.93	7.93	2.06	Ad. large reef assoc.	1.48	1.33	1.33	1.33	1.33			
Billfish		2	3.55	7.61	11.4	1.33	Juv. large reef assoc.	1.48	1.86	4.73	21.5	3.25			
Ad. large sharks		2	1	1	1	1	Ad. medium reef assoc.	1.48	1.04	1.04	1.04	1.04			
Juv. large sharks		2	3.2	3.2	3.2	3.2	Juv. medium reef assoc.	1.48	2.18	2.72	6.22	1			
Ad. small sharks		2	1	1	1	1	Ad. small reef assoc.	1.48	1	2.42	11.6	1			
Juv. small sharks		2	5.8	1	3.67	1	Juv. small reef assoc.	1.48	1	1	3.38	1			
Adult rays		2	1	1	1	1	Ad. large demersal	1.48	1.63	1.63	1.63	1.63			
Juv. rays		2	3.8	3.8	3.8	3.8	Juv. large demersal	1.48	1	2.33	2.45	1			
Ad. butterflyfish		2	2.6	2.6	2.6	2.6	Ad. small demersal	1.48	1	1	2.63	1			
Juv. butterflyfish		2	2.97	2.9	102	6.93	Ad. large planktivore	1.48	1	3.7	7.4	1			
Cleaner wrasse		2	3.42	3.7	116	2.22	Ad. small planktivore	1.48	2.66	1.09	11.2	1.6			
Ad. large pelagic		2	29.3	22.6	22	29.3	Juv. small planktivore	1.48	1.66	1	3.42	1			
Juv. large pelagic		2	2.34	2.47	2.53	2.34	Ad. anchovy	1.48	1.48	1	1	1.09			
Ad. medium pelagic		2	12.2	19.8	6.51	19.8	Juv. anchovy	1.48	4.38	3	7.07	3.18			
Juv. medium pelagic		2	1	1	1	1	Ad. deepwater fish	1.48	2.81	2.81	2.81	1			
Ad. small pelagic		1.01	6.01	2.1	8.04	18.7	Juv. deepwater fish	1.48	1	3.49	10.8	1			
Juv. small pelagic		2	276	276	276	276	Ad. macro algal browsing	1.48	11.1	1.11	4.96	1.11			
Ad. large reef assoc.		2	5.6	2.8	5.6	5.6	Ad. eroding grazers	1.48	1	1	1	1			
Juv. large reef assoc.		2	3.2	7.69	34.6	6.41	Ad. scraping grazers	1.48	1.55	15.5	15.5	15.5			
Ad. medium reef assoc.		2	1.6	1.6	1.6	1.6	Juv. scraping grazers	1.48	2.92	2.14	24.8	8.76			
Juv. medium reef assoc.		2	2.38	7.93	16.5	1	Detritivore fish	1.48	2.01	2.68	70.5	1.2			
Ad. small reef assoc.		2	1	3.8	18.6	1	Penaeid shrimps			2	2				
Juv. small reef assoc.		2	1	2.11	10.5	1	Shrimps and prawns	1.48	1	1	1	1			
Ad. large demersal		2	2.8	2.8	2.8	2.8	Squid	1.48	2.03	10.1	11.1	2.03			
Ad. small demersal	2	1.14	1	4.23	1	Octopus			2	2					
Ad. large planktivore	2	1.34	6.7	13.4	1.34	Lobsters	1.48	2.07	2.07	2.07	2.07				
Juv. large planktivore	2	1	1	1	1	Large crabs	1.48	1	1	1	1				
Ad. small planktivore	2	5.3	1.89	18	2.65	Small crabs	1.48	1	1	1	1				
Juv. small planktivore	2	2.78	1.35	5.5	1.67	Giant triton	1.48	2.31	3.85	10.9	1.15				
Ad. anchovy	2	2.39	2.32	5.48	1.19	Bivalves			2	2					
Juv. anchovy	2	7.58	4.33	10.2	5.05	Epifaunal det. inverts.	1.48	2.19	8.21	12	1.31				
Ad. deepwater fish	2	1.25	5	14.3	1	Epifaunal carn. inverts	1.48	1	1	1	1				
Juv. deepwater fish	2	2.09	6.08	17.5	1	Infaunal inverts.	1.48	1	1	1	1				

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	
Ad. medium pelagic	Carn. zooplankton	1.48	2.24	2.59	15.4	1.35	Ad. large reef assoc.	Juv. rays	2	4.95	19.8	20.1	1	
	Other tuna	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. large pelagic	2	4.48	11.9	3.08	1.28	
	Mackerel	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. medium pelagic	2	2.24	1	1	1.12	
	Billfish	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. small pelagic	2	1.64	2.05	2.12	1.64	
	Juv. butterflyfish	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. large planktivore	2	37.6	37.6	37.6	1.88	
	Ad. large pelagic	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. small planktivore	2	13.2	1.2	6.6	1.32	
	Juv. large pelagic	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. anchovy			2	2		
	Ad. medium pelagic	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. anchovy	2	5.2	5.2	5.2	5.2	
	Juv. medium pelagic	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. deepwater fish	2	1.84	18.4	18.4	1	
	Ad. small pelagic	1.01	2.32	2.82	6.12	4.35		Penaeid shrimps			2	2		
	Juv. small pelagic	>1E8	>1E8	>1E8	>1E8	>1E8		Shrimps and prawns	2	18.2	18.2	18.2	1.82	
	Ad. large planktivore	>1E8	>1E8	>1E8	>1E8	>1E8		Squid	2	6.99	69.9	21.8	1.4	
	Juv. large planktivore			2	2			Octopus			2	2		
	Ad. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8		Lobsters	2	4	20	20.3	4	
	Juv. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8		Large crabs	2	9.2	9.2	9.2	1	
	Ad. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8		Small crabs	2	9.2	9.2	9.2	1	
	Juv. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8		Giant triton	2	4.24	21.2	20.8	1.41	
	Ad. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8		Bivalves			2	2		
	Juv. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8		Epifaunal det. inverts.	2	2.5	25	15.3	1	
	Penaeid shrimps			2	2			Epifaunal carn. inverts	2	2	2	2	2	
	Shrimps and prawns	>1E8	>1E8	>1E8	>1E8	>1E8		Infaunal inverts.	2	7.8	7.8	7.8	1	
	Squid	>1E8	>1E8	>1E8	>1E8	>1E8		Jellyfish and hydroids	2	2.36	7.88	13	1	
	Octopus			2	2			Carn. zooplankton	2	2.42	7.82	12.3	1	
	Lobsters	>1E8	>1E8	>1E8	>1E8	>1E8		Large herb. zooplankton	2	120	782	1226	22.6	
	Large crabs	>1E8	>1E8	>1E8	>1E8	>1E8		Small herb. zooplankton	2	9.55	30.5	48	1.78	
	Small crabs	>1E8	>1E8	>1E8	>1E8	>1E8		Phytoplankton			2	2		
	Giant triton	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. small pelagic	Juv. large sharks	1	2.82	3.06	4.21	1.81
	Bivalves			2	2			Juv. small sharks	1	1	1.06	1	1	
	Epifaunal det. inverts.	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. rays	1	2.56	9.31	9.72	1	
	Epifaunal carn. inverts	>1E8	>1E8	>1E8	>1E8	>1E8		Cleaner wrasse	1	2.67	7.67	69.1	3.87	
Infaunal inverts.	>1E8	1	1	1	1	Juv. large pelagic	1	1.95	5.45	1.5	1			
Other tuna	4.16	3.37	1	5.86	1	Juv. medium pelagic	1	1.03	4.67	1	1			
Mackerel	4.16	10.8	7.83	46.7	4.31	Juv. small pelagic	1	2.69	2.68	2.74	1			
Juv. large sharks	4.16	3.11	9.58	41.7	14.2	Juv. large planktivore	1	3.93	27.2	28.5	1			
Juv. small sharks	4.16	4.38	1.25	19.4	1.79	Juv. small planktivore	1	1.89	1	3.27	1			
Juv. rays	4.16	5.41	9.01	54.1	2.7	Ad. anchovy			2	2				
Juv. butterflyfish	4.16	15.3	8.72	908	22.1	Juv. anchovy	1	1	1	1	1			
Ad. large pelagic	4.16	30.8	3.85	11.7	3.08	Juv. deepwater fish	1	1.94	16.3	12.2	1.36			
Juv. large pelagic	4.16	8.37	4.88	14.9	4.88	Penaeid shrimps			2	2				
Ad. medium pelagic	4.16	1	1	1	1	Shrimps and prawns	1	2.1	21	17.2	1.05			
Juv. medium pelagic	4.16	4.89	1.25	4.15	4.89	Squid	1	3.2	3.2	3.2	3.2			
Ad. small pelagic	4.16	3.86	1.69	9.65	7.23	Octopus			2	2				
Juv. small pelagic	4.16	3.55	1	10.2	10.6	Lobsters	1	2.84	9.47	9.66	1.42			
Ad. large planktivore	4.16	28.3	9.43	28.3	2.83	Large crabs	1	2.81	28.1	9.4	1			
Juv. large planktivore	4.16	13.1	18.7	131	6.55	Small crabs	1	5.11	51.1	18.3	1.28			
Ad. small planktivore	4.16	18.1	3.17	106	9.05	Giant triton	1	2.93	11.7	10.2	1			
Juv. small planktivore	4.16	11.4	1	32.3	3.81	Bivalves			2	2				
Ad. anchovy	4.16	8.18	254	1722	3.47	Epifaunal det. inverts.	1	1.3	25.9	7.55	1			
Juv. anchovy	4.16	124	2.1	14.6	12.4	Epifaunal carn. inverts	1	5.5	5.5	5.19	1			
Ad. deepwater fish	4.16	3.27	10.9	65.3	1	Infaunal inverts.	1	4.3	4.3	4.3	1			
Juv. deepwater fish	4.16	6.12	12.2	103	1.53	Jellyfish and hydroids	1	1	4.01	6.32	1			
Penaeid shrimps			2	2		Carn. zooplankton	1	4.2	13.9	21.7	1			
Shrimps and prawns	4.16	11.6	11.6	11.6	11.6	Large herb. zooplankton	1	1.91	8.17	12.8	1			
Squid	4.16	12	36	105	5.14	Small herb. zooplankton	1	4.5	12.3	19.4	1			
Octopus			2	2		Phytoplankton	1	2.66	8.93	4.64	1			
Lobsters	4.16	6.24	6.24	62.4	6.24	Ad. large reef assoc.	Ad. groupers	1	3.55	17.8	21.3	1.18		
Large crabs	4.16	15	15	15	15	Sub. groupers	1	3.68	36.8	1	1.23			
Small crabs	4.16	15	15	15	15	Juv. groupers	1	1	1	1	1			
Giant triton	4.16	1	1	1	1	Ad. snappers	1	28.4	28.4	12.8	28.4			
Bivalves			2	2		Sub. snappers	1	1.78	1	1	2.45			
Epifaunal det. inverts.	4.16	19.6	19.6	19.6	1.96	Juv. snappers	1	17	1	1	24.7			
Epifaunal carn. inverts	4.16	9.57	9.57	9.57	9.57	Ad. Napoleon wrasse	1	1	1.52	1	1			
Infaunal inverts.	4.16	2.5	2.5	2.5	2.5	Sub. Napoleon wrasse	1	1	1	1.16	1			
Jellyfish and hydroids	4.16	4.85	3.46	62.7	1.74	Juv. Napoleon wrasse	1	1	1	1	1			
Carn. zooplankton	4.16	11.3	8.07	146	4.03	Skipjack tuna	1	12.7	20.2	4.49	4.82			
Large herb. zooplankton	4.16	7.64	10.9	196	2.71	Other tuna	1	10.3	1846	3.64	5.95			
Small herb. zooplankton	4.16	18.2	7.07	128	6.51	Mackerel	1	1.24	2.04	1	1			
Phytoplankton	4.16	16	3.71	22.5	3.99	Billfish	1	1.43	4	1.27	1			
Ad. small pelagic	Juv. large sharks	2	1.47	22.7	8.64	3.56	Ad. coral trout	1	2.63	27.7	12.4	52.6		
	Juv. small sharks	2	2.09	230	4.02	1	Juv. coral trout	1	2.21			30.9		

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	
	Ad. large sharks	1	1	1	1	1		Juv. groupers	1	8.18	26	32.7	1	
	Juv. large sharks	1	1	1	1	1		Ad. snappers	1	1	1	1	1	
	Ad. small sharks	1	7.1	9.86	5.12	5.46		Sub. snappers	1	1.3	1.3	1.3	1.3	
	Adult rays	1	1	1.69	1	1		Juv. snappers	1	1.84	1	3.42	1.23	
	Juv. rays	1	3.37	5.55	4.6	2.92		Ad. Napoleon wrasse	1	1	1	1	1	
	Ad. butterflyfish	1	2.78	1.66	12.5	1.09		Sub. Napoleon wrasse	1	1	1	1	1	
	Juv. butterflyfish	1	1.89	2.2	17.2	1		Juv. Napoleon wrasse	1	1	1	1	1	
	Cleaner wrasse	1	15.8	1.79	13	1.05		Juv. coral trout	1	1.4	42	24.7	42	
	Ad. large pelagic	1	1	1.02	1	1		Juv. small sharks	1	1	1.46	1	1	
	Juv. large pelagic	1	1.07	13	2.82	1.2		Juv. rays	1	1.35	2.16	1.73	1	
	Ad. medium pelagic	1	1014	1014	1014	1014		Ad. butterflyfish	1	15.5	1.72	11.7	1	
	Juv. medium pelagic	1						Juv. butterflyfish	1	1.43	1.81	12.7		
	Ad. small pelagic	1	10.1	4.34	3.66	35.5		Cleaner wrasse	1	1.07	1.41	9.77	1	
	Ad. large reef assoc.	1	1	1.54	4.29	1		Juv. small pelagic	1	1	1	1	1	
	Juv. large reef assoc.	1	1	1	1	1		Ad. large reef assoc.	1	1	1	1.05	1	
	Ad. medium reef assoc.	1	1	1.87	1	1		Juv. large reef assoc.	1	1.05	1	1	1	
	Juv. medium reef assoc.	1	1.83	1	1	2.05		Ad. medium reef assoc.	1	48.2	48.2	48.2	48.2	
	Ad. small reef assoc.	1	4.3	6.63	7.28	1.12		Juv. medium reef assoc.	1	1.38	1.35	1.35	2.93	
	Juv. small reef assoc.	1	1	2.26	2.53	1		Ad. small reef assoc.	1	3.06	15.3	15.4	1.13	
	Ad. large demersal	1	1.53	17.3	3.93	3.32		Juv. small reef assoc.	1	1.49	7.48	7.45	1	
	Juv. large demersal	1	1	1.88	1	1		Ad. large demersal	1	1	1.37	1	1	
	Ad. small demersal	1	1.17	3.02	4.26	1		Juv. large demersal	1	1	1.52	1	1	
	Juv. small demersal	1	1.38	9.28	1.49	1.13		Ad. small demersal	1	2.9	8.35	1	1	
	Ad. large planktivore	1	1	1.75	1.6	1		Juv. small demersal	1	1	1	1.01	1	
	Juv. large planktivore	1	1.99	4.78	4.29	1.69		Ad. large planktivore	1	1	1	1	1	
	Ad. small planktivore	1	1.97	473	2	1.31		Juv. large planktivore	1	1	2.14	1	1	
	Juv. small planktivore	1	1	1	1	1		Ad. small planktivore	1	6.4	1	1.5	1	
	Ad. anchovy	1	1	1	3.57	1		Juv. small planktivore	1	1	3.4	1	1	
	Juv. anchovy	1	1	2.17	1	1		Ad. anchovy	1	1	1	1	1	
	Ad. deepwater fish	1	1.35	6.5	3.99	1.13		Juv. anchovy	1	2.39	1	1	1	
	Juv. deepwater fish	1	1.76	6.36	3.9	1.46		Ad. deepwater fish	1	12.1	12.1	12.1	1.21	
	Ad. macro algal browsing	1	2.47	2.32	1	1.77		Juv. deepwater fish	1	1	2.48	1.44	1.35	
	Juv. macro algal browsing	1	1	1	1	1.01		Ad. macro algal browsing	1	1.47	1	1	1	
	Ad. eroding grazers	1	5.4	1	5.4	5.4		Juv. macro algal browsing	1	1	1	1.47	1	
	Juv. eroding grazers	1	4.73	5.02	29.4	6.18		Ad. eroding grazers	1	36.7	1	36.7	36.7	
	Ad. scraping grazers	1	2.07	32.1	18.2	7.93		Juv. eroding grazers	1	75.5	1	1.84	75.5	
	Juv. scraping grazers	1	1	1	1	1		Ad. scraping grazers	1	80.7	80.7	80.7	80.7	
	Detritivore fish	1	1.43	2.41	12.5	1		Juv. scraping grazers	1	1.46				
	Azooxanthellate corals	1	1.89	3.78	7.03	1.89		Detritivore fish	1	1	1.61	7.84	1	
	Hermatypic corals	1	1	1	1	1		Azooxanthellate corals	1	3.2	3.2	3.2	3.2	
	Non reef building corals	1	1	4.75	9.5	9.5		Hermatypic corals	1	1	1	1	1	
	Soft corals	1	1.89	3.78	6.63	1.89		Non reef building corals	1	1.9	1.9	1.9	1.9	
	Anemonies	1	1.42	14.2	4.37	2.84		Soft corals	1	3.2	3.2	3.2	3.2	
	Penaeid shrimps			2	2			Anemonies	1	1	7.7	4.38	1	
	Shrimps and prawns	1	1	1.56	1.07	1		Penaeid shrimps			2	2		
	Squid	1	1.46	7.47	1.71	1		Shrimps and prawns	1	1.5	3.65	2.36	1	
	Octopus	1	1.87	71.6	1.59	1.62		Squid	1	5.48	6.92	1.47	2.26	
	Sea cucumbers	1	1.21	3.3	1.47	1.06		Octopus	1	1	1.54	1	1	
	Lobsters	1	4.05	5.79	4.62	6.48		Sea cucumbers	1	1.02	2.68	1.1	1	
	Large crabs	1	1	1.78	1	1		Lobsters	1	1.1	1.29	1.37	1	
	Small crabs	1	1.43	10.1	1.83	1.23		Large crabs	1	1.01	6.73	1.52	1	
	Crown of thorns	1	1.14	1	1	1		Small crabs	1	1.08	7.69	1.35	1	
	Giant triton	1	1.33	2.65	1.83	1.33		Crown of thorns	1	1.1	1.33	2.21	1	
	Herbivorous echinoids	1	2.81	6.9	2.59	1.23		Giant triton	1	1.16	2.1	1.42	1	
	Bivalves	1	2.19	3.39	2.31	1.89		Herbivorous echinoids	1	1.34	3.81	1.43	1	
	Sessile filter feeders	1	1.18	3.56	2.43	1.03		Bivalves	1	2.23	3.66	2.35	1	
	Epifaunal det. inverts.	1	1	1.77	1	1		Sessile filter feeders	1	1.08	2.21	1.43	1	
	Epifaunal carn. inverts	1	1	1.86	1	1		Epifaunal det. inverts.	1	1	2.68	1	1	
	Infaunal inverts.	1	1.01	1.24	1	1		Epifaunal carn. inverts	1	1	1.14	1	1	
	Jellyfish and hydroids	1	1	1.53	1.98	1		Infaunal inverts.	1	1	1.39	1	1	
	Carn. zooplankton	1	4.35	6.12	8.16	2.92		Jellyfish and hydroids	1	5.9	8.74	10.6	1.88	
	Large herb. zooplankton	1	2.97	8.1	10.9	2		Carn. zooplankton	1	1.1	1.57	1.98	1	
	Small herb. zooplankton	1	3.08	5.37	5.66	2.07		Large herb. zooplankton	1	1.2	3.54	4.44	1	
	Phytoplankton		2			2		Small herb. zooplankton	1	1.6	1.78	2.24	1	
	Macro algae	1	1.77	1	1.48	1.47		Phytoplankton	1	1	1.53	1	1	
	Sea grass	1	1.74	4.17	2.48	1.89		Macro algae	1	1	1	1	1	
	Fishery discards	1	2	2	2	2		Sea grass	1	1	3.22	1.41	1	
	Detritus	1	2	2	2	2		Ad. medium reef assoc.	Ad. groupers	>1E8	>1E8	>1E8	>1E8	>1E8
Juv. large reef assoc.	Ad. groupers	1	1	1	1	1		Sub. groupers	>1E8	>1E8	>1E8	>1E8	>1E8	
	Sub. groupers	1	5	16.7	20.6	1		Juv. groupers	>1E8	>1E8	>1E8	>1E8	>1E8	

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
Ad. snappers	>1E8	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. medium reef assoc.	Large herb. zooplankton	>1E8	>1E8	>1E8	>1E8	>1E8
Sub. snappers	>1E8	>1E8	>1E8	>1E8	>1E8	Small herb. zooplankton		>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
Juv. snappers	>1E8	>1E8	>1E8	>1E8	>1E8	Phytoplankton		>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
Ad. Napoleon wrasse	>1E8	>1E8	>1E8	>1E8	>1E8	Macro algae		>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
Sub. Napoleon wrasse	>1E8	>1E8	>1E8	>1E8	>1E8	Sea grass		>1E8	>1E8	>1E8	>1E8	>1E8	>1E8
Juv. Napoleon wrasse	>1E8	>1E8	>1E8	>1E8	>1E8	Fishery discards		2	2	2	2	2	2
Skipjack tuna	>1E8	>1E8	>1E8	>1E8	>1E8	Detritus		>1E8	2	2	2	2	2
Other tuna	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. groupers		2	1	1	1	1	1
Mackerel	>1E8	>1E8	>1E8	>1E8	>1E8	Sub. groupers		2	7.64	7.64	34	7.64	
Billfish	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. groupers		2	8.77	11.2	49	8.77	
Juv. coral trout	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. snappers		2	1.88	1	5.7	14.1	
Ad. large sharks	>1E8	1	1	1	1	Juv. Napoleon wrasse		2	1	1	1	2.9	
Juv. large sharks						Juv. coral trout		2	2.14	21.4	51.4	64.2	
Ad. small sharks	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. rays		2	1	1	1	1	
Adult rays	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. butterflyfish		2	1	1	1	1	
Juv. rays	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. large reef assoc.		2	1	1	1.51	4.44	
Ad. butterflyfish	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. medium reef assoc.		2	1.08	1	1.48	1.08	
Juv. butterflyfish	>1E8	1	1	1	1	Juv. medium reef assoc.		2	2.5	1.52	3.57	2.5	
Cleaner wrasse	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. small reef assoc.		2	1	1	3.24	1.56	
Ad. large pelagic	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. small reef assoc.		2	2.17	4.36	15.7	7.65	
Juv. large pelagic	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. large demersal		2	1	1	1	1	
Ad. medium pelagic	>1E8	1	1	1	1	Ad. small demersal		2	1	1	1	1	
Ad. small pelagic	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. large planktivore		2	1	1	1	1	
Ad. large reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. large planktivore		2	4.85	6.72	19.6	18.5	
Juv. large reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. small planktivore		2	2.16	1	3.1	7.21	
Ad. medium reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. small planktivore		2	1.31	203	1	3.86	
Juv. medium reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. anchovy		2	1.18			3.54	
Ad. small reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. anchovy				2	2		
Juv. small reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. deepwater fish		2	1.8	1	1.8	1.8	
Ad. large demersal	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. macro algal browsing		2	1.33	1	1.55	5.05	
Juv. large demersal	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. eroding grazers				2	2		
Ad. small demersal	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. scraping grazers		2	2.15	1	11	37.1	
Ad. large planktivore	>1E8	>1E8	>1E8	>1E8	>1E8	Detritivore fish		2	2.11	1.54	25.9	6.33	
Juv. large planktivore	>1E8	>1E8	>1E8	>1E8	>1E8	Azooxanthellate corals		2	1.75	1.9	11.6	11.2	
Ad. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8	Hermatypic corals		2	2.36	2.62	14.8	23.6	
Juv. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8	Non reef building corals		2	1	1.5	8.6	4.92	
Ad. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8	Soft corals		2	1	1	3.23	3.51	
Juv. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8	Anemonies		2	1	1	1	1	
Ad. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8	Penaeid shrimps				2	2		
Juv. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8	Shrimps and prawns		2	2.09	2.12	4.97	9.42	
Ad. macro algal browsing	>1E8	>1E8	>1E8	>1E8	>1E8	Squid		2	1.28	4.27	2.75	12.8	
Juv. macro algal browsing	>1E8	>1E8		>1E8	>1E8	Octopus		2	1	1	1	1.09	
Ad. eroding grazers	>1E8	>1E8	>1E8	>1E8	>1E8	Sea cucumbers		2	1.48	1.43	2.06	5.92	
Juv. eroding grazers	>1E8	>1E8	>1E8	>1E8	>1E8	Lobsters		2	6.8	1	2.89	6.8	
Ad. scraping grazers	>1E8	>1E8	>1E8	>1E8	>1E8	Large crabs		2	1.55	3.17	2.65	6.19	
Juv. scraping grazers	>1E8	>1E8	>1E8	>1E8	>1E8	Small crabs	2	1.53	4.48	2.85	5.89		
Detritivore fish	>1E8	>1E8	>1E8	>1E8	>1E8	Crown of thorns	2	1.52	1	4.58	12.1		
Azooxanthellate corals	>1E8	>1E8	>1E8	>1E8	>1E8	Giant triton	2	1.64	1.43	3.2	5.9		
Hermatypic corals	>1E8	>1E8	>1E8	>1E8	>1E8	Herbivorous echinoids	2	1	1	1	1		
Non reef building corals	>1E8	>1E8	>1E8	>1E8	>1E8	Bivalves	2	2.27	1.51	3.37	7.58		
Soft corals	>1E8	>1E8	>1E8	>1E8	>1E8	Sessile filter feeders	2	1.03	1	2.12	4.3		
Anemonies	>1E8	>1E8	>1E8	>1E8	>1E8	Epifaunal det. inverts.	2	1	1	1	1		
Penaeid shrimps			2	2		Epifaunal carn. inverts	2	1	1	1	1		
Shrimps and prawns	>1E8	>1E8	>1E8	>1E8	>1E8	Infaunal inverts.	2	1.23	1	1.85	4.9		
Squid	>1E8	>1E8	>1E8	>1E8	>1E8	Jellyfish and hydroids	2	1	1	1	2.07		
Octopus	>1E8	>1E8	>1E8	>1E8	>1E8	Carn. zooplankton	2	1.64	>1E8	1.21	4.95		
Sea cucumbers	>1E8	>1E8	>1E8	>1E8	>1E8	Large herb. zooplankton	2	2.63	4.13	1	7.97		
Lobsters	>1E8	>1E8	>1E8	>1E8	>1E8	Small herb. zooplankton	2	2.65	1	1.52	8.03		
Large crabs	>1E8	>1E8	>1E8	>1E8	>1E8	Phytoplankton	2	5.6	1	1	5.6		
Small crabs	>1E8	>1E8	>1E8	>1E8	>1E8	Macro algae	2	1.54	2.75	20.4	5.72		
Crown of thorns	>1E8	>1E8	>1E8	>1E8	>1E8	Sea grass	2.03	1.32	16.6	32.2	6.46		
Giant triton	>1E8	>1E8	>1E8	>1E8	>1E8	Fishery discards	2	2	2	2	2		
Herbivorous echinoids	>1E8	>1E8	>1E8	>1E8	>1E8	Detritus	2	2	2	2	2		
Bivalves	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. groupers	>1E8	1	1	1	1		
Sessile filter feeders	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. snappers	>1E8	>1E8	>1E8	>1E8	>1E8		
Epifaunal det. inverts.	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. Napoleon wrasse	>1E8	>1E8	>1E8	>1E8	>1E8		
Epifaunal carn. inverts	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. coral trout	>1E8	>1E8	>1E8	>1E8	>1E8		
Infaunal inverts.	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. rays	>1E8	>1E8	>1E8	>1E8	>1E8		
Jellyfish and hydroids	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. butterflyfish	>1E8	>1E8	>1E8	>1E8	>1E8		
Carn. zooplankton	>1E8	>1E8	>1E8	>1E8	>1E8	Juv. large reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8		

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Juv. medium reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8		Lobsters	2	9.48	2.02	2.16	94.8
	Ad. small reef assoc.	>1E8						Large crabs	2	14.5	10.4	2.09	14.5
	Juv. small reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8		Small crabs	2	83.4	152	17.6	83.4
	Juv. large demersal	>1E8	>1E8	>1E8	>1E8	>1E8		Giant triton	2	52	3.47	2.3	52
	Juv. small demersal	>1E8	>1E8	>1E8	>1E8	>1E8		Bivalves		2	2		
	Juv. large planktivore	>1E8	>1E8	>1E8	>1E8	>1E8		Sessile filter feeders	2	3.78	1.06	1	3.78
	Juv. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8		Epifaunal det. inverts.	2	3.93	3.52	1.05	4.72
	Juv. macro algal browsing	>1E8	>1E8	>1E8	>1E8	>1E8		Epifaunal carn. inverts	2	10.9	3.27	1.64	12.7
	Juv. eroding grazers	>1E8	>1E8	>1E8	>1E8	>1E8		Infauanal inverts.	2	6.56	1.56	1	7.42
	Juv. scraping grazers	>1E8	>1E8	>1E8	>1E8	>1E8		Jellyfish and hydroids	2	5.31	1.56	1.48	5.31
	Azooxanthellate corals	>1E8	>1E8	>1E8	>1E8	>1E8		Carn. zooplankton	2	13.4	1.71	2.12	11.6
	Hermatypic corals	>1E8	>1E8	>1E8	>1E8	>1E8		Large herb. zooplankton	2	12.1	4.91	6.11	10.4
	Non reef building corals	>1E8	>1E8	>1E8	>1E8	>1E8		Small herb. zooplankton	2	28.6	2.53	3.14	24.7
	Soft corals	>1E8	>1E8	>1E8	>1E8	>1E8		Phytoplankton	2		1	1	
	Anemonies	>1E8	>1E8	>1E8	>1E8	>1E8		Macro algae	2	13	5.59	10.8	14.2
	Penaeid shrimps			2	2			Sea grass	2	17.3	29.2	16.2	23.9
	Shrimps and prawns	>1E8	>1E8	>1E8	>1E8	>1E8		Fishery discards	2	2	2	2	2
	Squid	>1E8	>1E8	>1E8	>1E8	>1E8		Detritus	2	2	2	2	2
	Octopus	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. large demersal	Ad. groupers	>1E8	>1E8	>1E8	>1E8	>1E8
	Sea cucumbers	>1E8	>1E8	>1E8	>1E8	>1E8		Sub. groupers	>1E8	>1E8	>1E8	>1E8	>1E8
	Lobsters	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. snappers	>1E8	>1E8	>1E8	>1E8	>1E8
	Large crabs	>1E8	>1E8	>1E8	>1E8	>1E8		Sub. snappers	>1E8	>1E8	>1E8	>1E8	>1E8
	Small crabs	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. butterflyfish	>1E8	>1E8	>1E8	>1E8	>1E8
	Crown of thorns	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. butterflyfish	>1E8	>1E8	>1E8	>1E8	>1E8
	Giant triton	>1E8	>1E8	>1E8	>1E8	>1E8		Cleaner wrasse	>1E8	>1E8	>1E8	>1E8	>1E8
	Herbivorous echinoids	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. large reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8
	Bivalves	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. large reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8
	Sessile filter feeders	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. medium reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8
	Epifaunal det. inverts.	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. small reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8
	Epifaunal carn. inverts	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. small reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8
	Infauanal inverts.	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. large demersal	>1E8	>1E8	>1E8	>1E8	>1E8
	Jellyfish and hydroids	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. small demersal	>1E8	>1E8	>1E8	>1E8	>1E8
	Carn. zooplankton	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. small demersal	>1E8				
	Large herb. zooplankton	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. large planktivore	>1E8	>1E8	>1E8	>1E8	>1E8
	Small herb. zooplankton	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. large planktivore			2	2	
	Phytoplankton	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8
	Macro algae	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8
	Sea grass	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8
	Fishery discards	>1E8	2	2	2	2		Ad. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8
	Detritus	>1E8	2	2	2	2		Juv. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8
Juv. small reef assoc.	Juv. groupers	2	77	38.5	60.6	77		Ad. macro algal browsing	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. snappers	2	5	5	5	5		Ad. scraping grazers	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. Napoleon wrasse	2	20.4	1	1	20.4		Juv. scraping grazers			2	2	
	Juv. rays	2	1.21	1	1	1		Detritivore fish	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. butterflyfish	2	8.63	2.17	10.6	43.2		Penaeid shrimps			2	2	
	Juv. large reef assoc.	2	1	1	1	1.56		Shrimps and prawns	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. medium reef assoc.	2	13	13	13	13		Octopus			2	2	
	Juv. medium reef assoc.	2	11.4	1	2.25	5.68		Lobsters	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. small reef assoc.	2	2.88	2.62	2.76	2.88		Large crabs	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. small reef assoc.	2	44.8	29.9	31	44.8		Small crabs	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. large demersal	2	3.56	2.48	1	2.14		Giant triton	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. small demersal	2	3.71	1	1	1.86		Bivalves			2	2	
	Juv. small demersal	2	5.47	1	1	2.83		Epifaunal det. inverts.	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. large planktivore	2	1	1	1	1		Epifaunal carn. inverts	>1E8	>1E8	>1E8	>1E8	>1E8
	Ad. small planktivore	2	15.6	1.6	2.46	15.6		Infauanal inverts.	>1E8	>1E8	>1E8	>1E8	>1E8
	Juv. small planktivore	2	2.16	23	1	1.83		Detritus	>1E8				
	Ad. anchovy	2	1	1	1	1	Juv. large demersal	Ad. groupers	2	1	1	1	1
	Juv. anchovy	2	1	1	1	1		Sub. groupers	2	122	60.8	122	12.2
	Ad. deepwater fish	2	3.2	3.2	2.06	3.2		Ad. butterflyfish	2	9.44	4.97	94.4	9.44
	Juv. macro algal browsing	2	11.1	1.32	1.22	11.1		Juv. butterflyfish	2	9.77	6.86	226	39.1
	Juv. eroding grazers	2	4	1	1	4		Ad. large reef assoc.	2	4.04	4.49	18.7	40.4
	Juv. scraping grazers	2	50.2	1	1			Juv. large reef assoc.	2	6.25	11.8	50.6	43.8
	Azooxanthellate corals	2	12.1	5.98	9.26	24.2		Ad. medium reef assoc.	2	235	235	235	235
	Hermatypic corals	2	11.8	5.9	10.4	11.8		Juv. medium reef assoc.	2	8.57	11.2	24	4.29
	Non reef building corals	2	12.1	8.97	13	24.2		Ad. small reef assoc.	2	2.4	6	27.2	4
	Soft corals	2	13.8	5.15	8.73	32.3		Juv. small reef assoc.	2	1	1.72	7.94	1
	Penaeid shrimps			2	2			Ad. large demersal	2	15.8	5.27	5.05	15.8
	Shrimps and prawns	2	16.2	6.11	3.94	16.2		Ad. small demersal	2	1.79	1.01	6.2	1.68
	Squid	2	12.3	15.4	2.42	12.3		Ad. large planktivore	2	4.93	8.71	33.6	7.4
	Octopus			2	2			Juv. large planktivore			2	2	

Table D.3.2. Cont. Vulnerability matrices for 5 Ecosim models.

Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool	Predator	Prey	RA 1990	RA 2005	Kofiau	Dampier	Misool
	Ad. small planktivore	2	10.3	2.9	26.3	17.1		Juv. snappers	1	3.57	107	16.1	10.7
	Ad. anchovy	2	4.74	9.02	20	9.47		Juv. Napoleon wrasse	1	2.2	3.14	1	4.4
	Juv. anchovy	2	11	6.65	14.5	21.9		Juv. coral trout	1	4.07	122	122	122
	Ad. deepwater fish	2	2.55	7.77	20.9	2.55		Juv. rays	1	1	1	1	1
	Juv. deepwater fish	2	3.91	9.54	25.6	3.91		Juv. butterflyfish	1	1	2.74	15.2	4.67
	Ad. scraping grazers	2	10.8	98	238	108		Juv. large reef assoc.	1	1	7.78	5.18	3.37
	Juv. scraping grazers			2	2			Ad. medium reef assoc.	1	28	280	64.6	28
	Detritivore fish	2	6.73	7.22	166	11.4		Juv. medium reef assoc.	1	1.02	6.98	2.44	1
	Penaeid shrimps			2	2			Ad. small reef assoc.	1	1	13.3	9.96	1.59
	Shrimps and prawns	2	9.03	14.6	41.9	22.6		Juv. small reef assoc.	1	1.69	27.5	20.1	3.27
	Octopus			2	2			Juv. large demersal	1	1	12.8	1.95	1
	Lobsters	2	3.86	4.29	24.1	38.6		Ad. small demersal	1	20	50.1	52.4	20
	Large crabs	2	23	23	23	23		Juv. small demersal	1	10.4	22.9	23.8	10.4
	Small crabs	2	8.86	29.5	24.1	8.86		Juv. large planktivore	1	1	6.69	4.07	1.38
	Giant triton	2	5.6	5.6	5.6	5.6		Ad. small planktivore	1	8.71	13.2	19.7	14.5
	Bivalves	2	21.2	10.6	21.2	21.2		Juv. small planktivore	1	2.2	1	2.71	3.67
	Epifaunal det. inverts.	2	4.59	13.5	18.5	7.65		Ad. anchovy	1	1	4.83	1.75	1
	Epifaunal carn. inverts	2	4.31	5.55	12.7	8.15		Juv. anchovy	1	2.53	4.97	1.77	5.06
	Infaunal inverts.	2	4.05	4.63	13.5	8.1		Ad. deepwater fish	1	1	5.41	2.32	1
	Carn. zooplankton	2	7.16	6.4	36.2	11		Juv. deepwater fish	1	1	1	1	1
	Large herb. zooplankton	2	4.81	8.59	48.7	7.44		Juv. macro algal browsing	1	2.4	5.99	4.4	4.79
	Small herb. zooplankton	2	11.5	6.85	38.8	17.8		Juv. eroding grazers	1	6.6	1	3.16	6.6
	Detritus			2	2			Juv. scraping grazers	1	3.75	26.3	46.6	52.5
Ad. small demersal	Juv. groupers	>1E8	>1E8	>1E8	>1E8	>1E8		Detritivore fish	1	1.18	7.07	24.8	2
	Juv. snappers	>1E8	>1E8	>1E8	>1E8	>1E8		Penaeid shrimps			2	2	
	Juv. Napoleon wrasse	>1E8	>1E8	>1E8	>1E8	>1E8		Shrimps and prawns	1	3.49	29.5	14.2	7.67
	Juv. coral trout	>1E8	>1E8	>1E8	>1E8	>1E8		Squid	1	2.05	52.6	8.8	4.61
	Juv. rays	>1E8	>1E8	>1E8	>1E8	>1E8		Octopus	1	3.23	16.1	7.56	6.88
	Juv. butterflyfish	>1E8	>1E8	>1E8	>1E8	>1E8		Sea cucumbers	1	1	6.01	1.84	1.54
	Ad. large reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8		Lobsters	1	4.48	8.96	8.15	44.8
	Juv. large reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8		Large crabs	1	2.29	34.3	7.61	6.86
	Ad. medium reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8		Small crabs	1	1.13	25.5	3.32	2.45
	Juv. medium reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8		Crown of thorns	1	2.19	10.4	13.2	8.31
	Ad. small reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8		Giant triton	1	6.7	6.7	6.7	6.7
	Juv. small reef assoc.	>1E8	>1E8	>1E8	>1E8	>1E8		Herbivorous echinoids	1	1	3.24	1	1
	Ad. large demersal	>1E8	>1E8	>1E8	>1E8	>1E8		Bivalves	1	3.6	19.1	8.75	8.1
	Juv. large demersal	>1E8	>1E8	>1E8	>1E8	>1E8		Sessile filter feeders	1	4.21	29.4	13.5	8.41
	Ad. small demersal	>1E8	>1E8	>1E8	>1E8	>1E8		Epifaunal det. inverts.	1	1.7	28.3	6.24	3.64
	Juv. small demersal	>1E8	>1E8	>1E8	>1E8	>1E8		Epifaunal carn. inverts	1	1.73	12	4.45	3.71
	Ad. large planktivore	>1E8	>1E8	>1E8	>1E8	>1E8		Infaunal inverts.	1	2.1	11.3	5.23	4.9
	Juv. large planktivore	>1E8	>1E8	>1E8	>1E8	>1E8		Macro algae	1	2.6	3.67	5.24	5.63
	Ad. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8		Sea grass					2
	Juv. small planktivore	>1E8	>1E8	>1E8	>1E8	>1E8		Detritus	1				
	Ad. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8	Ad. large planktivore	Ad. groupers	2.42	3.63	3.63	3.63	3.63
	Juv. anchovy	>1E8	>1E8	>1E8	>1E8	>1E8		Sub. groupers	2.42	25	25	36.7	6.82
	Ad. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. groupers	2.42	4.3	3.95	5.82	1.13
	Juv. deepwater fish	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. snappers	2.42	5.81	5.81	3.14	5.81
	Juv. macro algal browsing	>1E8	>1E8	>1E8	>1E8	>1E8		Sub. snappers	2.42	6.65	24.9	6.1	9.97
	Juv. eroding grazers	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. snappers	2.42	6.92	27.7	6.1	13.8
	Juv. scraping grazers	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. Napoleon wrasse	2.42	3.91	5.02	2.39	3.78
	Detritivore fish	>1E8	>1E8	>1E8	>1E8	>1E8		Skipjack tuna	2.42	1.45	1	1	1
	Penaeid shrimps			2	2			Other tuna	2.42	1.4	2.12	17	1.77
	Shrimps and prawns	>1E8	>1E8	>1E8	>1E8	>1E8		Mackerel	2.42	2.24	59.4	29.7	10.3
	Squid	>1E8	>1E8	>1E8	>1E8	>1E8		Billfish	2.42	5.42	5.38	2.13	2.98
	Octopus	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. coral trout	2.42	10.5	63	55	630
	Sea cucumbers	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. large sharks	2.42	1.71	3.41	1.33	34.1
	Lobsters	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. small sharks	2.42	2.37	1.08	1	2.17
	Large crabs	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. rays	2.42	6.23	3.22	3.08	3.12
	Small crabs	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. butterflyfish	2.42	3.14	2326	10.5	2.87
	Crown of thorns	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. butterflyfish	2.42	2.58	1	8.66	8.03
	Giant triton	>1E8	>1E8	>1E8	>1E8	>1E8		Cleaner wrasse	2.42	6.43	2.61	21.7	5.64
	Herbivorous echinoids	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. large pelagic	2.42	3.86	1.48	1	4.96
	Bivalves	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. large pelagic	2.42	7.33	50.6	14.2	9.78
	Sessile filter feeders	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. medium pelagic	2.42	1	1	1	1
	Epifaunal det. inverts.	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. medium pelagic	2.42	2.45	1	1	6.12
	Epifaunal carn. inverts	>1E8	>1E8	>1E8	>1E8	>1E8		Ad. small pelagic	2.42	2.26	1.61	1.53	10.3
	Infaunal inverts.	>1E8	>1E8	>1E8	>1E8	>1E8		Juv. small pelagic	2.42	3	1	1	30
	Macro algae	2						Ad. large reef assoc.	2.42	4.09	1.86	2.4	4.09
	Detritus	>1E8	2	2	2	2		Juv. large reef assoc.	2.42	1	1	1.13	1.34
Juv. small demersal	Juv. groupers	1	16.7	167	167	16.7		Ad. medium reef assoc.	2.42	4.82	2.58	1.59	1.21

D.4. Age-structure parameters

Table D.4.1 Multi-stanza life history information for the Raja Ampat models

Group	1990						2005					
	Age, start (months)	Biomass (t·km ⁻²)	Z (yr ⁻¹)	Q/B (yr ⁻¹)	Growth constant (K)	W _{MAT} /W _{INF}	Age, start (months)	Biomass (t·km ⁻²)	Z (yr ⁻¹)	Q/B (yr ⁻¹)	Growth constant (K)	W _{MAT} /W _{INF}
Juv. groupers	0	0.007	1.200	41.302	0.18	0.12	0	0.043	1.200	26.675	0.32	0.12
Sub. groupers	24	0.039	0.400	18.181	-	-	24	0.156	0.400	13.110	-	-
Ad. groupers	56	0.800	0.160	9.086	-	-	56	0.500	0.225	9.086	-	-
Juv. snappers	0	0.105	1.447	22.345	0.29	0.27	0	0.128	1.447	21.377	0.29	0.27
Sub. snappers	24	0.145	1.100	11.586	-	-	24	0.178	1.100	11.085	-	-
Ad. snappers	48	0.500	0.290	7.105	-	-	48	0.345	0.400	7.105	-	-
Juv. Napoleon wrasse	0	0.026	1.200	30.238	0.25	0.09	0	0.016	1.200	29.815	0.25	0.09
Sub. Napoleon wrasse	24	0.173	0.500	13.067	-	-	24	0.083	0.500	12.952	-	-
Ad. Napoleon wrasse	72	0.200	0.400	8.900	-	-	72	0.049	0.450	8.900	-	-
Juv. coral trout	0	0.005	0.700	7.955	0.17	0.10	0	0.007	0.550	7.103	0.17	0.10
Ad. coral trout	48	0.036	0.280	3.303	-	-	48	0.033	0.350	3.303	-	-
Juv. large sharks	0	0.085	0.900	5.914	0.51	0.38	0	0.039	0.900	6.058	0.51	0.38
Ad. large sharks	36	0.080	0.600	3.600	-	-	30	0.061	0.700	3.600	-	-
Juv. small sharks	0	0.046	2.432	6.620	1.18	0.38	0	0.106	1.800	6.072	0.38	1.18
Ad. small sharks	24	0.008	1.200	4.000	-	-	24	0.041	1.120	4.000	-	-
Juv. rays	0	0.071	1.200	5.240	0.25	0.44	0	0.031	1.200	5.923	0.25	0.44
Ad. rays	24	0.196	0.960	2.416	-	-	24	0.177	0.600	2.416	-	-
Juv. butterflyfish	0	0.060	1.600	10.959	1.50	0.42	0	0.093	2.000	11.163	0.42	1.50
Ad. butterflyfish	12	0.249	1.004	6.720	-	-	12	0.243	1.004	6.720	-	-
Juv. large pelagic	0	0.059	1.079	4.545	0.62	0.08	0	0.044	1.079	4.544	0.62	0.08
Ad. large pelagic	24	0.125	0.800	2.667	-	-	24	0.074	0.800	2.667	-	-
Juv. medium pelagic	0	0.118	1.500	7.838	0.93	0.18	0	0.045	1.500	7.860	0.93	0.18
Ad. medium pelagic	24	0.084	1.000	5.000	-	-	24	0.030	1.000	5.000	-	-
Juv. small pelagic	0	0.290	3.980	25.251	1.24	0.28	0	0.108	3.980	25.284	1.24	0.28
Ad. small pelagic	12	0.200	2.000	13.266	-	-	12	0.071	2.000	13.266	-	-
Juv. large reef assoc.	0	3.327	0.600	5.794	0.58	0.13	0	3.165	0.600	5.696	0.58	0.13
Ad. large reef assoc.	48	7.100	0.300	4.000	-	-	48	5.000	0.400	4.000	-	-
Juv. medium reef assoc.	0	1.827	1.200	8.080	0.83	0.13	0	2.356	1.400	8.114	0.83	0.13
Ad. medium reef assoc.	24	4.000	0.600	5.000	-	-	24	2.853	0.800	5.000	-	-
Juv. small reef assoc.	0	0.965	3.000	26.892	1.08	0.09	0	0.135	4.000	30.345	1.08	0.09
Ad. small reef assoc.	12	0.900	2.500	15.000	-	-	8	0.259	3.000	15.000	-	-
Juv. large demersal	0	0.486	0.920	4.829	0.50	0.12	0	0.135	0.920	5.140	0.50	0.12
Ad. large demersal	48	0.238	0.600	3.067	-	-	36	0.127	0.600	3.100	-	-
Juv. small demersal	0	0.348	2.568	16.128	1.00	0.09	0	0.135	2.568	15.718	1.00	0.09
Ad. small demersal	12	0.700	1.600	8.560	-	-	12	0.192	2.000	8.600	-	-
Juv. large planktivore	0	0.635	1.600	13.289	1.11	0.22	0	0.887	2.000	7.511	1.11	0.22
Ad. large planktivore	15	1.496	1.100	8.000	-	-	15	1.000	1.500	4.500	-	-
Juv. small planktivore	0	0.728	2.000	8.001	4.56	0.16	0	0.614	2.000	7.373	4.56	0.16
Ad. small planktivore	12	0.300	2.000	6.667	-	-	10	0.414	2.000	6.000	-	-
Juv. anchovy	0	1.009	2.500	27.540	0.94	0.25	0	2.237	3.370	26.706	0.94	0.25
Ad. anchovy	12	2.000	1.800	14.625	-	-	12	1.500	3.370	14.625	-	-
Juv. deepwater fish	0	1.294	1.000	5.573	0.80	0.17	0	0.794	1.000	5.316	1.00	0.17
Ad. deepwater fish	24	1.594	1.100	3.667	-	-	24	0.600	1.100	3.667	-	-
Juv. macro algal browsing	0	0.585	1.400	8.981	1.59	0.02	0	0.500	1.400	18.888	1.59	0.02
Ad. macro algal browsing	24	0.164	1.339	6.696	-	-	20	0.250	1.339	13.760	-	-
Juv. eroding grazers	0	0.255	1.000	2.200	1.00	0.21	0	0.256	1.000	2.200	1.00	0.21
Ad. eroding grazers	24	0.525	0.435	1.451	-	-	24	0.526	0.435	1.451	-	-
Juv. scraping grazers	0	1.137	3.000	8.920	1.03	0.21	0	1.656	3.000	22.729	1.03	0.21
Ad. scraping grazers	18	0.239	2.339	5.000	-	-	18	0.348	2.339	12.740	-	-

APPENDIX E - EWE MODEL OUTPUT

E.1. TIME SERIES

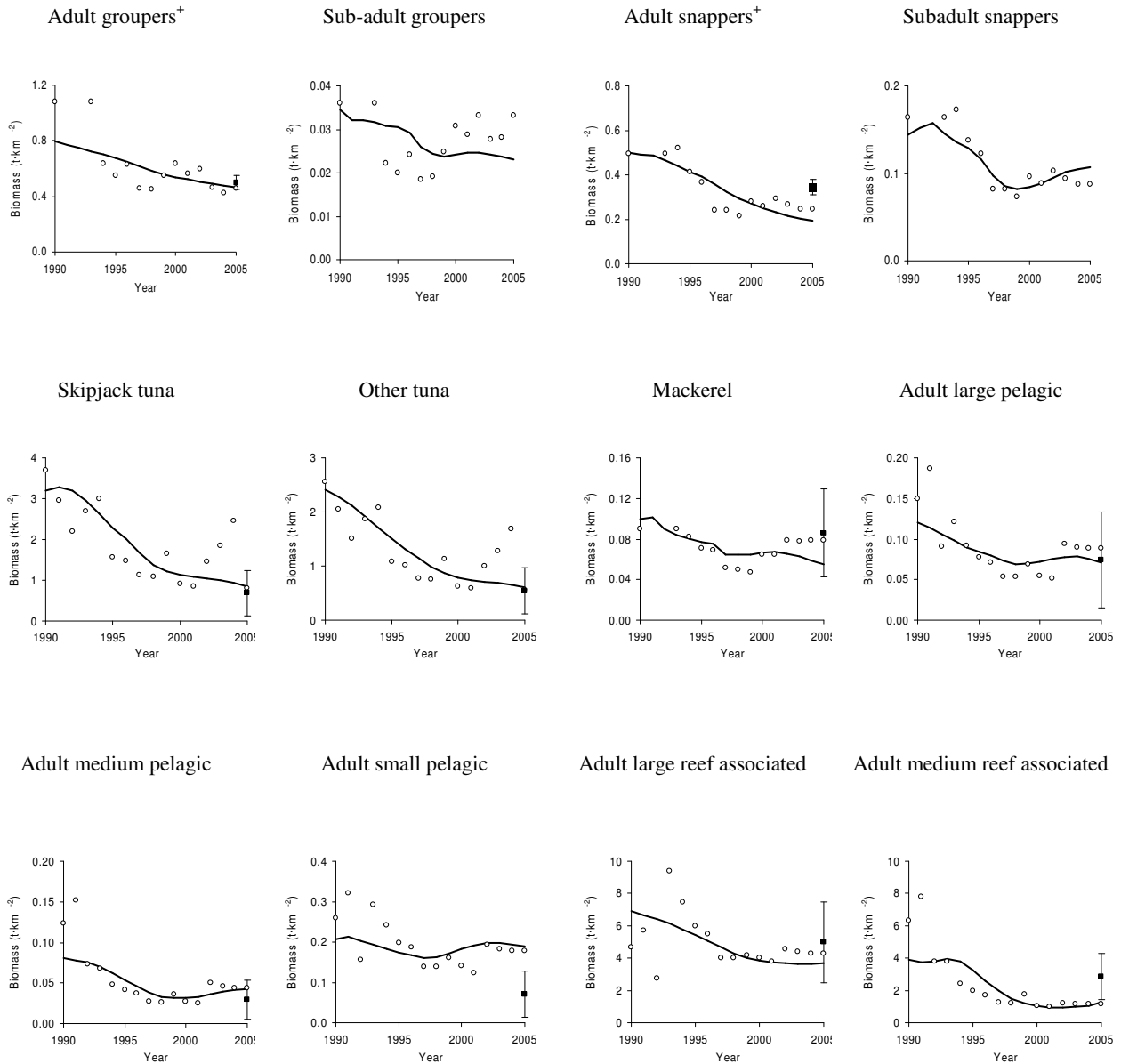
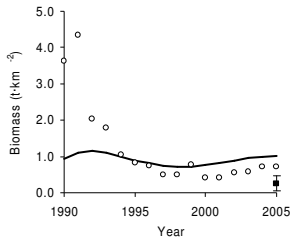
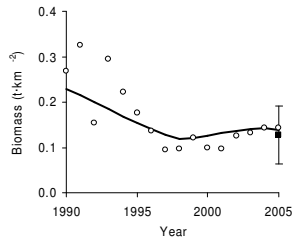


Figure E.1.1. Dynamic biomass prediction (1990-2005). Biomass predicted by model (line) versus relative biomass estimated from CPUE trends (open circles). Square shows 2005 model biomass with confidence interval suggested by Ewe pedigree (see text). All figures represent adult stanza biomass unless otherwise specified. The original CPUE data (assembled by Ainsworth et al. 2007, visible in Figure B.2.2) indicated a population increase in the last few years for grouper and snapper. We assume this trend is errant because these animals are fished in spawning aggregations (see text). For these groups the last 5 and 3 CPUE data points, respectively, were entered *ad hoc* to create a declining

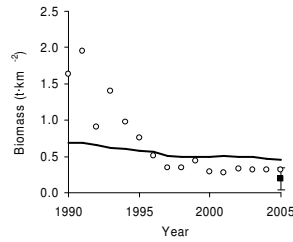
Adult small reef associated



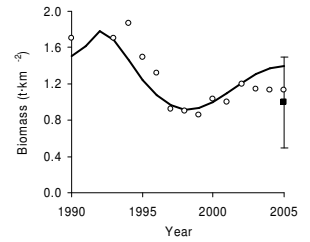
Adult large demersal



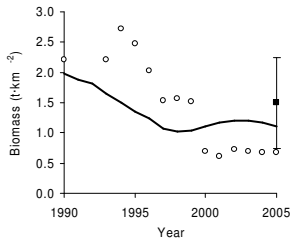
Adult small demersal



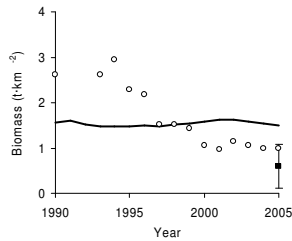
Adult large planktivore



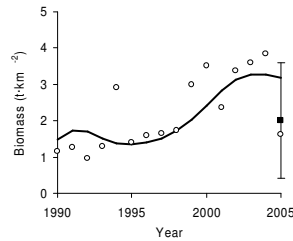
Adult anchovy



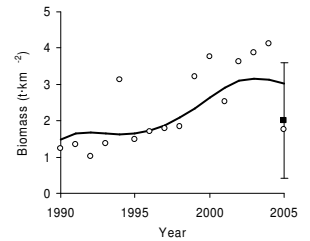
Adult deepwater fish



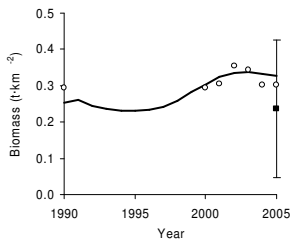
Penaeid shrimps



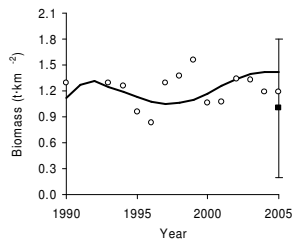
Shrimps and prawns



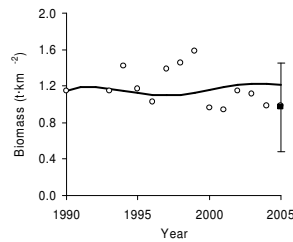
Squid



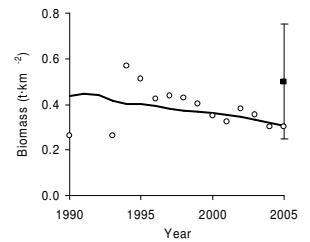
Octopus



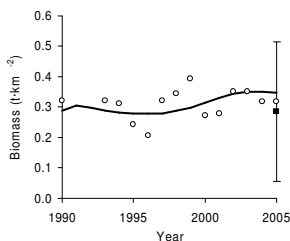
Sea cucumbers



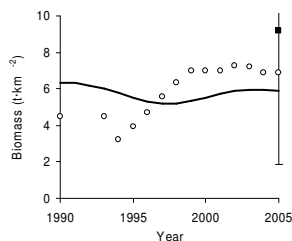
Lobsters



Large crabs



Bivalves



Epifaunal carnivorous inverts.

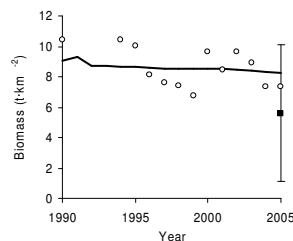


Figure E.1.1. Cont. Dynamic biomass prediction (1990-2005).

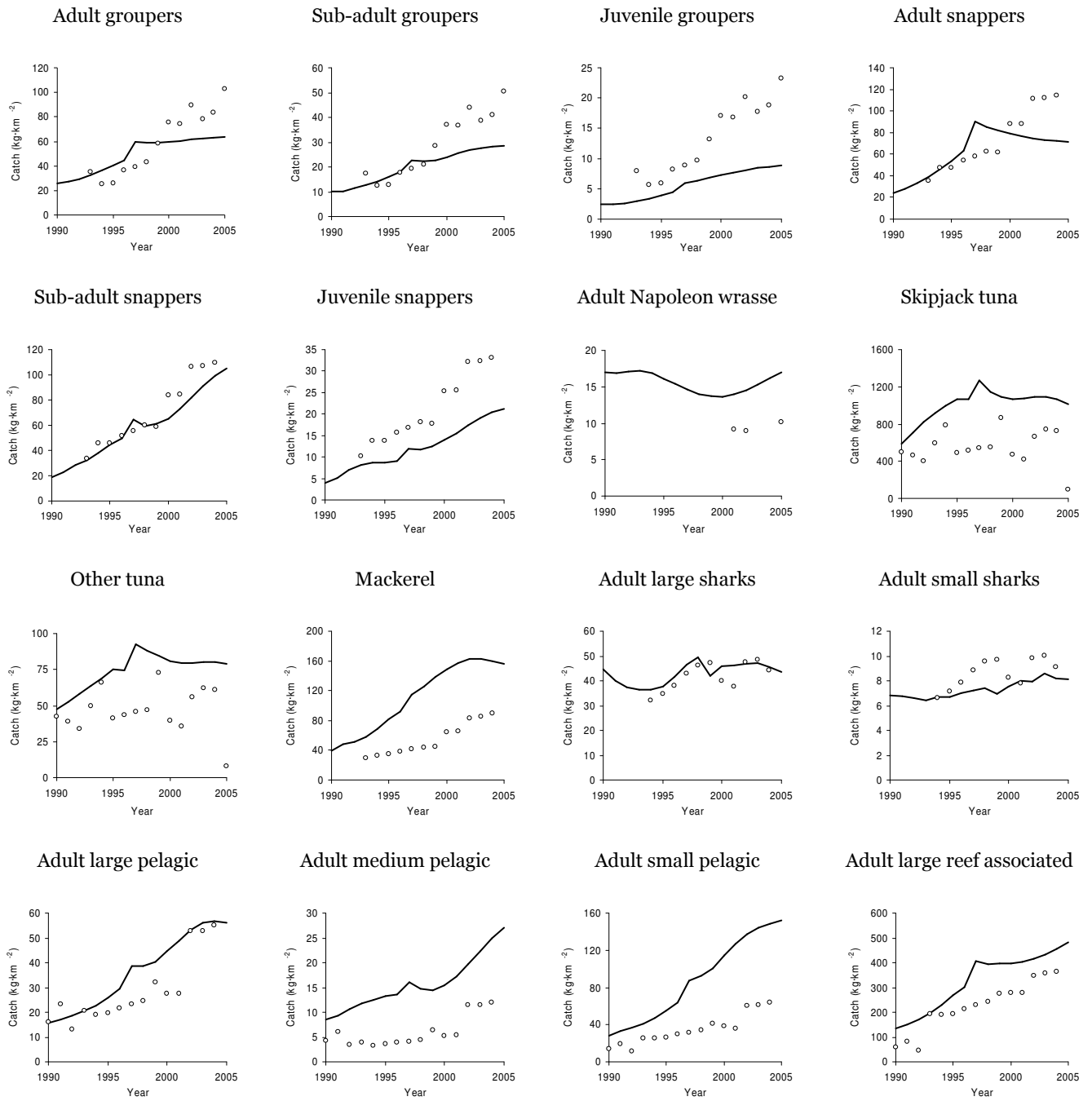


Figure E.1.2. Dynamic catch prediction (1990-2005). Catch predicted by model (line) versus catch estimated from government records and IUU study (open circles).

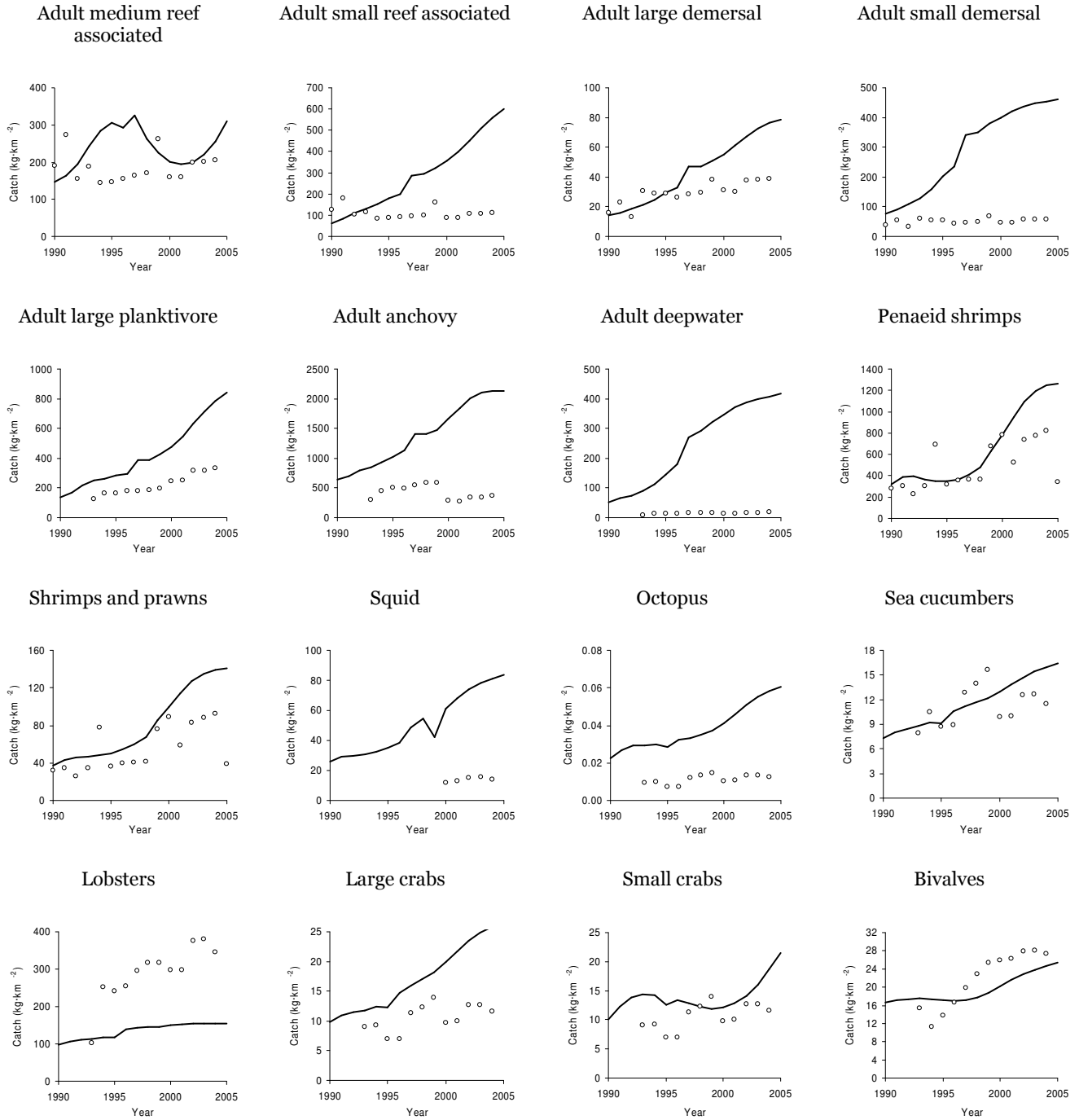


Figure E.1.2. Cont. Dynamic catch prediction (1990-2005). Catch predicted by model (line) versus catch estimated from government records and IUU study (open circles).

E.2. EQUILIBRIUM ANALYSIS

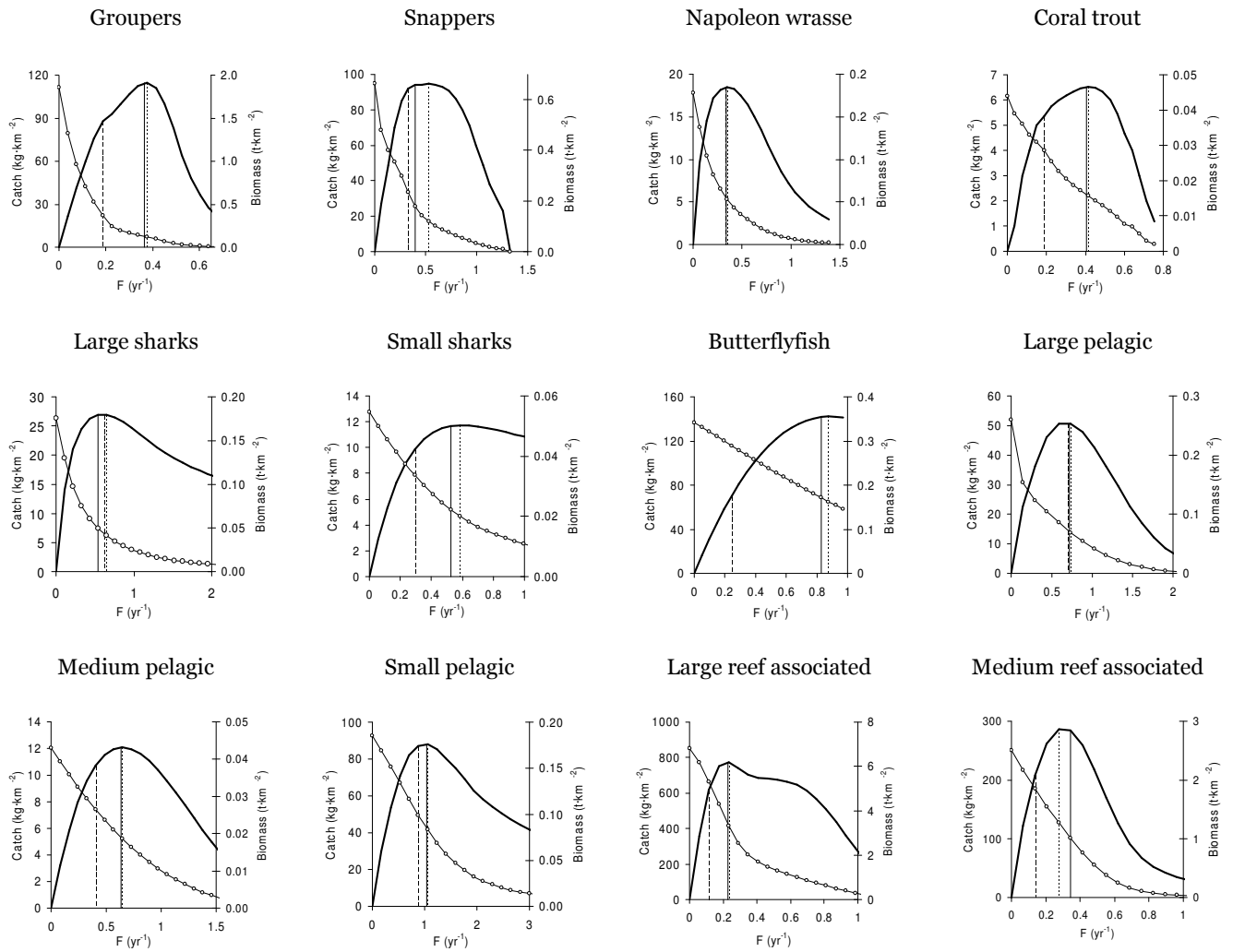


Figure E.2.1. Multispecies biomass and catch equilibria (RA 2005 model) X-axis shows fishing mortality (F), curve shows surplus yield; dotted vertical line shows F_{MSY} ; dashed vertical line shows fishing mortality in 2005 (F_{2005}) (i.e., model baseline); solid vertical line shows $F_{0.1}$. Where vertical lines overlap they have been slightly offset for clarity. Adult stanzas shown for multi-stanza groups. F was incremented manually in Ecosim. Fishing mortality on sub-adult stages was increased by the same proportion as adult (versus baseline).

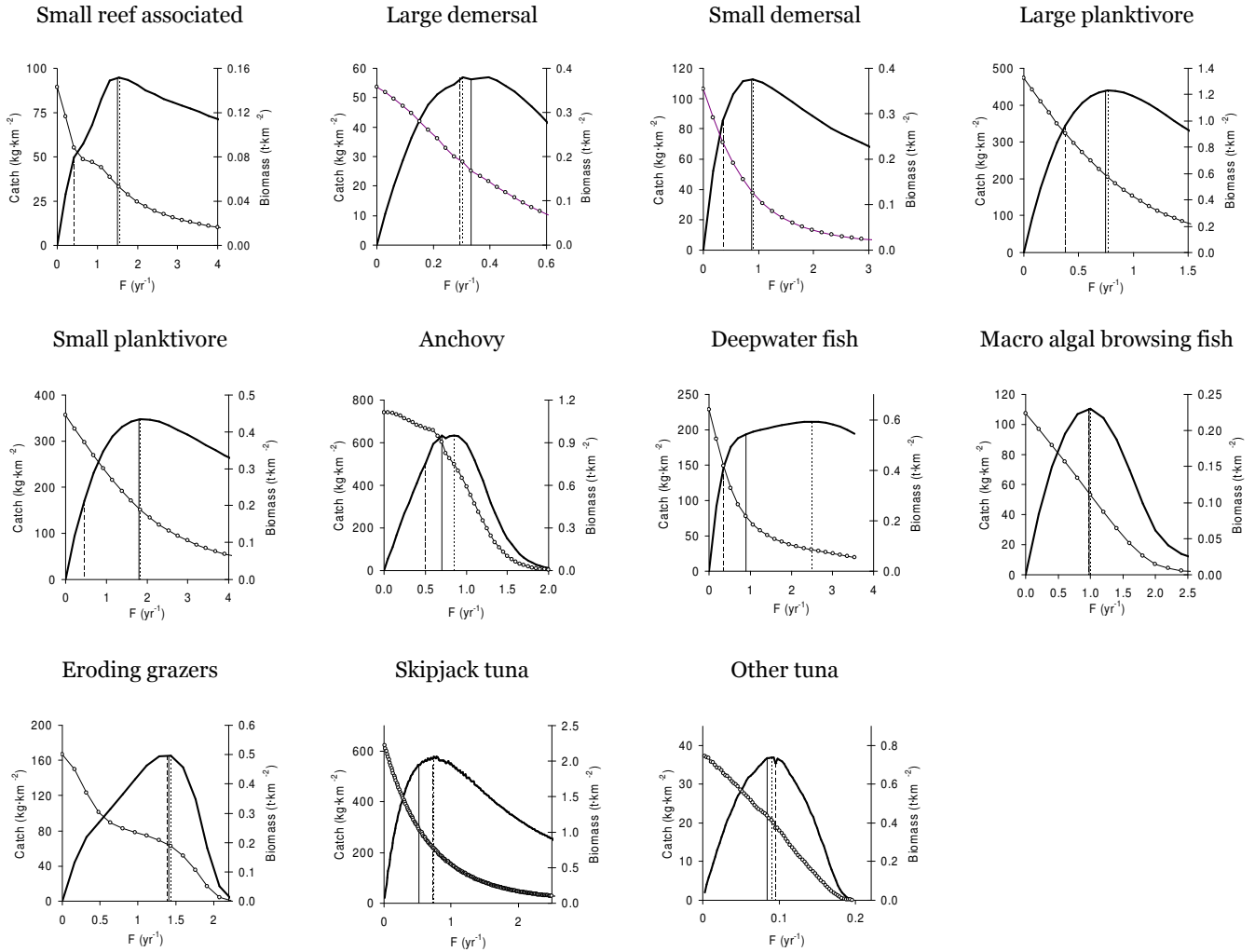


Fig. E.2.1. Cont. Multispecies biomass and catch equilibria (RA 2005 model) X-axis shows fishing mortality (F), curve shows surplus yield; dotted vertical line shows F_{MSY} ; dashed vertical line shows fishing mortality in 2005 (F_{2005}) (i.e., model baseline); solid vertical line shows $F_{0.1}$.

APPENDIX F – ABSTRACTS OF MANUSCRIPTS SUBMITTED AND IN PREPARATION (AS OF MAY 2008)

Estimating illegal and unreported catches in Raja Ampat Regency, Indonesia

In final draft

D.A. Varkey, C.H. Ainsworth, T.J. Pitcher and G. Johanés*

*The Nature Conservancy, Raja Ampat, Indonesia

Abstract

This article estimates the scope of illegal, unreported and unregulated (IUU) fishing in Raja Ampat in Eastern Indonesia. Evidently, there are massive illegal and unreported catches by both foreign and national fishing vessels in Indonesia. The analysis was initiated when marine ecosystem model built to evaluate management options for the region revealed that the declines in fish population could not be explained by the reported catches. Here, we present preliminary estimates of the quantity of IUU catches from 1950 to 2005 for the reef fish, tuna, anchovy, shark, lobster and sea cucumber fisheries in Raja Ampat. We create a timeline of the fisheries documenting regulatory, technological, political and market changes in the history of the fishery. The trend in IUU revealed by the timeline is converted into estimates of missing catch based on independent estimates of misreporting. Our methodology employed a Monte Carlo routine to determine the associated error range.

Exploration of ecological and economic benefits from implementation of marine protected areas in Raja Ampat, Indonesia

In preparation

D.A. Varkey, C.H. Ainsworth and T.J. Pitcher

Abstract

This article uses a marine ecosystem model to investigate marine protected areas (MPAs) as management tools for coral reef fisheries in Raja Ampat, Indonesia. The research questions have been proposed by Regency fisheries managers and scientific partners working in Eastern Indonesia. The Ecopath, Ecosim and Ecospace models were developed using field data from an integrated and diverse research project. We analyze fisheries and ecological benefits of effort reduction and specific gear reduction inside MPAs using the Ecospace model for Raja Ampat. The smaller Ecospace models (for Dampier strait, Misool and Kofiau) have been used for comparison between single large and several small MPAs. MPAs of several sizes have been tested to evaluate optimum size for an MPA.

Evidence of fishery depletions and shifting cognitive baselines in Eastern Indonesia

2008 Biological Conservation 141: 848-859

C.H. Ainsworth, T.J. Pitcher and C. Rotinsulu*

* Conservation International, Jl. Gunung Arfak. 45. Sorong, Papua, Indonesia

Abstract

We analyze fisher interview data collected in the Raja Ampat archipelago of Eastern Indonesia to demonstrate a perceived decline in the abundance of living marine resources targeted by commercial and artisanal fisheries. The decline appears ubiquitous among all tested species and a clear trend emerges in which older fishers recall greater past abundance than younger fishers. This provides evidence for the shifting baseline syndrome, a dangerous cognitive condition in which each generation of fishery stakeholders accepts a lower standard of resource abundance as normal. We use a fuzzy expert system to standardize and quantify the anecdotal evidence, and combine it with additional depletion indicators to produce a decadal time series of resource abundance from 1970 to present. Using governmental catch-per-unit-effort data from more recent years we hindcast to establish an absolute scale with which to interpret the perceived decline. The interview information suggests that some exploited species may have declined by as much as an order of magnitude since 1970.

Ecosystem simulations supporting Ecosystem Based Fisheries Management in the Coral Triangle, Indonesia

2008 Ecological Modeling 214:361-374

C.H. Ainsworth, D.A. Varkey and T.J. Pitcher

Fisheries Centre, University of British Columbia, Vancouver, Canada

Abstract

A comprehensive field study ongoing in Eastern Indonesia has provided data for a trophic ecosystem model of the Raja Ampat archipelago on the west coast of New Guinea. The model is used in this article to investigate five high priority research questions related to ecosystem based fisheries management (EBFM) in the region. The questions were posed by Regency fisheries managers and scientific partners working in Indonesia. Here, we analyze the ecosystem impacts of blast fishing, including trophic effects and removal of refuge space, and we quantify the likely trophic impacts of limiting commercial fisheries for grouper and commercial net fisheries for reef fish. We also evaluate the exploitation status of anchovy and tuna and report on the ecosystem effects of these fisheries. All of the fisheries we examine in this article appear fully exploited in Raja Ampat or nearly so. There are indications that some targeted species perform valuable ecosystem services.

Trophodynamic effects of restoring reef-associated marine turtles: keystone predators on coral reefs

In preparation

C. Ainsworth and T.J. Pitcher.

Abstract

Fisheries Centre, University of British Columbia, Vancouver, Canada Using a marine food-web model of the Raja Ampat Islands in Eastern Indonesia we investigate the impacts of hawksbill turtles as keystone predators on coral reefs. Hawksbill turtles predate on herbivorous echinoderms, which in turn consume algae. These relationships are established through the diet matrix of the Ecopath with Ecosim trophodynamic mass-balance model. A prevalence of algae negatively impacts corals in the model through use of special non-trophic mediation functions that represent the smothering effect of dense algal mats. In turn, the health of the corals impacts the vulnerability of juvenile reef fish to their predators, which reflects the availability of refuge space. Therefore, through indirect effects, the abundance of hawksbill turtles has a determining effect on the coral reef assemblage through trophic and non-trophic means. To frame the keystone impacts of hawksbills turtles we model two situations. The first situation is analogous to the unfished ecosystem in which the biomass of hawksbills is high, and the biomass of herbivorous reef fish, as competitors to echinoderms, is also high. Unexploited biomass of hawksbills is estimated by the ecosystem model. The second situation represents a restoration scenario, in which the biomass of hawksbill turtles is increased to unexploited biomass, but herbivorous reef fish remain depleted through the continued activity of fisheries.

Ecolocator: A New Visualization Tool to Represent Fine-Scale Biomass Distributions in Marine Ecosystems.

In preparation.

Ainsworth, C. Pitcher, T. and Varkey, D.

Abstract

We introduce Ecolocator, a visualization tool to display the local biomass distributions of marine flora and fauna in a study area based on highly resolved spatial habitat information and our knowledge of species ecology. A graphical user interface allows the user to sketch habitat regions onto a map, which represents a study area. The habitat regions can reflect substrate type, coral cover, bathymetry or other physical or oceanographic features that influence species distributions. The user then defines the biomass distribution of a species in cross-section with regard to central 'node' cells and peripheral 'boundary' cells of the habitat region, or selects from pre-made patterns appropriate to species niche characteristics. The inputs are extremely flexible in their definition and so Ecolocator can be used to represent a wide variety of species. The absolute biomass for the study area can come from sampling (e.g., dive transects) or from an independent model. We demonstrate the use of Ecolocator by peering into the coarse spatial cells of an Ecospace map and generating an animation of reef fish biomass dynamics. Ecolocator can add functionality to other modelling systems by providing a graphics capability, and make site-specific biomass data more interpretable by non-specialists.

CHAPTER 2

TOWARDS ECOSYSTEM-BASED MANAGEMENT IN THE BIRD'S HEAD FUNCTIONAL SEASCAPE OF PAPUA, INDONESIA: THE ECONOMIC SUB-PROJECT³²

Megan Bailey and U. Rashid Sumaila

*Fisheries Economics Research Unit, Fisheries Centre,
University of British Columbia, 2202 Main Mall, Vancouver, BC, Canada, V6T 1Z4*

ABSTRACT

This paper addresses two economic issues in marine resource management: discounting and interdependence of economic sectors. By applying both conventional and intergenerational discounting approaches, we compare the value of Raja Ampat's economic sectors through time. A simple mining case study reveals that a conservation-minded decision might not seem valuable with conventional discounting, but in fact does appear to have net benefits if values are calculated using the intergenerational approach. Interviews were conducted with staff members of Conservation International Indonesia in an attempt to identify how various economic sectors in Raja Ampat may interact with one another. The publication of these interview discussions is meant primarily to ensure their availability to any researcher wishing to take the next step in quantifying sector interactions.

INTRODUCTION

To many people around the world, fish and fisheries resources mean food, income, livelihood and culture. The increasing pressure for fisheries development, along with unsustainable fisheries management practices, has caused drastic declines in fisheries resources, and, in some cases, has driven fish and marine species into extinction, resulting in hardship and poor quality of life in many fishing communities. It is clear that traditional methods of marine resource management have focused on only the short-term benefits of commodity production (Berman and Sumaila 2006), and therefore have not resulted in sustainable fisheries (Sumaila 2004). Consequently, there is a need for alternative management schemes which incorporate socio-economic, political, and ecological factors into decision making (Gislason et al. 2000). Ecosystem-based management is such a scheme, which has the potential to address the varying and complex dynamics of resource management in the developing world.

Ecosystem-based management (EBM) is a widely-used term in the resource management literature, but it is not well-defined or understood (Hirshfield 2005, UNEP 2006). The basic idea of marine EBM is that management of fisheries resources should take into account all complexities of an ecosystem, including the biology and ecology, as well as the human dynamics such as socio-economic and political factors (US Oceans 2004). One of the more difficult concepts for fisheries managers is that EBM can involve short-term costs in order to attain longer-term benefits (Sumaila et al. 2005). From a political point of view, it's often difficult to put in place a management scheme that will result in obvious short-term costs, especially a management scheme that is so poorly-defined. However, the very essence of EBM implies that no 'fixed' definition could do it justice (Ward et al. 2002). EBM must be able to adapt and evolve as information, ideas, models, and tools are added to the repertoire of available management approaches. In this regard, it can be considered a particularly flexible tool for managers.

The Raja Ampat regency is seeking management recommendations for their economic development, and is considering implementing an EBM approach. The regency is rich in resources, specifically those of a marine nature, although logging and mining are also key sectors. Understanding how to manage these

³² Cite as: Bailey, M., Sumaila U.R. (2008). Towards ecosystem-based management in the Bird's Head Functional Seascape of Papua, Indonesia: the economic sub-project. Pages 125-141 in Bailey, M., Pitcher, T.J. (Eds), *Ecological and Economic Analyses of Marine Ecosystems in the Bird's Head Seascape, Papua, Indonesia: II*. Fisheries Centre Research Reports 16(1): 186 pp.

resources in an EBM context could help the Raja Ampat government ensure a flow of benefits to regency citizens in the future.

OBJECTIVES

This sub-project combines recent economic research methods and tools, coupled with an understanding of fisheries ecosystems, to contribute to the goals of biodiversity conservation and sustainable resource use by the communities of the Raja Ampat regency. This specific chapter analyzes the role of discounting on valuing future economic returns from Raja Ampat sectors, and discusses how different economic sectors in Raja Ampat may impact each other.

Objective 1: Intergenerational discounting

In 1973, Colin Clark suggested that disregarding the concept of discounting in fisheries economics “denies the fundamental principles of economics itself” (Clark 1973). The discount rate is a number that allows us to convert values to be received in the future into values today. Generally, the discount rate is positive, which implies that we value the present more than we value the future. As the discount rate increases, we value the future less and less, usually due to uncertainty and risk (Clark 1990). This results in high discount rates favouring short-sighted fisheries policies (Sumaila 2004).

Discounting involves determining the value of something to be received in the future. Conventional discounting applies the same discount rate for each time step to be considered. The World Bank suggests a discount rate of 10% for developing countries. This would imply that \$100 to be received next year is worth only \$90 today, while \$100 to be received in two years is worth \$82.62 today, and so on. To calculate the present value of an amount to be received in the future, we use the following equation:

$$V_p = df^t Vf_t \quad (1)$$

where the present value of the item to be received in the future, V_p , is equal to the discount factor raised to the time the value is to be received, df^t , times the amount to be received Vf_t , at that given time. The discount factor is equal to $1/1+r$, where r is the discount rate.

We are generally interested in the sum of these values over the time period of interest. This sum is called the net present value (NPV) and is calculated as:

$$NPV = \sum_{t=0}^{t=T} V_p, \quad 0 \leq t \leq T \leq \infty \quad (2)$$

It has been argued that conventional discounting ignores inter-temporal equity, that is, it does not fairly consider the needs of future generations (Sumaila and Walters 2005). Schelling (1995) argued that discounting within a given generation is acceptable, but it should not be applied between generations. The fact that the use of resources by today’s generation affects the availability of those resources to future generations requires us to include the future generation’s needs in our resource use policies. This is especially true in planning the sustainable use of a resource, as the word sustainability explicitly considers future generations. Sumaila (2004), and Sumaila and Walters (2005), have developed a new approach to discounting, termed intergenerational (IG) discounting, that attempts to appropriately consider the future in our decision-making today. This brief analysis compares conventional and intergenerational discounting considering the value of the economic sectors of Raja Ampat.

Objective 2: Development options

The Raja Ampat regency is rich in natural resources, with fisheries, mining, and logging being important sectors in the economy (Dohar and Anggraeni 2007). The discounting analysis explained in Objective 1 of

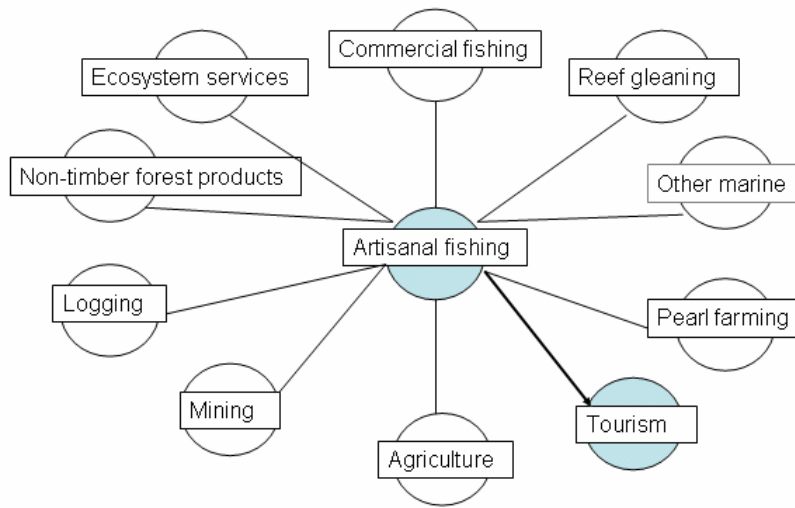


Figure 1. Raja Ampat economic sectors

this report is an attempt at calculating the net present value (NPV) of these sectors over a certain period of time (30 years). We assumed that the nine Raja Ampat economic sectors identified as important to the regency will continue to contribute the same value for each year into the future. Of course that is unlikely. How the value of those sectors behaves in the future depends on all of the other sectors. The current methods for managing resources often overlook this very important fact. For example, artisanal fisheries in Raja Ampat could most certainly influence the economic potential of marine tourism.

Figure 1 gives a visual representation of the economic sectors in Raja Ampat. In this example, we can ask how development of the artisanal fishing sector might affect other sectors, for example, tourism. By defining how these sectors influence each other, possible development plans put forth by the government can be simulated and tested. For example, should the government decide to pursue mining in the future, the implications of that decision can be modelled.

METHODS

INTERGENERATIONAL DISCOUNTING

Researchers from Conservation International Indonesia (CI) and the University of Papua (UNIPA) conducted an economic valuation study in Raja Ampat in 2006 (Dohar and Anggraeni 2007). They identified nine main economic sectors in the regency, whose values are indicated in Table 1 below. Values

Table 1. Value of Raja Ampat's main economic sectors. Values are converted from Inonesian Rupiah (IDR) to USD using the conversion rate of 9000 IRD to 1 USD.

Sector	Billion IDR	Million USD
Artisanal fisheries	63.1	7.01
Commercial fisheries	20.5	2.28
Reef gleaning	2.2	0.244
Other marine	0.023	0.0026
Pearl farming	41.0	4.56
Tourism	14.4	1.60
Agriculture	14.8	1.64
Mining	1.7	0.189
Logging	12.2	1.36
TOTAL VALUE	169.9	18.89

were converted from Indonesian Rupiah (IDR) to USD using a rounded exchange rate of 9000 IDR to 1 USD.

We simulated the value of these sectors through time (30 years) by assuming that in each year they provide the same real value to the Raja Ampat regency. For example, in each of the 30 years the artisanal fisheries sector is worth US \$7.01 million. These values for each sector were then discounted using the conventional approach for different discount rates, and discounted using the IG approach.

An intergenerational approach to discounting modifies the discounting clock with each year (Sumaila 2004). The concept of a discounting clock refers to the time perspective of a given generation (Sumaila

2004). So the IG approach discounts future benefits at a rate that is relevant to the generation that will be receiving the benefits. The NPV is calculated as follows:

$$NPV = \sum_{t=0}^{t=T} W_t V_t f_t \quad (3)$$

where W_t is a weight applied each year on the value to be received in that year.

DEVELOPMENT OPTIONS

The development options scenario component of the project is aimed at describing the linkages and interactions in the different sectors identified by CI, the 9 given above in Table 1, plus non-timber forest products and ecosystem services:

1. Artisanal fisheries
2. Commercial fisheries
3. Reef gleaning
4. Other marine (seaweed farming)
5. Pearl farming
6. Tourism
7. Agriculture
8. Mining
9. Logging
10. Non-timber forest products (NTFP)
11. Ecosystem services (ES)

By defining how these sectors influence each other, possible development plans put forth by the government can be simulated and tested.

In order to model, however, we need to find ways of quantifying these sector relationships. An interview with CI staff in November of 2006 was conducted by this paper's first author in an attempt to describe the relationships. Whether or not these relationships are quantifiable at this stage is difficult to say. The following document is a summary of issues discussed in the CI interview, as well as from separate conversations with Mark Erdman and Chris Rotinsulu from CI, and from conversations with Raja Ampat fishers and some regency officials.

The aim of this economic subproject objective is to understand how these sectors are linked, and to determine the possible and probable impacts sectors could have on each other. We interviewed members of Conservation International Indonesia from the Sorong office to get their expert opinion on interactions and dependences in Raja Ampat's major sectors. From these interviews, we constructed a matrix, illustrating the direction of the impact of an increase in one sector (the first row) on other sectors (across the columns). The main purpose in publishing the issues discussed at the interviews is to ensure that these issues are accessible to any researcher choosing in the future to study different development options in Raja Ampat.

RESULTS

INTERGENERATIONAL DISCOUNTING

Figure 2 illustrates the value of all economic sectors in Raja Ampat through time, at various discount rates.

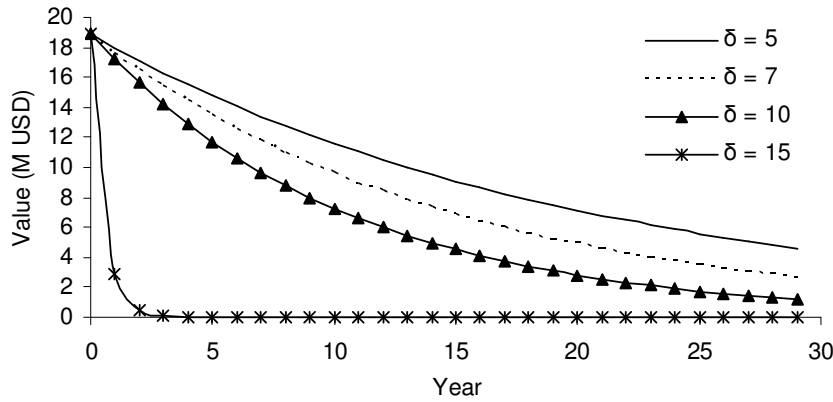


Figure 2. Net present value of Raja Ampat's 9 sectors at different rates of discount, δ

As we can see, higher rates of discount lead to future values being worth less to us today. It is important to understand this concept in planning. If fishers have a discount rate of 15%, then the simulations in this study show that any potential benefits to be received more than three years into the future hold no benefit for fishers today. For example, suppose the Raja Ampat regency was considering a management plan that would close a certain fishery to allow a species to recover (Napoleon wrasse, for

example). The regency could expect sustainable returns in the future for this present-day sacrifice. However, with high rates of discount, using the conventional approach, the regency would most likely not be willing to accept this plan, as they do not put a high value on promised future benefits (see Sumaila 2004 for an example of how conventional discounting could lead to the rejection of a restoration program).

We can compare the proportion of the total benefits that each generation is to receive to illustrate the differences in intergenerational equity that exist with IG discounting compared to the conventional method. Figure 3 illustrates this comparison, for three generations, where we assume that one generation is equal to 10 years.

What this graph shows is that the IG approach allocates higher proportions of the total benefits to be received through time to future generations. This suggests that there is in fact a benefit to restoring a fishery today, from the regency's point of view.

Mining case study

The issue of mining in Raja Ampat was brought up several times during the first author's field trips to Raja Ampat. Although no formal model has been developed to show how mining could impact fishing in Raja Ampat, we can make some assumptions in our discounting study to assess how possible mining plans could impact fisheries in the regency. The above results hold the real value of each economic sector constant through time. In this section, we assume that an increase in mining would have a negative impact

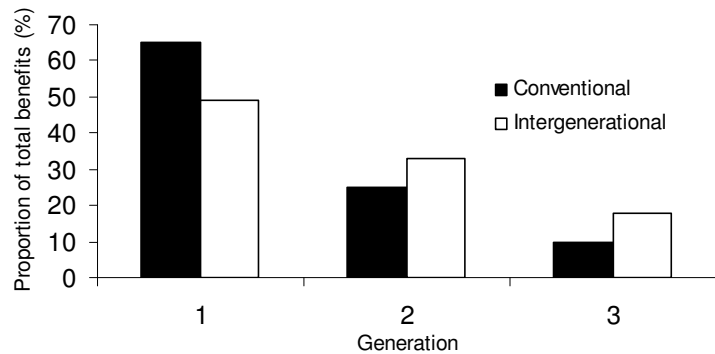


Figure 3. Proportion of total net benefits accruing to each of three generations given two different discounting approaches.

on artisanal and commercial fisheries, and on reef gleaning (see Development Options objective below for the rationale for this assumption). Our assumptions are as follows:

1. Mining activity is increased, leading to a constant return of 0.700 million USD in each year (versus 0.189 million USD in the above section). This is a large increase, and it is debatable how long such a scenario could continue, given that mining is, unlike fisheries, a non-renewable resource;
2. This increase leads to a decrease in artisanal fishing revenue (from 7 million to 6.5 million USD), commercial fishing revenue (from 2.28 million to 2 million USD), reef gleaning (from 0.244 million to 0.200 million USD), and eco-tourism revenue (from 1.6 to 1.2 million USD).

We can also model how a plan that does not allow mining may affect the NPV of Raja Ampat, by assuming that the elimination of mining would positively affect fisheries and gleaning. For this scenario, our assumptions are as follows:

1. Mining activity is turned off in year one of the simulation, leading to no mining revenue in future years;
2. This leads to an increase in artisanal fishing revenue (from 7 million to 9 million USD), commercial fishing revenue (from 2.28 million to 2.5 million USD), reef gleaning (from 0.244 to 0.3 million USD), and eco-tourism revenue (from 1.6 to 2 million USD) in year 20 of the simulation. We assume here that there is a time lag in the ability of the ecosystem to restore itself from current mining damages such that benefits do not begin to materialize until 2 decades of recovery have passed.

Table 2 presents the NPV calculated with conventional and IG discounting for the 3 scenarios: business as usual, increased mining, and no mining. This NPV is the sum over 30 years.

Table 2. Raja Ampat regency NPV under 2 scenarios and 2 discounting approaches.

Scenario	NPV Conventional Discounting (M USD)	NPV IG Discounting (M USD)
Business as usual	251	495
Increased mining	241	476
No mining	251	508

Table 2 shows that if we only used the conventional approach, it would appear that there are no benefits to the regency from

eliminating mining. This is of course because the benefits are felt 20 years into the future. However, because the IG approach to discounting values benefits from the perspective of the generation to receive them, we do see an increase in the NPV of the Raja Ampat regency as a result of allowing fish stocks to recover through the elimination of mining. Generally, the scenario with the highest NPV is the one selected in planning, assuming it meets the goals and objectives of policy makers. Discounting with the IG approach would lead decision makers in Raja Ampat to eliminate mining in the regency under these scenarios.

DEVELOPMENT OPTIONS

The following section presents the results of interviews with staff members of CI. No analysis was performed, but rather the discussions were meant to highlight important considerations for the regency government in their development planning. This should help start the process of understanding how different economic sectors impact each other. Although the obvious linkages might appear to be of an ecological nature (for example, an increase in coastal mining could negatively affect coastal fish stocks) these discussions brought to light other important linkages such as employment and health.

Fishing

Background

The national government is under the impression that more fish should be caught from the fairly productive and pristine Raja Ampat waters. In 2005, an estimated 38,000 tonnes were extracted from the 4.3 million hectare area. In order to take advantage of the Raja Ampat fisheries wealth, the national government is promoting transmigration (subsidizing fishers to move to Sorong, or to Raja Ampat) in order to increase fisheries production. Also, the government is encouraging more vessels from western Indonesia to head east and fish in Raja Ampat. However, the new fisheries minister at the national level is Papuan, and so he may attempt to put a fisheries plan in place that does not encourage further

exploitation of the stocks in Eastern Indonesia. The fishing grounds in Western Indonesia are overfished (Pauly and Martosubroto 1996), and some are worried that the same fate will meet Raja Ampat if such policies continue.

Social Issues of the Fishery

Many people in Raja Ampat are worried about the lack of human resources in the area. Although enrollment (room, board and tuition) at the fisheries technical academy, APSOR (Academi Perikanan of Sorong) is free, and despite Raja Ampat having been declared a maritime regency, there are no students from Raja Ampat currently enrolled. At the same time, fishers in the villages speak about their desire to learn more about fisheries, about sustainability, about the impacts of different gear. Raja Ampat has virtually no skilled sector of any kind in terms of natural resource management. Those having such jobs are often from outside the area.

Artisanal Fishing

There has not been any observation of artisanal fishing impacting commercial fishing. However, any fisheries catching fish from the same stock will impact upon one another in some way, even if it is small quantitatively in a model. Furthermore, some artisanal fishing areas and gears may disturb nursery grounds for commercially-caught species.

Commercial Fishing

Although Becky Rahawarin, Head of the Raja Ampat Fisheries Bureau, or DKP, has made it clear that he will never give out a purse seine license in Raja Ampat, the official data show that there are indeed purse seines operating in Raja Ampat and that these seiners have licenses. Most likely, these are leftover from previous years of management, but are still valid. In fact, one day while out on a research vessel, the first author met with other area researchers who said they had seen 3 purse seiners operating in the northwest recently. It appears that although purse seining is illegal, there really isn't legislation in place to deal with previously-licensed vessels.

Interviewees all agreed that commercial fisheries impact the artisanal sector. The majority of commercial fishers come from Sorong, so there is no competition for employment. However, large scale capture of similar species means that the commercial sector negatively impacts the artisanal stocks. Both commercial and artisanal fishers say they have to fish in different, further areas than in the past, most likely due to a decrease in target stock sizes.

About 90% of the commercial Raja Ampat catch is landed and sold in Sorong³³. Thus, any landings tax is applied in Sorong, with tax revenues going to the Sorong regency and not to Raja Ampat. Jeffman (a village/island between Salawati and Sorong) has been suggested as a Raja Ampat landings port. Fish would be landed in Jeffman, subject to applicable taxes, and then would be re-landed in Sorong. This option could be an interesting decision variable in a development option model: where to land (and tax) fish.

³³ Christovel Rotinsulu, Conservation International, personal communication.

Possible sector relationships

Table 3. Effect of artisanal and commercial fishing on other economic sectors in Raja Ampat.

	Artisanal	Comm- ercial	Reef gleaning	Other marine	Pearl farming	Tour- ism	Agri- culture	Mining	Logging	NTPF	Ecosystem services
Artisanal		-	-/+	?	?	-	?	?	?	?	-
Comm- ercial	-		?	?	?	-	?	?	?	?	-
Reef gleaning	-	?		?	?	-	?	?	?	?	-
Other marine	?	?	?		?	?	?	?	?	?	?
Pearl farming	-/+	-/+	?	?		?	?	?	?	?	?
Tourism	-/+	-	?	?	?		?	?	?	?	-
Agri- culture	?	?	?	?	?	-		-	-	-	-
Mining	-	-	-	?	?	-	?		-	-	-
Logging	-	?	?	?	?	-	-/+	?		-	-
NTPF	?	?	?	?	?	?	?	?	-		-
Ecosystem services	+	+	+	+	+	+	+	?	+	+	

The above table is read across the rows as: how does an increase in artisanal fishing affect the other sectors; and down the columns as: how is artisanal fishing affected by increases in the other sectors.

Table 3 presents a matrix of the interactions between the fisheries sector and other sectors. For increases in artisanal fishing, we assume that there is a negative impact (no matter how small) on commercial fisheries. The impact on reef gleaning can be either positive or negative. Negative if there is less larval food availability for collected invertebrates due to the artisanal catch. However, it may also be argued that if the fish caught are predators of the gleaned species, then an increase in artisanal fisheries may alleviate that predation pressure, resulting in an increase in gleaned species abundance. Interviewees did not discuss the impact on other sectors due to increases in artisanal (or commercial) fishing, for example pearl farming and agriculture. Perhaps here employment/number of workers may limit how much effort can go into these sectors. However, many artisanal fishers are 'farmers' too and therefore it doesn't seem as if an increase in the number of artisanal fishers necessarily means a decrease in the number of farmers. It is most likely argued that increases in artisanal (and commercial) fisheries will have a negative impact on ecosystem services.

Commercial fisheries have a similar sort of impact on the different sectors. In terms of reef gleaning, however, the commercial fishers may be targeting fish in areas far from the coast (where gleaning occurs along the coastline) and thus its impact on reef gleaning may or may not be negligible. Also, because the majority of commercial fishermen come from Sorong, an increase in commercial fishing may not affect the available pool of employees for the other sectors.

With regards to tourism, conventional wisdom has it that increases in fisheries may have a negative impact on tourism. However, if increased fisheries revenue leads to increased management in Raja Ampat, then these negative impacts may be minimized.

Mining

Political

Currently Gag Island and Waigeo Utara (North) are both potential mining sites, and considered protected forests. The Papuan government is claiming that its special autonomy gives it the right to allow mining where it sees fit. However, the national government has publicly stated that it does not support mining in protected forests. The licenses from mining come from the central government, however, their distribution depends on recommendations from the province or regency in question. Therefore Papua

promoted the idea of mining in Waigeo Utara, and thus the national government did in fact grant the license³⁴.

Social

Not all villages agree with mining. Families in Teluk Mayalibit (which would be impacted by the mine in Waigeo Utara) supporting the mines have been criticized by other members of the villages. Furthermore, people choosing to work at the mines could be marginalized in their villages. Informal traditional village laws still exist today, and thus such social exclusion could have a major impact on village cohesiveness.

On Gag Island, however, most villagers agree that the mine might be good for the area. BHP Billiton, the largest mining company in the world, has been given rights to mine Gag. They conducted a thorough environmental impact assessment and have committed to having the least negative impact on the community as possible. The Gag villagers (there is one village on Gag, with a fairly small (648 people) population) think they would benefit from mining employment. Although these villagers do consume fish, they are predominantly coconut farmers. They believe that the social benefits of diversified economic activities on the island would outweigh the environmental costs of the marine ecosystem impacts. As long as soil conditions remain conducive to agricultural activities, the main livelihood of the village/island will not be compromised. The oceanographic features off Gag could be conducive to mining, as the predominant currents would sweep any effluent quickly away from the island³⁴.

Despite local thought that mining will bring employment to the area, the mining companies will generally not employ large numbers of individuals from the community. For example, the company wanting to mine in Kapadiri (Waigeo Utara) said they would employ 20 local, unskilled laborers. The local revenue function may therefore change very little as a result of mining in the area.

The health of workers in the mines is an issue, as the proper controls to ensure worker safety will most likely be lacking. Depending on the specific site, groundwater contamination could lead to decreases in village health. Furthermore, in areas where much of the population consumes large amounts of filter feeders (for example, 42 different types of bivalves are consumed in T. Mayalibit), village health may be affected by toxin build-up in such food items.

Environmental and economic

The main environmental issues with mining include sedimentation and toxic deposits to the water. Mayalibit is an extreme case, as there is a limited amount of water exchange in the south with the Dampier Strait (but some outflow, allowing for the possibility of impacts on the strait). Sedimentation as a result of mining would most surely build up in the bay and choke the ecosystem. All villages in Raja Ampat are coastal, and therefore sedimentation, due to runoff from adjacent hilly areas, will most surely be felt at the village level. The fringing reefs along Waigeo would be heavily impacted by changes in sedimentation and turbidity³⁵. However current regimes, depths, and oxygen levels for each anticipated site will have to be studied in order to predict such effects (these data are currently not of good enough quality to be incorporated quantitatively in a model). Gag is a secluded island on the western side of Raja Ampat. Again, as indicated above, dominant currents flow from east to west through this area, and the ocean is quite deep. It is therefore possible that the effects from mining on Gag will be minimized due to high dispersion and dilution of sediment and toxins.

In order to mine, large plots of land must be cleared. This has two main outcomes on the other economic sectors: 1. an increase in revenues from logging, as the current proposal suggests that the area cleared will be 'logged', and thus generate income, and 2. the loss of ecosystem services (ES) as a result of lost forest land. Data on the percent forest cover will be needed in potential sites to estimate how much loss of ES will occur, and to estimate revenues from logging.

Some studies have suggested that mining activities increase illegal logging potential due to increased road access by illegal loggers to remote forest areas. The majority of mining activity would be focused in areas close to the coast. This is beneficial with respect to not increasing the amount of illegal logging (as roads

³⁴ Mark Erdmann, Conservation International, personal communication.

³⁵ Christovel Rotinsulu, Conservation International, personal communication.

will not go deep into forested land). However, this will increase the potential effects on the coastal reef ecosystems and thus on villagers, as the mines are destined to be placed quite close to villages. Furthermore, decreasing illegal logging has been a major focus of both the Papuan and the national governments, and thus is no longer one of the main threats in the area.

Possible sector relations

Table 4. Effect of mining on other economic sectors in Raja Ampat.

	Artisanal	Comm- ercial	Reef gleaning	Other marine	Pearl farming	Tour- ism	Agri- culture	Mining	Logging	NTFP	Ecosystem services
Artisanal	-	-	-/+	?	?	-	?	?	?	?	-
Comm- ercial	-	-	?	?	?	-	?	?	?	?	-
Reef gleaning	-	?	-	?	?	-	?	?	?	?	-
Other marine	?	?	?	-	?	?	?	?	?	?	?
Pearl farming	-/+	-/+	?	?	-	?	?	?	?	?	?
Tourism	-/+	-	?	?	?	-	?	?	?	?	-
Agri- culture	?	?	?	?	?	-	-	-	-	-	-
Mining	-	-	-	?	?	-	?	-	-	-	-
Logging	-	?	?	?	?	-	-/+	?	-	-	-
NTFP	?	?	?	?	?	?	?	?	-	-	-
Ecosystem services	+	+	+	+	+	+	+	?	+	+	-

It seems obvious that mining negatively affects most sectors. For example, sediment and toxins will most likely have a negative impact on artisanal and commercial fishing, and definitely on gleaning (filter feeding invertebrates). In fact, for T. Mayalibit, the negative impacts on gleaned species may be more of an important health risk than an economic risk. Most likely mining will also negatively impact tourism potential, by affecting water clarity and negatively affecting fish stock abundance and coral reef health. The effect of mining on logging and agriculture should be looked into further. Agriculture is an issue for Gag villagers, but not as much so for T. Mayalibit villages. Because Waigeo Utara is so mountainous, there isn't much agriculture space behind the villages lining the Bay, and thus farming is not as important to these villages as the collection of the bay's invertebrates. Furthermore, an increase in mining is most surely to negatively affect ecosystem services.

Tourism and MPAs

Tourism

Like the benefits of landed fish, tourism benefits go directly to Sorong. Travel agents work out of Sorong, and food and fuel are purchased there. Some have suggested that opening Jeffman's airport again would help the Sorong regency³⁶. This would allow tourists to fly directly to Raja Ampat, creating local employment at the airport. However, the logistics of getting Merpati and Garuda (domestic carriers) to fly to Jeffman could be difficult. Tourists could spend the night in Jeffman (again direct tourism benefits to the island), before setting out on the live-aboard boats. This would mean that tourists never set foot in Sorong.

The current level of tourism in Raja Ampat is pretty small, compared to other similar areas worldwide (e.g., Hawaii and Caribbean). Growth in this sector could be a way to increase revenue, provided that it is done in a way that benefits the villagers of Raja Ampat, and not just the Sorong regency. The tourism office is planning on creating a tourism base on an island close to the capital village of Waisai (between Waisai and Saonek). Any boats entering Raja Ampat (whether from Sorong, or from Jeffman) will have to

³⁶ Christovel Rotinsulu and Mark Erdmann, Conservation International, personal communication.

pass through this base, paying a fee for each diver on board. This has the potential to educate tourists that Raja Ampat is separate from Sorong, and deserves proper independent management.

Collecting dive fees raises the important question of who those fees will benefit. Ideally fees collected will be at least partially shared at the local government level³⁷. But exactly who should benefit from divers? Should it be every village/villager in Raja Ampat or only those close to dive sites? The customary marine tenure situation in Raja Ampat makes this difficult, because there are several overlapping tenure arrangements, for example more than one village claims ownership of a given bay³⁸. If only villages near the dive sites should benefit, is that an incentive for migration from other areas in Raja Ampat (or elsewhere) to these villages? If the villages are given straight funds, will there be stipulations on how these funds can and should be spent? One suggestion is that each village put forth a proposal on how they would like the money spent³⁶. For instance, some villages may request books for their school; others may need mosquito nets, or better access to fresh water, etc. One thing is certain though, tourism revenue should be used in whatever way to improve the standard of living for people residing in Raja Ampat.

Possible sector relationships

Table 5. Effect of tourism on other economic sectors in Raja Ampat.

	Artisanal	Comm- ercial	Reef gleaning	Other marine	Pearl farming	Tour- ism	Agri- culture	Mining	Logging	NTFP	Ecosystem services
Artisanal		-	-/+	?	?	-	?	?	?	?	-
Comm- ercial	-		?	?	?	-	?	?	?	?	-
Reef gleaning	-	?		?	?	-	?	?	?	?	-
Other marine	?	?	?		?	?	?	?	?	?	?
Pearl farming	-/+	-/+	?	?		?	?	?	?	?	?
Tourism	-/+	-	?	?	?		?	?	?	?	-
Agri- culture	?	?	?	?	?	-		-	-	-	-
Mining	-	-	-	?	?	-	?		-	-	-
Logging	-	?	?	?	?	-	-/+	?		-	-
NTFP	?	?	?	?	?	?	?	?	-		-
Ecosystem services	+	+	+	+	+	+	+	?	+	+	

The effect of tourism on the other sectors is complex. For example, an increase in tourism may be a positive thing for artisanal or commercial fishers, if fresh fish is purchased from villages/villagers by the live-aboard vessels. However, dive sites and fishing sites compete for space. For example, there may be zones that are no-take (see MPA discussion below) and thus the area fishers can use may be decreased. However, these no take zones *may* positively affect fish stock abundance, thus having a positive effect on fisheries. Whether tourism would affect agriculture and logging was not addressed in discussions. But if villagers could also sell fresh fruit, vegetables and tubers (cassava) to live-aboard operators, then tourism may benefit the 'agricultural' sector. Tourism can have a negative effect on ecosystem services. However there is enough literature and experience available to assist the regency government and tourism officials to proceed with expanding the tourism sector carefully.

MPAs

Several MPAs are being discussed, including large ones in Wayag and Sayang, the Dampier Strait, and Ayau, which were informally 'declared' in 2007. These will be zoned MPAs. There will be some zones that allow for diving, and other zones where diving is not allowed. Enforcement of zoning systems may prove difficult. Wayag, for example, can be converted to a no take area quite easily, because there are no villages

³⁷ Mark Erdmann, Conservation International, personal communication.

³⁸ Jacinta Djuang, Conservation International, personal communication.

there currently fishing. However, villages in and around the Dampier Strait will continue to depend on marine resources for their daily livelihood. These villages may be informed that small (20 Ha) no-take zones (effectively 'marine sanctuaries') will be implemented near them. There will be no artisanal fishing allowed in these areas. Suitable compensation will need to be devised in order to encourage villagers to collaborate and not fish in the no-take zones. However, if the village head and traditional village leader sign onto the idea of MPAs, then most likely villagers will behave accordingly. Villages with marine sanctuaries are effectively saving some of their resources, and hope to benefit from the interest on this 'natural capital' in the future. The problem here (and what could be an interesting variable in a quantitative model) is the issue of discounting. Villagers who are poor may have high discount rates, and thus the promotion of resource investment by conservation-minded people may not be properly understood, or accepted, by them. Of course, it may go in the opposite direction too, that villagers, who under the customary marine tenure laws have rights to coastal resources, may have low discount rates because of their closeness and attachment to the ocean.

The timeline for expected social, environmental, and economic benefits from MPAs ranges in the literature. Although small community MPAs may show successes in 2 years, larger MPAs, such as the Dampier Strait (maybe 10,000 Ha), may have a timeline for expected benefits in the order of decades. The protection of corals will ultimately enable the regeneration of the ecosystem. Corals will enable population increases with reef-associated fishes, and thus the overflow or spillover effect can be expected in areas adjacent to the MPA. Large MPAs may be a valid approach in Raja Ampat due to the low population, whereas small MPAs may be more valid in highly populated areas³⁹.

There will most likely not be a huge economic loss due to decreased fishing effort because of MPAs, nor will villagers be unfairly stripped of their resource rights. The population is small, and thus affects to losses in marine exploitation will be minimal. The idea of empowering villages is important. Villagers have been sitting by and watching, or at times participating, in illegal and destructive fishing activities, feeling powerless. However, MPAs in their area make them aware that 1. there are environmental threats in their area (education); 2. they have the ability to monitor such threats (empowerment); and 3. future returns from marine resource use will continue to flow to the community (benefits). Anxiety about future means of providing for their families is a valid concern for villagers here. And although all fishers admit that there are fewer fish in their area now than in the past, hardly any villagers identify over-fishing as a current threat to coastal systems in Raja Ampat⁴⁰. Fishers know there are less fish, but they cannot identify why, so they have no understanding of how to improve their situation.

The possibility of compensation for villagers near marine sanctuaries is strongly recommended in this situation. Some villagers already receive compensation for allowing illegal/destructive fishing to occur in their tenured area (generators, roofing, etc.). One possible solution is to compensate villages having marine sanctuaries with tourist revenues (one of the presumed effects of MPAs will be an increase tourism, and thus in revenues). However, one worrisome aspect of a compensation plan is that it might offer an incentive for Raja Ampat citizen migration. Why not move your family to a nearby village where you are guaranteed more money for doing nothing? Whether this will be a problem or not is debatable. The village of Yellu provides an interesting example.

Yellu, in Southeast Misool, is a village/island where a private MPA is currently being established. Here, 250 km² has been purchased from Yellu by a private interest in order to build and operate a diving resort. Also in this area are many pearl farms, promising alternative livelihoods. Yellu has experienced an increase in population since the pearl farms have been introduced, and also on account of jobs in the tourism sector with the new resort. Only one quarter of the small island remains forested and undeveloped, the remaining three quarters are overloaded with housing. However, newly migrated individuals are not afforded the same employment opportunities. Potential employers approach the village chief for advice on who to hire, with the village head usually recommending local villagers that have lived in the area for years (or generations)³⁸.

There are two obvious complications with the above situation. Firstly, if those migrating face social exclusion and lack of employment opportunities, they may engage in illegal fishing activities to make a living (alternatively they may move back from where they had come). Secondly, this offers incentive for

³⁹ Christovel Rotinsulu, Conservation International, personal communication.

⁴⁰ This paper's first author spoke with fishers in Raja Ampat and specifically asked their thoughts on why there were less fish today. Not one fisher suggested overfishing.

the village head to receive bribes in order to promote a certain individual or family for employment. Transparency in resource management is paramount to its success.

The private investors in the project have noted the need to compensate villages for lost fishing grounds because of the resort. *Rumpons*, or fish-aggregating devices (FADs), have been suggested. These FADs will be given to a few families in Yellu, and will be set up in deep areas outside of the no-take zone (at least 60 m deep). This is quite far from the village, and will require a lot of effort for the fishers to reach the area (motors for boats will definitely be required). The idea of giving the Rumpons away, and not just setting them up and allowing fishers to use them is of critical importance in Raja Ampat. Traditional marine tenure agreements remain quite strong in Raja Ampat. If a family sets up its rumpon, others are not allowed to use it by informal law. Enforcement of a private MPA will be a challenge, as will enforcement to ensure that commercial fishers do not descend upon the rumpons and capture all the fish. However, the hope is that with the villagers using the rumpons daily, there will be little opportunity for outsiders to engage in fishing there. Only traditional gear (lines and spears etc) will be employed here (no purse seines, which are often the common-place gear used around FADs).

Logging

There is evidence that illegal logging may be an issue in Raja Ampat. Most of the islands are forest preserves, and thus clearing of the land is technically illegal in most areas. There is also sand mining on some of the islands (Batanta and Salawati) which is controversial. Sand is mined and sent to cities for construction purposes, but is technically illegal⁴¹.

Possible sector relationships

Table 6. Effect of logging on other economic sectors in Raja Ampat.

	Artisanal	Comm- ercial	Reef gleaning	Other marine	Pearl farming	Tour- ism	Agri- culture	Mining	Logging	NTPF	Ecosystem services
Artisanal		-	-/+	?	?	-	?	?	?	?	-
Comm- ercial	-		?	?	?	-	?	?	?	?	-
Reef gleaning	-	?		?	?	-	?	?	?	?	-
Other marine	?	?	?		?	?	?	?	?	?	?
Pearl farming	-/+	-/+	?	?		?	?	?	?	?	?
Tourism	-/+	-	?	?	?		?	?	?	?	-
Agri- culture	?	?	?	?	?	-		-	-	-	-
Mining	-	-	-	?	?	-	?		-	-	-
Logging	-	?	?	?	?	-	-/+	?		-	-
NTPF	?	?	?	?	?	?	?	?	-		-
Ecosystem services	+	+	+	+	+	+	+	?	+	+	

If logging takes place close to the coast, then it may be argued that growth in this sector could negatively affect artisanal fishers, and perhaps seaweed farms and reef gleaning. Logging could be potentially positive for agriculture, as the land would be cleared by loggers, and perhaps some of that cleared space could be given to nearby villagers for agricultural endeavors. Most likely logging negatively impacts ecosystem services. Whether logging would affect tourism is hard to say. Large scale coastal operations probably would, but smaller-scale logging efforts, if sufficiently inland, would probably have a negligible effect on tourism.

⁴¹ Christovel Rotinsulu, Conservation International, personal communication.

Pearl farming

Social Issues

At first glance, pearl farms tend to have more positive than negative impacts. Firstly, the majority of employees at the farm are local, unskilled laborers from Raja Ampat, whose opportunity cost of labour is low, if not zero. This is especially true in Misool. In addition to employment, pearl farming offers benefits such as access to transportation and electricity. The investments from the pearl farms in infrastructure should not be overlooked, as this is one of the major issues in trying to increase standards of living in Raja Ampat. For villagers, transportation between the pearl farm and Sorong is free in most areas of Raja Ampat. The current alternative is usually to take a longboat, which can be a dangerous and lengthy journey. Also, a pearl farm in an area means there is always available fuel for people to buy, instead of having to make the trip into Sorong to purchase fuel. This saves the villager both time and money, as well as decreases risks at sea, which during the rainy season can be quite substantial. One further social issue that comes with increased transportation to Sorong is the increased exposure to city health risks, such as HIV/AIDS. The increased availability in trips to Sorong may be endangering villager health as Papua is the second most affected Indonesian area by HIV/AIDS, with Sorong being the most affected city in Papua⁴².

Fisheries

In addition to the benefits mentioned above, there are direct benefits to local fish populations from pearl farms. They provide ample detritus as a food source, and the lines holding the oysters serve as artificial shelter for fishes. This means that areas adjacent to farms are often rich with fish, and thus may lead to increased revenue from artisanal fisheries, and maybe even commercial fisheries in the vicinity.

Of course, by setting up pearl farms in areas that may have once been fished, those areas are no longer accessible to fishers. Thus, there could be a decrease in artisanal fishing for 2 reasons: 1. due to the decrease in available fishing area, and 2. due to decreased available work force as individuals move to the pearl farming sector for employment. Furthermore, the pearl farm officials hold power over the villagers. Officials have demanded that villagers bring them turtles to eat⁴¹. Turtles in the area are under increasing threats due to their use as bait for shark fishing, and due to the poaching of their eggs.

Some villagers have expressed concern that if the pearl farms go under, they will be left with nothing: no human resources, no increased capacity in resource management and no infrastructure. Interestingly though, Raja Ampat citizens generally do not work laborious jobs full time, and villagers have complained that work at the pearl farms is too hard, but don't feel they have alternatives⁴¹. Most pearl farm employees used to be fishers. They may have spent 4 or 6 hours a day doing what they loved and knew. Now they are working 12 hour days and feel they aren't learning any skills that could be applied anywhere else.

⁴² Jacinta Djuang, Conservation International, personal communication.

Possible sector relationships

Table 7. Effect of pearl farming on other economic sectors in Raja Ampat.

	Artisanal	Commercial	Reef gleaning	Other marine	Pearl farming	Tourism	Agriculture	Mining	Logging	NTFP	Ecosystem services
Artisanal		-	-/+	?	?	-	?	?	?	?	-
Commercial	-		?	?	?	-	?	?	?	?	-
Reef gleaning	-	?		?	?	-	?	?	?	?	-
Other marine	?	?	?		?	?	?	?	?	?	?
Pearl farming	-/+	-/+	?	?		?	?	?	?	?	?
Tourism	-/+	-	?	?	?		?	?	?	?	-
Agriculture	?	?	?	?	?	-		-	-	-	-
Mining	-	-	-	?	?	-	?		-	-	-
Logging	-	?	?	?	?	-	-/+	?		-	-
NTFP	?	?	?	?	?	?	?	?	-		-
Ecosystem services	+	+	+	+	+	+	+	?	+	+	

As stated above, there can be social and fisheries benefits from pearl farming, but all aspects of pearl farming should be considered to ascertain whether or not the net contribution of pearl farms are in fact beneficial to local residents.

Health and demographics

Two major health issues in the area include HIV/AIDS and malaria. Regarding malaria, villagers tend to treat themselves mostly with natural/traditional medicines, with some malaria patients heading into Sorong for treatment⁴³. The risk of malaria in this area is one of the highest in the world, and this may be a barrier to the tourism industry.

Other health issues include diarrhea, skin issues, throat infections, and bronchitis. Bronchitis affects not only the adult population (most of who smoke) but also children⁴⁴. Many women and children are sick due to improper kitchen/cooking equipment. Most homes do not have exhaust systems, resulting in fumes polluting the air for those inside. Furthermore, as access to fresh water is limited, food preparation may not be sanitary.

The population is growing at 3% per year. The Papuan government is promoting this, as they believe more people will bring about more aid and more autonomy⁴⁵. In fact, the regency government is refusing to issue contraceptives to the population of Raja Ampat. Sexual education and family planning are almost unheard of in Raja Ampat⁴².

DISCUSSION AND CONCLUSION

INTERGENERATIONAL DISCOUNTING

The concept of discounting cannot be ignored in resource use planning, as it truly determines how a resource will be exploited today, which impacts its future availability. It might be a worthwhile endeavour for the Raja Ampat regency to fund research to determine the discount rates of fisheries managers and the fishers themselves. Even if managers and planners are on board with intergenerational discounting, and can value future benefits as a result of present-day short term costs, the fishers' perceptions and actions

⁴³ Jacinta Djuang, Conservation International, personal communication.

⁴⁴ Anita Dohar, Conservation International, personal communication.

⁴⁵ Mark Erdmann, Conservation International, personal communication.

also impact the resource. Intergenerational discounting can be a useful approach to illustrate the benefits of a restorative fisheries program, where catch is limited today, as this can promote sustainable fishing in the future, and help ensure a flow of benefits to Raja Ampat regency citizens through time. A key endeavour in resource economics is to find ways to mitigate and reduce the discounting of future gains.

DEVELOPMENT OPTIONS

Constructing sector matrices is the first step in deciding the direction of impacts of certain resource decisions. There are many relationships that are unknown, as illustrated by the large amount of question marks in the matrices above. These can be answered by other experts in the area, and through a thorough literature review. The next step is to quantify sector impacts. This is understandably more difficult than just identifying the direction. One way at quantifying these impacts would be to use input/output theory.

Once there are quantitative relationships defined, a model could be developed linking all sectors, with the net present value (NPV) of different development options being compared. For example, we could increase mining by 2% each year and see how that changes the potential values from artisanal fishing in the future. The modelling possibilities are endless. The calculation of the NPV without linking sectors could be considered the 'business as usual' approach to management. A model developed with all sectors linked could be considered an EBM approach. A comparison of these two model simulations and results could indicate that ecosystem modelling is a far more realistic and illuminating approach. The development options framework described herein begins this process by attempting to link the identified economic sectors in Raja Ampat. Through this approach, the tradeoffs between different development plans can be modelled and compared from an ecosystem perspective.

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CHAPTER 3

DESTRUCTIVE FISHING IN RAJA AMPAT, INDONESIA: AN APPLIED PRINCIPAL-AGENT ANALYSIS⁴⁶

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ABSTRACT

The occurrence of cyanide and dynamite fishing, collectively referred to as destructive fishing, in Raja Ampat, Indonesia, threatens the integrity of reef ecosystems and the sustainability of reef fisheries. The perverse incentives of destructive fishing in the artisanal sector are examined by applying game theory to analyze how the probability of detecting illegal fishers and the fine owed by apprehended fishers can be used to decrease the occurrence of illegal fishing. Results suggest that the elimination of blast fishing, targeting primarily snapper (*Lutjanidae*) species, could result in a stable snapper stock biomass an estimated increase in the net present value of the fishery of US \$3.68 million over the next 45 years. However, the high profitability of the cyanide fishery targeting grouper species appears to be a substantial barrier to the elimination of this gear, and to a large increase in economic value of a completely legal fishery.

INTRODUCTION

The Raja Ampat regency in Papua province, Indonesia, is currently trying to develop and implement a sustainable fisheries management system. Raja Ampat boasts the world's highest coral reef biodiversity, with 75% of known hard coral species found in the area (Halim and Mous 2006) and is home to over 1,200 species of fish (Ainsworth et al. 2007). Artisanal fishing in Indonesia is an important economic sector (Dohar and Anggraeni 2007), but the introduction of new gears can throw off the traditional balance artisanal fisheries often exhibit (Kusuma-Atmadja and Purwaka 1996). The use of destructive fishing gears, mainly explosives and cyanide, is one of the major threats to sustainable fisheries in the Raja Ampat regency (Halim and Mous 2006). Both practices are illegal. This paper develops a model comparing the profitability of illegal (destructive) fishing methods to legal methods. Principal-agent theory is used to simulate how incentives offered by the government could encourage fisher effort away from illegal methods.

IUU FISHING

Illegal, unreported, and unregulated fishing (IUU), is gaining attention around the world, with fisheries scientists listing it as a major barrier to the sustainability of marine resource use (Pitcher et al. 2002; Sumaila et al. 2006). Illegal fishing is any type of fishing that violates a regulatory measure. In Indonesia, the use of illegal fishing gears, such as cyanide and explosives, is considered one of the biggest threats to the marine ecosystem (Pet-Soede and Erdmann 1998; Pet-Soede et al. 1999; Halim and Mous 2006). IUU fishing can undermine management programs (FAO 2002) by underestimation of catch and effort (Pitcher et al. 2002). Furthermore, both dynamite and cyanide fishing negatively affect fish habitat, and are thus inherently unsustainable fishing methods (Pauly 1989).

PRINCIPAL-AGENT THEORY

The majority of the world's fisheries are common pool or shared in nature. As such, the use of game theory, essentially the study of strategic interactions between players, has been widely applied to fisheries

⁴⁶ Cite as: Bailey, M., Sumaila U.R. (2008). Destructive fishing in Raja Ampat, Indonesia: An applied principal-agent analysis. Pages 143-169 in Bailey, M., Pitcher, T.J. (Eds), *Ecological and Economic Analyses of Marine Ecosystems in the Bird's Head Seascape, Papua, Indonesia: II*. Fisheries Centre Research Reports 16(1): 186 pp.

management models (Munro 1979; Clarke and Munro 1987; Sumaila 1995; 1997; 1999; Trisak 2005; Kronbak and Lindroos 2007). In an era of ecosystem-based management (EBM), the ability to model multiple users of an ecosystem is becoming increasingly important (Sumaila 2005). Differences in resource user uncertainty, rates of discount, and risk aversion can impede sustainable fisheries (Munro 1979; Sumaila 2005), a core EBM goal. Game-theoretic models, because they explicitly model the expected utility functions of the user groups, can help economists elucidate the factors that impede or assist in the collaborative management process, and thus, perhaps, explain why EBM is such a hard goal to reach.

Principal-agent theory is a special type of game-theoretic approach that models situations where one player in the game (the principal) has effective 'ownership' over the resource and those actors exploiting the resource (the agents). In the first best solution, the principal can perfectly control the agents' actions in order to maximize his/her objective function (Clarke and Munro 1987). In terms of fisheries management, for example, the manager would be able to perfectly control the agents' fishing effort. If this first best solution occurs, then the objectives of the principal are fully met, and the benefits realized to the principal are exactly equal to what the principal expects. However, it is unrealistic to assume that perfect control is within the power of the principal and thus that the first best solution would occur. Rather, most situations end up at the second best solution, where due to imperfect control, and imperfect information, the realized benefits to the principal are less than expected.

The difference between the realized benefits in the first and second best solutions is called the incentive gap (Clarke and Munro 1987). Principal-agent theory seeks to decrease this gap through the use of appropriate incentives. The optimal incentive scheme is one that minimizes the incentive gap at a minimal cost to the principal. To our knowledge, only three published articles have applied principal-agent analysis to study fisheries problems. All of these use taxes and subsidies as incentives (Clarke and Munro 1987; 1991; Jensen and Vestergaard 2002). In the current paper, however, the probability of detecting illegal fishers, and the penalty faced by violators, are used as disincentives.

DISCOUNTING

The discount rate is a number that allows us to convert values to be received in the future into values today. Theoretically, the discount rate can take both negative and positive values. A negative discount rate implies that we value the future more than the present. If the discount rate is zero, it means we have no time preference. But generally, the discount rate is positive, which implies that we value the present more than the future. As the discount rate increases, we value the future less and less. Generally, we do not value the future as much as we value the present, due to uncertainty and risk (Clark 1990). In the example of resource conservation, we are uncertain about stock sizes, about ex-vessel prices, and about the costs of fishing. We know the present-day profitability of fishing, yet we are uncertain of the future and thus we prefer values from fishing today. Furthermore, by foregoing present benefits, we are losing possible interest accumulation on those benefits. Discounting is a complex issue that economists have frequently discussed and debated (Clark 1973; 1990; Nordhaus 1997; Weitzman 2001; Ainsworth and Sumaila 2005; Sumaila and Walters 2005; Berman and Sumaila 2006). One thing seems very clear though: higher rates of discount (social or private) lead to greater resource depletion. To determine the possible differences in management scenarios given such uncertainty in discounting, each of the two models in this chapter (snapper and grouper) is run with various discount rate assumptions.

MODEL OUTLINE

Artisanal Fisheries

The artisanal fisheries sector in Raja Ampat was valued at 63 billion Indonesian Rupiah (IDR) in 2006, equivalent to about US \$7 million (Dohar and Anggraeni 2007). Generally speaking, the artisanal fishery is a mixed-species fishery, with several target species pursued with several gear types. For example, one fisher may fish at any time with a hand line, or spear, and target snapper (Lutjanidae family), grouper (Serranidae family), or trevally (Siganidae family). Legal fishing gears used for artisanal fishing include

handline, dip net, gill net, permanent trap, and spear/harpoon. The average artisanal fisher in Raja Ampat fishes about 15 days per month (Dohar and Anggraeni 2007).

Fishing with the use of explosives and cyanide also occurs in Raja Ampat. Pet-Soede and Erdmann (1998), report that the low population densities in eastern Indonesia make monitoring and enforcement difficult. Blast and cyanide fishing are used to catch reef-associated fish, with snapper (dynamite), grouper and Napoleon wrasse (*Cheilinus undulatus*) (cyanide), being the main targets (Pet-Soede et al. 1999). When Halim and Mous (2006) asked households in Raja Ampat if family members engaged in destructive fishing practices, all respondents said no. However, most fishers interviewed during field trips of the first author in Raja Ampat admitted that they usually heard blast fishing every day. The environmental damage that occurs due to blast fishing may result in a loss of 13% coral cover per year (Saila et al. 1993). Reefs exposed to repeated blasts are often reduced to little more than "shifting rubble fields" (Pet-Soede and Erdmann 1998). Today blast fishing occurs with homemade fertilizer bombs (Pet-Soede et al. 1999), which means the cost of making the bombs is probably much lower than it once was, when fishers used actual dynamite. Blast fishers in large operations can make between US \$50-\$150 per week (Pet-Soede and Erdmann 1998), while the small-scale blast fishers net about US \$14 per week (Pet-Soede et al. 1999).

The current management regime states that fishers have to be caught in the act of cyanide fishing in order to be charged with illegal fishing (Mark Erdmann, Conservation International, personal communication). The result is that regulators are powerless even if they find a fisher with cyanide and live fish in his boat⁴⁷. The discussion regarding how much reef damage is caused by cyanide fishing varies widely, but quantitative simulations suggest that the worst-case scenario could result in a loss of 9.5 % coral cover per year (Saila et al. 1993). Furthermore, the high catch per unit effort of cyanide fishing can quickly lead to overfished populations (Mous et al. 2000). The price for live fish caught using cyanide varies, but Pet-Soede and Erdmann (1998), report that live fish, such as the coral trout (a grouper species, *Plectropomus leopardus*), can fetch up to US \$18.8/kg.

Players

Principal-agent analysis is structured around the players in the game, and their objective functions. Because the regency government is the effective legal 'owner' of marine resources in Raja Ampat, it is assigned the role of the principal in this analysis. However, villagers tend to respect the authority of the traditional village clan over the formal government (Halim and Mous 2006). Based on his journey through the remote islands of Indonesia, Severin (1997 p. 67), writes "...the authority of these traditional leaders was more respected than the regulations which ultimately come from Jakarta ... exploitation of the land and sea should be done according to custom." Customary marine tenure rights are still enforced and respected in Raja Ampat. The traditional clans represent descendants from the first families in Raja Ampat. These clans, present in each village, are the informal 'owners' of land and marine resources⁴⁸. The model developed herein assumes that the agents in the game are the clans, who have the ability to control fisher actions. That is, the clans have two different fishing strategies available to them: legal or illegal (or any combination thereof).

Two principal-agent models are simulated to evaluate the effort and profitability of illegal fishing, and the possible incentives that can be applied by the regency. The first model considers blast fishing targeting snapper species. Using grouper species, the second model analyzes the cyanide fishery, and the implications for effort, profit, and management. Both simulations are based on the same model developed below. The software package Powersim was used to carry out the simulations (Powersim Software AS 1996).

⁴⁷Although women do participate in some fishing activities, such as coastal gleaning, boats are generally owned and operated by men.

⁴⁸A. Suebu, The Nature Conservancy, personal communication.

METHODS

BIOLOGICAL MODEL

Population dynamics without fishing

A simple logistic-growth model is used here to describe the biology of the system. This model assumes that change in the population biomass with time is related to the intrinsic rate of growth of the stock, r , the stock's carrying capacity, K , and the current stock size, B_t , as per the following equation:

$$\frac{dB_t}{dt} = rB_t \left(1 - \frac{B_t}{K} \right), B_t \geq 0 \quad (1)$$

Equation (1) implies that $dB_t/dt > 0$ for $0 < B_t < K$, and thus that the stock can recover from depletion so long as $B_t > 0$.

Population dynamics with fishing

The above equation factors in only natural mortality, contained within the intrinsic rate of growth parameter. Catch is obviously an important part of any fished stock's population dynamics. A simple production model of the Cobb-Douglas form, (Cobb and Douglas 1928), is used to simulate catch, h_t :

$$h_t = qE_t^\alpha B_t^\beta, E_t > 0, B_t > 0 \quad (2)$$

where q is the catchability coefficient, which is assumed constant in this model over time. The catchability coefficient represents the proportion of the total biomass that is removed by one unit of effort in a given period. In this model, effort, E , is measured in number of trips per year, and must be greater than or equal to zero. It is further assumed that $\alpha = \beta = 1$, that is, there are constant returns to catch based on unit increases in effort or biomass. Hyperstability is implied if the parameters α and/or $\beta < 1$ (increases in biomass and/or effort result in less than equal increases in catch), while α and/or $\beta > 1$ implies hyperdepletion (increases in biomass and/or effort result in greater than equal increases in catch) (Walters and Martell 2004). This simplified catch equation, $h_t = qE_t B_t$, is often known as the Schaefer catch equation (Schaefer 1957).

By incorporating the catch equation (2) into (1), we get a more complete picture of the population dynamics of the stock:

$$\frac{dB_t}{dt} = rB_t \left(1 - \frac{B_t}{K} \right) - qE_t B_t \quad (3)$$

Fishing strategies

Recall that the village clan is assumed to be able to allocate fisher effort to one of two types of fishing strategies: using legal or illegal gears (or any combination thereof). Let the type of strategy, s , be the set of these two types of fishing: $s := \{s, -s\}$, where s represents legal fishing and $-s$ represents illegal fishing.

We can rewrite (3):

$$\frac{dB_t}{dt} = rB_t \left(1 - \frac{B_t}{K} \right) - q_s E_{s,t} B_t - q_{-s} E_{-s,t} B_t \quad (4)$$

ECONOMIC MODEL

Revenue

Total revenue, TR , is the product of the catch, h_t , and the unit price, P . Unit price is assumed to be constant over time, however, catches with different fishing strategies can command different prices. Similarly, due to differing catchabilities and effort levels with each strategy, ht is also indexed by s . We can describe the single period total revenue for a given strategy as:

$$TR_{s,t} = P_s h_{s,t}, \forall s, t \quad (5)$$

with the total revenue of that strategy through time being:

$$TR_s = \sum_{t=0}^T TR_{s,t}, \forall s \quad (6)$$

and the total revenue to the Clan over time and over both strategies as:

$$TR = TR_s + TR_{-s} \quad (7)$$

Cost

We assume perfectly malleable capital in this model, i.e., the capital investment for the boat is a sunk cost (the fisher has already paid for the vessel, whether he fishes or not), and the same vessel is used for either type of fishing strategy. Fishing effort can therefore be easily allocated to either strategy on a trip by trip basis. Therefore, only variable costs are considered in this model. The total cost, TC , of fishing is the product of the effort, E , and the unit variable cost of effort, co , and is modeled as an "almost" linear function (Sumaila 1995). The unit cost of effort is assumed constant through time. Let the single period cost of a given catch strategy be:

$$TC_{s,t} = \frac{co_{s,t} E_{s,t}^{1+b}}{1+b}, \forall s, t \quad (8)$$

here, as b approaches 0, the cost function is almost linear. This introduces concavity in the profit function, thus ensuring convergence to a solution (Sumaila 1995).

The total cost of fishing using a given strategy over time is:

$$TC_s = \sum_{t=0}^T TC_{s,t}, \forall s \quad (9)$$

and the total cost of fishing to the Clan over time and over both strategies is computed as:

$$TC = TC_s + TC_{-s} \quad (10)$$

One more cost must be factored in, namely, the potential cost when caught engaging in illegal fishing. This cost is assumed to be a function of the monitoring and enforcement plan put in place by the regency government:

$$Pen_t = \rho Fee E_{-s,t} \quad (11)$$

In effect, it is the product of the probability of being apprehended, ρ , the penalty imposed when apprehended, Fee , and the amount of illegal effort. Therefore, the single period cost of fishing illegally is:

$$TC_{-s,t} = \frac{co_{-s,t} E_{-s,t}^{1+b}}{1+b} + \rho Fee E_{-s,t} \quad (12)$$

With the total cost over time as:

$$TC_{-s} = \sum_{t=0}^T TC_{-s,t} \quad (13)$$

Net benefit

The single period net benefit to the clan, π_t , is therefore the sum of the difference between the total revenue and the total cost of each fishing strategy in a given period:

$$\pi_t = (TR_{s,t} - TC_{s,t}) + (TR_{-s,t} - TC_{-s,t}) \quad (14)$$

with the discounted total net benefit over time calculated as:

$$\pi = \sum_{t=0}^T \delta^t (TR_{s,t} - TC_{s,t}) + \sum_{t=0}^T \delta^t (TR_{-s,t} - TC_{-s,t}) \quad (15)$$

where δ is the discount factor, and is equal to $1/(1+r)$, where r is the discount rate of the village clans (in this model we have assumed a discount rate of 7%; see the section on discounting for a discussion on how changes in this assumption can change the model results).

OPTIMIZATION

The objective of the village clans is to decide on a sequence of effort through time, using legal and/or illegal methods, to maximize their net benefit, π , or discounted economic rent, through time, subject to the obvious constraints. This model represents a 2-step principal-agent situation. In step 1, the regency government (principal) sets its monitoring and enforcement program, which produces some probability of detecting illegal fishing, and the penalty that will be applied to apprehended illegal fishers. In the second step, the clan (agent) decides, given the probability of apprehension and the expected penalty, how to allocate effort between legal and illegal fishing for the entire simulation time (50 years). As such, the optimization is treated like a cooperative solution, in that the overall objective is to maximize the combined discounted net benefits of both fishing strategies.

The simulation is run over 4000 iterations, and for a 50 year time period. An artifact of models driven by profitability is that the players see the model's end (year 50 in this model) as the end of the world, and as such, will tend to catch as much as they can in the final years of the simulation. In the results section below, simulation outputs are thus discussed up to year 45, with the final 5 years of the simulations disregarded.

Lagrangian function

A Lagrangian function is used in this model to solve for the maximization problem facing the clan, subject to the constraints of the model. The natural biological constraint, $B_t \geq 0$, must be met, and thus the model applies a penalty (y_t) when $B_t < 0$.

$$L_t(B_t, E_{s,t}, y_t) = \delta' \pi_t + y_t \phi^-(B_t, E_{s,t}), \forall s \quad (16)$$

where the term ϕ represents the constraint function for which the modified Lagrange multiplier, y_t , is applied only in the case when $\phi < 0$. That is, ϕ is given by $\min(0; \phi)$ (Flam 1993). The profit and constraint functions are expanded in the following equation to give the entire Lagrangian:

$$\begin{aligned} L(B_t, E_{s,t}, E_{-s,t}, y_t) = & \delta' \sum_{t=0}^T \left(q_s E_{s,t} B_t P_t - \frac{c o_s E_{s,t}^{1+b}}{1+b} \right) + \delta' \sum_{t=0}^T \left(q_{-s} E_{-s,t} B_t P_{-s} - \frac{c o_{-s} E_{-s,t}^{1+b}}{1+b} - \rho F e e E_{-s,t} \right) \\ & + y_t \left[r B_t \left(1 - \frac{B_t}{K} \right) - q_s E_{s,t} B_t - q_{-s} E_{-s,t} B_t \right] \end{aligned} \quad (17)$$

The model developed for this analysis was originally constructed assuming an equal biological impact from both legal and illegal fishing. The reason that blast and cyanide fishing are illegal, however, is because they are detrimental to fish habitat, and therefore unsustainable. As such, the model was modified to incorporate this disproportionate impact on the reef. In the constraint equation ϕ , a new term, a , is added⁴⁹:

$$\begin{aligned} L(B_t, E_{s,t}, E_{-s,t}, y_t) = & \delta' \sum_{t=0}^T \left(q_s E_{s,t} B_t P_t - \frac{c o_s E_{s,t}^{1+b}}{1+b} \right) + \delta' \sum_{t=0}^T \left(q_{-s} E_{-s,t} B_t P_{-s} - \frac{c o_{-s} E_{-s,t}^{1+b}}{1+b} - \rho F e e E_{-s,t} \right) \\ & + y_t \left[r B_t \left(1 - \frac{B_t}{K} \right) - q_s E_{s,t} B_t - \alpha (q_{-s} E_{-s,t} B_t) \right] \end{aligned} \quad (18)$$

By changing a , we can change the relative impact of illegal fishing. When $a=1$, the impact of legal and illegal fishing is equal. For $a > 1$, the impact of illegal fishing is greater than that of legal fishing. This is more realistic, as blast and cyanide fishing decrease productivity of the reef habitat (Saila et al. 1993). In the analysis we varied the a term from 1 to 2.5.

Solution algorithm

The solution algorithm used in this analysis is modeled after Flam (1993), and Sumaila (1995), assuming a cooperative outcome. The partial differentials for the effort, biomass and multiplier adjustments are derived in this section in order to identify the rates of change of effort, biomass and the multiplier. For these equations, a switch function is used, and denoted $H(r)$. Let $H(r) = 1$ when $r < 0$, and $H(r) = 0$ otherwise. Thus $H(r)$ attains a value of one when a constraint is violated.

⁴⁹ The version of this chapter to be submitted to a journal will further address the issue of a . The baseline simulations will be run with $a = 1$, while the optimal simulations will be run with $a > 1$. This will allow us to use the impacts of destructive fishing as an externality that the Clans do not incorporate in their fishing decisions, but that society as a whole considers.

Effort adjustment:

How does the Lagrange function change with respect to a change in effort? This is in fact the agent's decision variable of the model. If the marginal profit of type s effort is greater than the marginal profit of type $-s$ effort, then effort will be reallocated from $-s$ effort to s effort.

First, we consider the adjustment of legal effort, s :

$$\frac{\partial L_t}{\partial E_{s,t}} = \delta' (q_s B_t P_s - c o_s E_{s,t}^b) + y_t H \left[r B_t \left(1 - \frac{B_t}{K} \right) - q_s E_{s,t} B_t - \alpha (q_{-s} E_{-s,t} B_t) (-q_s B_t) \right] \quad (19)$$

Now the adjustment of illegal effort, $-s$:

$$\frac{\partial L_t}{\partial E_{-s,t}} = \delta' (q_{-s} B_t P_{-s} - c o_{-s} E_{-s,t}^b) + y_t H \left[r B_t \left(1 - \frac{B_t}{K} \right) - q_s E_{s,t} B_t - \alpha (q_{-s} E_{-s,t} B_t) (-\alpha q_{-s} B_t) \right] \quad (20)$$

Biomass adjustment:

How does the Lagrange function change with respect to a change in the biomass? Here we consider the first order partial differential with respect to biomass:

$$\frac{\partial L_t}{\partial B_t} = \delta' (q_s E_{s,t} P_s + q_{-s} E_{-s,t} P_{-s}) + y_t H \left[r B_t \left(1 - \frac{B_t}{K} \right) - q_s E_{s,t} B_t - \alpha (q_{-s} E_{-s,t} B_t) \left(-1 + r - \frac{2r B_t}{K} - q_s E_{s,t} - \alpha q_{-s} E_{-s,t} \right) \right] \quad (21)$$

Multiplier adjustment:

How does the Lagrange function change with respect to a change in the multiplier? When the multiplier is higher, then essentially a higher punishment is applied within the Lagrangian function, forcing the system to obey the constraints.

$$\frac{\partial L_t}{\partial y_t} = -H \left[r B_t \left(1 - \frac{B_t}{K} \right) - q_s E_{s,t} B_t - \alpha (q_{-s} E_{-s,t} B_t) \left(r B_t \left(1 - \frac{B_t}{K} \right) - q_s E_{s,t} B_t - \alpha q_{-s} E_{-s,t} B_t \right) \right] \quad (22)$$

DATA

The following section outlines the data and assumptions used in the model. A subsection of the results presents a sensitivity analysis exploring how changes in some of the assumptions used affect the results of the model.

Snapper fishery biological data

The initial biomass (at $t=1$) and carrying capacity (K) for the model were taken from the Raja Ampat Ecopath with Ecosim model (EwE) developed by Ainsworth et al. (2007). This model presented biomass estimates for three age classes of snapper, aggregated across 26 species: adult, sub-adult, and juvenile (see Ainsworth et al. 2007, for an explanation of species used in the EwE model). These estimates were added together to produce a 2006 biomass of $0.153 \text{ t}\cdot\text{km}^{-2}$ (Ainsworth et al. 2007). The carrying capacity was estimated from the 1990 biomass estimates in the EwE report (Ainsworth et al. 2007). Although EwE has the ability to estimate an unfished population's biomass, the 1990 estimates are more reliable at this stage in the EwE model⁵⁰. We assumed that the 1990 biomass was about 20% lower than an unfished state, and multiplied the 1990 biomass estimates by 1.2 to estimate the carrying capacity resulting in $K=16,416$ tonnes. The estimated initial biomass and unfished biomass were then multiplied by the study area, $45,000 \text{ km}^2$, to give biomass estimates for all of Raja Ampat (Table 1).

The intrinsic rate of growth, r , was calculated using the equation

$$r = \frac{4MSY}{K} \quad (23)$$

where MSY is the maximum sustainable yield (maximum catch) and K is the carrying capacity, as described above (Cadima 2003). The MSY was taken from the Raja Ampat EwE model (Ainsworth et al. 2007).

Catchability for snapper was calculated by dividing the average biomass of fish caught per trip by the total estimated biomass in the system. According to Dohar and Anggraeni (2007), the average artisanal fisher catches 5 kg of mixed snapper species per trip. This value was used in the model. Pet-Soede et al. (1999), reported that small-scale blast fishers catch about 8 kg of fish per trip. Our model assumes that fishers are only targeting snapper, and thus uses this value. These catch estimates and the derived catchability coefficients are listed in Table 1.

Table 1. Snapper model biological and fishing parameters and sources.

Variable (units)	Symbol	Estimate	Source
Initial biomass (t)	B_0	6,885	Ainsworth et al. (2007)
Carrying capacity (t)	K	16,416	Estimated from Ainsworth et al. (2007)
Maximum sustainable yield (t)	MSY	369	Ainsworth et al. (2007)
Intrinsic rate of growth (year ⁻¹)	r	0.09	Derived from Ainsworth et al. (2007)
Catch per trip (kg)	-	$s=5, -s=8$	Dohar and Anggraeni (2007) and Pet-Soede et al. (1999)
Catchability (-)	q	$s=7.26\cdot 10^{-7}, -s=1.16\cdot 10^{-6}$	Derived from Dohar and Anggraeni (2007) and Pet-Soede et al. (1999)

⁵⁰ C. Ainsworth, UBC, personal communication.

Snapper fishery economic data

Price data used in the snapper model were taken from Dohar and Anggraeni (2007) and Pet-Soede et al. (1999). The average price of legal-caught adult snapper is about US \$1.26/kg (averaged over all legal gears) (Dohar and Anggraeni 2007). Pet-Soede et al. (1999) estimated that for small-scale blast fishing, fishers received on average US \$1/kg. We have assumed that blast fishing requires less time to fish and thus requires less fuel than trips using legal gear. As such, we have added one extra liter of diesel fuel to the legal cost of fishing (valued at \$0.25/L (Pet-Soede and Erdmann 1998)), resulting in a cost per trip of US \$3.25 for legal gears. Although the price of fuel has increased in Indonesia due to the reduction of fuel subsidies, such an increase would affect both legal and illegal fishing, and as such, is ignored in this model.

Table 2. Snapper model economic parameters and sources.

Variable (units)	Symbol	Estimate	Source
Unit price of fish (\$/t)	P	s=1,260, -s=1,000	Dohar and Anggraeni (2007) and Pet-Soede and Erdmann (1998)
Unit cost of effort (\$/trip)	co	s=3.25, -s=3.00	Pet-Soede and Erdmann (1998) and Pet and Pet-Soede (1999)

Grouper fishery biological data

A total of 46 grouper species (family Serranidae) were aggregated in the Raja Ampat EwE model (see Ainsworth et al. 2007, for a description of species). The same method described in the snapper section was used to estimate initial biomass ($t = 1$) and carrying capacity K . The Ainsworth et al. (2007) model reported an estimated 2006 grouper biomass, aggregated across the three age groups, of $0.257 \text{ t} \cdot \text{km}^{-2}$. The grouper carrying capacity was estimated by multiplying the 1990 EwE biomass estimate of $0.513 \text{ t} \cdot \text{km}^{-2}$ by 1.2, assuming that the unfished state is about 20% more than the 1990 biomass. The initial and unfished biomass estimates were then multiplied by the total marine area of Raja Ampat, $45,000 \text{ km}^2$, to determine initial biomass and carrying capacity (Table 3).

Again, the intrinsic rate of growth, r , is calculated using equation 23. The MSY parameter was taken from the Raja Ampat EwE model (Ainsworth et al. 2007). The catchability coefficients used in the grouper model were calculated in the same manner as for snapper. Dohar and Anggraeni (2007) reported that the average artisanal fisher catches about 11 kg of mixed grouper per trip. Pet and Pet-Soede (1999), reported that small-scale cyanide operations catch 1 kg of fish per trip with medium-scale operations catching up to 20kg. The average weight of one individual grouper varies, but a report conducted for the Madang region in Papua New Guinea found that the average weight of 'grouper' caught in that area was about 5 kg, although no gear types are mentioned (Kinch 2004). Based on this information, we assume in this model that the average catch per trip for small-scale cyanide fishers is equal to 5 kg, which could mean one large individual grouper, or 2-3 smaller fish. These two production values, 11 kg and 5 kg, are divided by the total grouper biomass to give the catchability coefficients used in the model (Table 3).

Table 3. Grouper model biological and fishing parameters and sources.

Variable (units)	Symbol	Estimate	Source
Initial biomass (t)	B_0	11,565	Ainsworth et al. (2007)
Carrying capacity (t)	K	27,702	Estimated from Ainsworth et al. (2007)
Maximum sustainable yield (t)	MSY	1,215	Ainsworth et al. (2007)
Intrinsic rate of growth (year^{-1})	r	0.18	Derived from Ainsworth et al. (2007)
Catch per trip (kg)	-	s=11, -s=5	Dohar and Anggraeni (2007) and Kinch (2004)
Catchability (-)	q	s= $9.51 \cdot 10^{-7}$, -s= $4.32 \cdot 10^{-7}$	Derived from Dohar and Anggraeni (2007) and Pet-Soede et al. (1999)

Grouper fishery economic data

The average price of legal-caught grouper in Raja Ampat was about US \$5.60/kg (averaged over all legal gear types), according to Dohar and Anggraeni (2007). Ainsworth et al. (2007), however, used an average price of US \$2.64, which included adult and sub-adult grouper. For the model, the average of these two estimates is used, \$4.13/kg. A price of US \$7.50/kg was used in the EwE model for the average unit price of cyanide-caught grouper (Ainsworth et al. 2007). However, Pet-Soede and Erdmann (1998) suggest that fishers can receive upwards of US \$18.80/kg for live coral trout (*Plectropomus leopardus*). We have used the average of these two estimates, US \$12.80/kg, in the model (Table 4).

The unit cost of US \$3.25 per trip for legal fishing estimated in the case of snapper is also used in the grouper model, as the same (legal) gear is used to target both types of fish. Pet and Pet-Soede (1999), report that cyanide is quite cheap, with a small-scale cyanide operation using about 1L of cyanide per trip, at a cost of \$1.11. We have therefore taken the Pet-Soede and Erdmann (1998) cost estimate for blast fishing, subtracted the cost of the locally-made bombs (\$2.50/trip), and added in the cost of cyanide (\$1.11), resulting in a cost estimate of US \$1.61 per trip.

Table 4. Grouper model economic parameters and sources.

Variable	Symbol	Estimate	Source
Unit price of fish (\$/t)	P	s=4,130, -s=12,800	Dohar and Anggraeni (2007) and Pet-Soede and Erdmann (1998)
Unit cost of effort (\$/trip)	co	s=3.25, -s=1.61	Pet-Soede and Erdmann (1998) and Pet and Pet-Soede (1999)

RESULTS

SNAPPER MODEL RESULTS

Exploring the value of the relative impact of illegal fishing

Because we have no information on how illegal fishing may impact the ecosystem, the model was run with four different values for a , the parameter that changes the relative impact of illegal fishing. Figure 1 shows these four scenarios. Figures 1A and 1B illustrate that there is less effort, both legal and illegal, with higher values for a . Consequently, there is also less catch with higher a values (Figure 1C and 1D). The biomass estimates over the 45 year period remain fairly similar regardless of the value a takes (Figure 1E). Due to smaller catches with a higher a , the net benefits from fishing also decrease (Figure 1F). Destructive fishing practices, such as cyanide and blast fishing, alter the marine habitat and are therefore unsustainable (Pauly 1989). The effects of destructive fishing could impact reefs at such a state that recovery from cyanide and explosives does not occur for over 2 decades (Saila et al. 1993; Fox and Caldwell 2006). The simulations run for this model suggest that lower catches occur with higher values of a . The impact of explosives and cyanide in Raja Ampat has led to a decrease in the catches of target and non target species.⁵¹ For this reason, as well as in keeping with ecosystem-based management principles, we took the precautionary approach and assumed that the impact of blast fishing (and cyanide fishing) on the biology of the system is about twice that of legal fishing (i.e. $a=2$). This value for a is used in running all subsequent snapper and grouper simulations.

⁵¹ Mark Erdmann, Conservation International, personal communication.

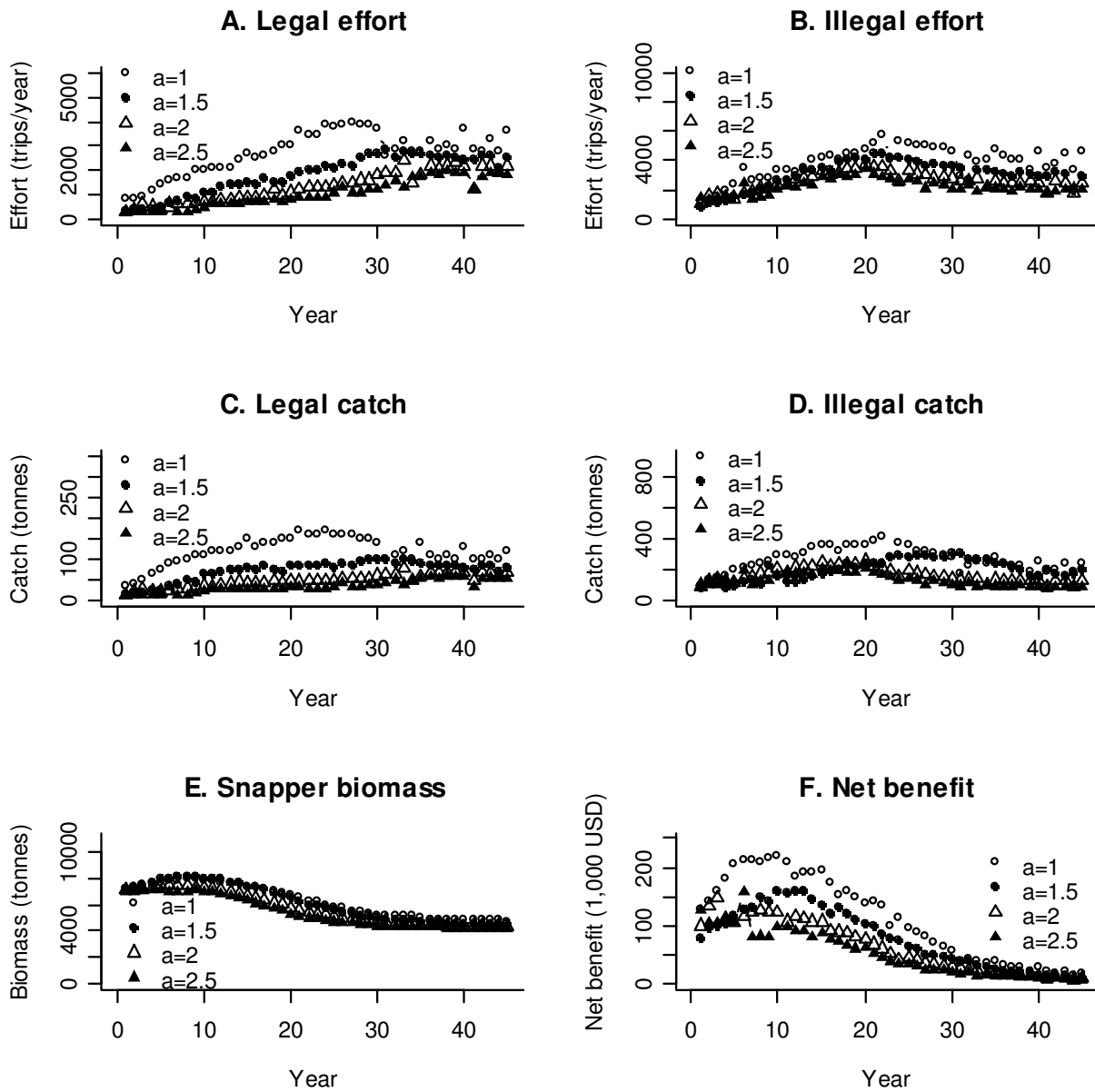


Figure 1. Snapper simulations run for varying α .

Baseline solution

There is currently no formal monitoring and enforcement program in Raja Ampat to detect and punish fishers using destructive gears⁵². The first model simulation is thus run with this in mind, such that there are no extra costs associated with illegal fishing. This is the baseline, or present-day, scenario, against which the potential monitoring and enforcement program is compared.

With no monitoring and enforcement, the total discounted net present value (discounted net benefits summed over time), or NPV, from legal fishing is US \$0.61 million. The NPV from blast fishing is almost four times this, at US \$2.24 million. The total NPV from both types of fishing is the summation of these two, and is equal to US \$2.85 million (Table 5). It is currently more profitable to fish snapper using bombs than with legal methods, as indicated by the effort trends (Figure 2A). For the most part, over all time periods more effort is allocated to blast fishing than to legal fishing. The higher effort level, along with the assumed higher catchability of blast fishing, leads to a greater catch by blast fishing at all time periods, shown in Figure 2B. Although catch initially increases through time (due to increased effort and an initial biomass increase), the future decrease in biomass leads to declining catches near the end of the model. Over the 45 year period, a total of 9,798 tonnes of snapper are caught, with an annual average catch of 218 tonnes. Figure 2C shows a decrease in snapper stock biomass over time. The net benefits from blast fishing are greater than those for legal-caught methods for all time periods (Figure 2D).

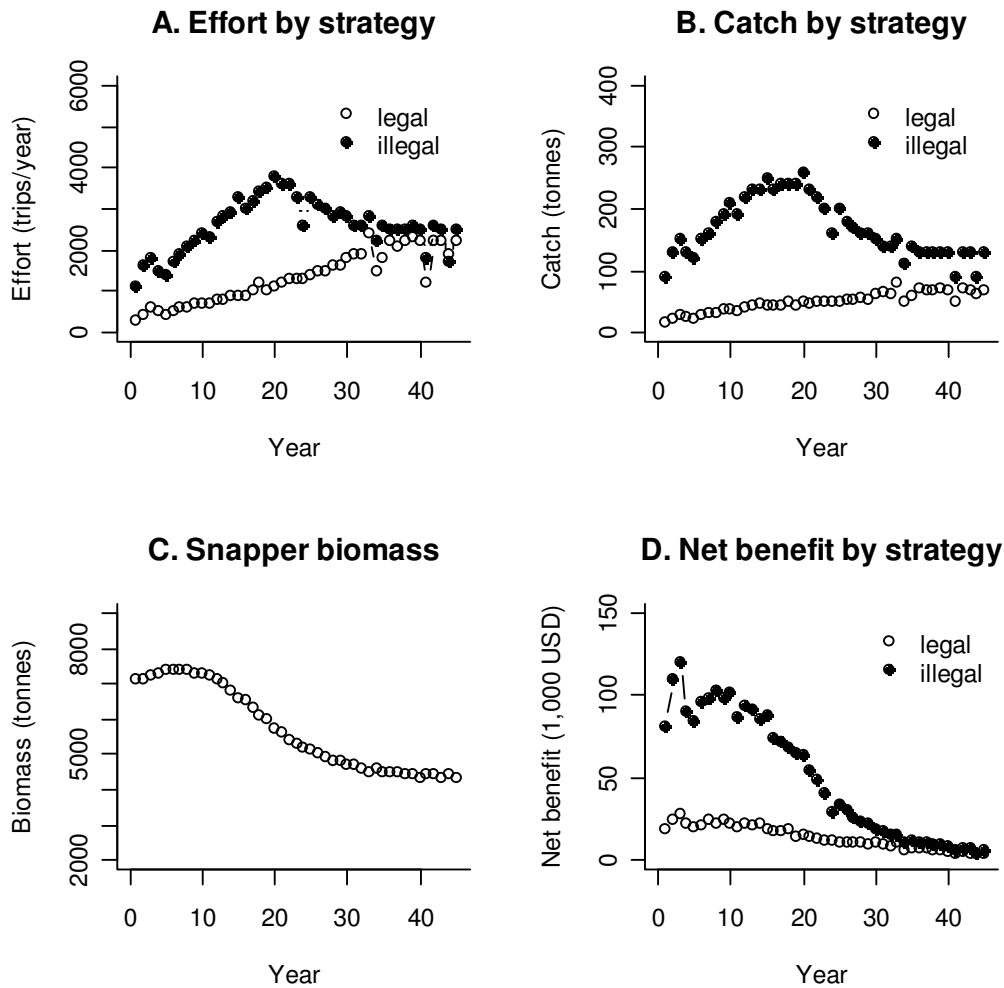


Figure 2. Snapper baseline simulations, no monitoring and enforcement.

⁵² Mark Erdmann, Conservation International, personal communication.

Optimal solution

Assuming that the objective of the government is to totally eliminate blast fishing, the simulations were rerun at increasing probabilities of detection, ρ , and penalty fees, Fee .

It is important to note that each of these regency decision variables needs to take on values that are both positive and realistic. Mathematically, they are multiplied with effort in the cost function, so if either value is zero then the fisher faces no extra cost from illegal fishing. This makes intuitive sense, as it does not matter how high the fines of illegal fishing are if the probability of detecting illegal fishing is zero. Similarly, there is no point in putting money into a detection program and then not imposing a penalty once an illegal fisher is apprehended. In terms of realism, with the Papuan per capita Gross Domestic Regional Product (GDRP) at less than US \$1000 (Bappeda, 2004 in Dohar and Anggraeni, 2007), one can imagine that fining fishers an exorbitant amount and expecting payment would be unrealistic.

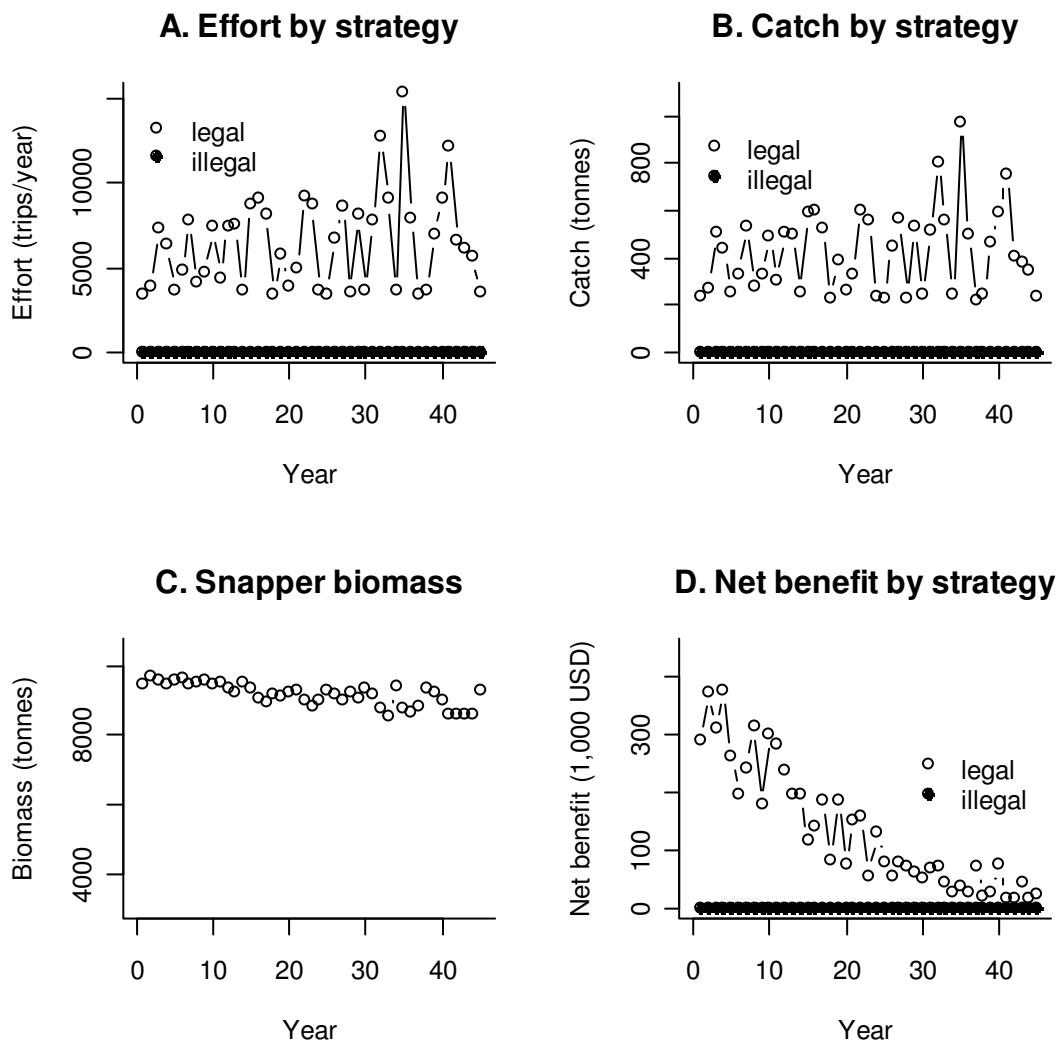


Figure 3. Snapper optimal simulations.

Table 5. Snapper baseline and optimal simulation net present value (NPV) in million USD.

Simulation	Legal NPV	Illegal NPV	Total NPV
Baseline	0.61	2.24	2.85
Optimal	6.53	0	6.53
Difference	5.92	-2.24	3.68

by, legal fishing. Over the 45 year period, a total of 19,090 tonnes of snapper are caught, averaging 424 tonnes/year. Figure 3C shows the biomass trajectory through time.

Several combinations of detection probabilities and fines are possible to reach the desirable solution of no blast fishing. Table 6 shows some of these combinations. The Raja Ampat government would have to evaluate the possible combinations to determine which meet their budget and fisheries management plans. As can be obviously noted in Table 6, there is a direct tradeoff between investing a lot in detecting power (monitoring)⁵³, versus investing little but fining apprehended fishers a high, and possibly unrealistic, amount (enforcement).

Table 6. Snapper optimal detection probability (ρ) and fine (*Fee*) combinations.

ρ (%)	Fee (USD)
10	2020
15	1350
20	1010
25	810
30	680

Figure 4 graphically compares the effort, catch, biomass and NPV results of the baseline and the optimal simulations. Catches are higher in the optimal solution. Also of obvious importance is the higher biomass through time associated with the optimal solution. Furthermore, the net benefits are higher with the elimination of blast fishing. We can measure the incentive gap in the principal-agent framework by comparing the first and second best solutions. Table 5 shows the difference between the baseline simulation (second best solution) and the optimal simulation (first best solution). The incentive gap is thus US \$3.68 million. This implies that the Raja Ampat regency is losing an estimated US \$82,000 per year in potential fisheries revenue by not eliminating blast fishing.

When blast fishing is completely eliminated, the net present value (NPV) of the artisanal snapper fishery increases from US \$2.85 million to US \$6.53 million over the 45 year period (Table 5, Figure 3D). Figures 3A and 3B show that all effort is allocated to, and thus all catch is taken

⁵³ This statement assumes that it would cost the regency government more to increase their probability of detection from 10 % to 15%, to 20%, etc.

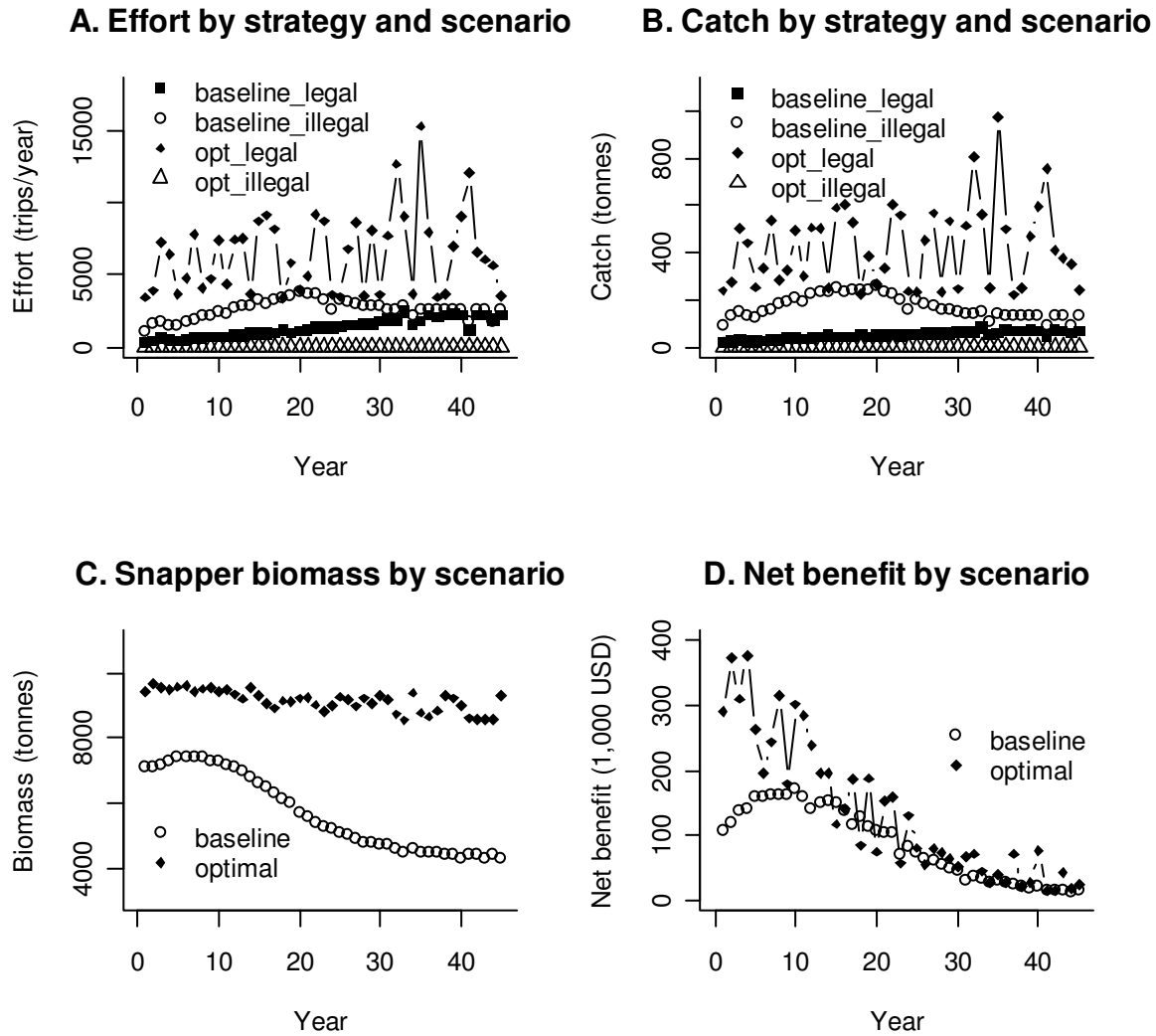


Figure 4. Snapper baseline and optimal simulations.

Discounting

Sustainability implies that the present generation's use of a resource does not prevent future generations from enjoying the same resource. It is known that high rates of discount tend to result in societies overexploiting their resources today (Clark 1990). The simulation results presented for the snapper model above were created by assuming a 7% discount rate (a discount factor of 0.935). To examine the effect of the discount rate on baseline catch, biomass and economic value of the fishery, the snapper simulations were re-run with varying discount rates. The catches and NPV, as well as the biomass in year 45, are shown for different discount rates in Table 7. In this model, as supported by the literature (Clark 1973; 1990; Sumaila 2004; Berman and Sumaila 2006), higher rates of discount generally lead to a lower stock size in the future, as well as a lower (NPV) of the fishery (Table 7). As the discount rate increases, the proportion of illegally caught fish decreases, most likely because legally caught fish actually command a higher price.

Table 7. Snapper baseline simulations run with increasing discount rates.

Benefit type	Discount rate			
	0*	4	7	10
Legal catch (t)	1246	1479	2228	2716
Illegal catch (t)	7148	7920	7570	6882
Total catch (t)	8394	9399	9798	9598
Illegal catch (%)	85	85	77	72
Legal NPV (\$•10 ⁶)	1.49	0.73	0.61	0.56
Illegal NPV (\$•10 ⁶)	6.88	3.2	2.24	1.74
Total NPV (\$•10 ⁶)	8.37	3.93	2.85	2.30
Biomass (t), year 45	8300	6100	4300	3600

* This is actually the limit as δ goes to 0, to allow convergence (Clark 2006).

It is particularly interesting to examine how the optimal *Fee* varies with the discount rate. Table 8 compares the optimal simulations run with a higher discount rate ($\delta=10\%$), to the original simulations run with $\delta=7\%$. If we keep the detection probability the same, a higher *Fee* is required in each case, given the higher discount rate. This is an important issue for the regency government to consider when instituting an incentive scheme.

Table 8. Snapper optimal combinations with different detection probabilities and discount rates (δ).

ρ (%)	<i>Fee</i> (USD)	
	$\delta=7\%$	$\delta=10\%$
10	2020	3370
15	1350	2230
20	1010	1680
25	810	1350
30	680	1150

Sensitivity analysis

Models are, by definition, simplifications of reality. Many data assumptions had to be made to apply the model. These assumptions are explored by rerunning the model while changing one variable at a time.

Carrying capacity

The carrying capacity (K) used to run the model was calculated by multiplying the 1990 snapper biomass by 1.2. The model was rerun using a lower K estimate, by assuming that the 1990 biomass was the unfished state, and a higher K , assuming that K is actually 1.5 times the 1990 biomass. As would be expected, a larger snapper carrying capacity leads to a greater catch and a higher NPV over time. Obviously, if the model simulations were being used to recommend allowable catches, it would be important to understand and quantify the uncertainty around this parameter, and thus the uncertainty inherent in the catch estimates. The sensitivity of the model to changes in the intrinsic rate of growth (r) is explored in the grouper section. Table 9 presents the biomass in year 45, total catches and NPV over the 45 year period at varying K values. The low and high values used in the sensitivity analysis simulation are given on either side of the main value used in the model. The relative profitability of the optimal solution (versus the baseline) ranges from about 2 to 2.7.

Table 9. Sensitivity analysis for snapper model: Carrying capacity.

Result	Simulation	Carrying capacity (t)		
		Low (13,680)	Model (16,416)	High (20,520)
Biomass (t), year 45	Baseline	4,320	4,300	4,326
	Optimal	7,298	9,300	10,352
Total catch (t)	Baseline	8,822	9,798	10,934
	Optimal	15,067	19,089	26,167
NPV (\$•10 ⁶)	Baseline	2.51	2.85	3.10
	Optimal	5.06	6.53	8.42
Difference in NPV (\$•10 ⁶)	-	2.55	3.68	5.32
Relative profitability	-	2.02	2.29	2.72

Price

The price of legally caught snapper used in this model is US \$1,260/tonne. The bounds for the sensitivity analysis were calculated by multiplying this price by 0.75 to get the low price bound and 1.25 to get a high price bound. The model was then rerun with these bounds (Table 10). A similar method was used to calculate the low and high bounds for illegally caught snapper: the base price of US \$1,000/tonne was multiplied by 0.75 and 1.25. Changes in price do not tend to change the biomass at the end of the simulation time, nor the total amount of catch over the 45 years, but they do obviously change the value of the catch. As would be expected, the relative profitability of eliminating illegal fishing increases with higher prices for legally-caught fish (Table 10). Conversely, when illegally-caught snapper fetches a higher price, the relative profitability of eliminating that fishing strategy decreases. The low and high values used in the sensitivity analysis simulation are given on either side of the main value used in the model.

Table 10. Sensitivity analysis for snapper model: Price.

Result	Simulation	Legal price (USD/t)		
		Low (945)	Model (1,260)	High (1,575)
Biomass (t), year 45	Baseline	4,297	4,300	4,440
	Optimal	8,954	9,300	8,948
Total catch (t)	Baseline	9,594	9,798	9,927
	Optimal	18,820	19,089	18,127
NPV (\$•10 ⁶)	Baseline	2.69	2.85	2.97
	Optimal	4.71	6.53	8.03
Difference in NPV (\$•10 ⁶)	-	2.02	3.68	5.40
Relative profitability	-	1.75	2.29	2.86
		Illegal price (USD/t)		
		Low (750)	Model (1,000)	High (1,250)
Biomass (t), year 45	Baseline	4,400	4,300	4,268
	Optimal	9,300	9,300	9,300
Total catch (t)	Baseline	10,080	9,798	9,775
	Optimal	19,087	19,089	19,087
NPV (\$•10 ⁶)	Baseline	2.33	2.85	3.34
	Optimal	6.53	6.53	6.53
Difference in NPV (\$•10 ⁶)	-	4.20	3.68	3.19
Relative profitability	-	2.80	2.29	1.96

GROUPER MODEL RESULTS

Exploring the value of the relative impact of illegal fishing

In order to model the negative ecological impact destructive fishing has on reef systems, a variable called a was introduced in equation 19. As explained above, the simulations were run several times while varying the value of a , essentially the relative ecosystem impact that destructive fishing has compared to non-destructive methods. Figure 5 shows the results of these simulations.

In keeping with the precautionary approach to management, a value of 2 was used for a in all subsequent grouper simulations.

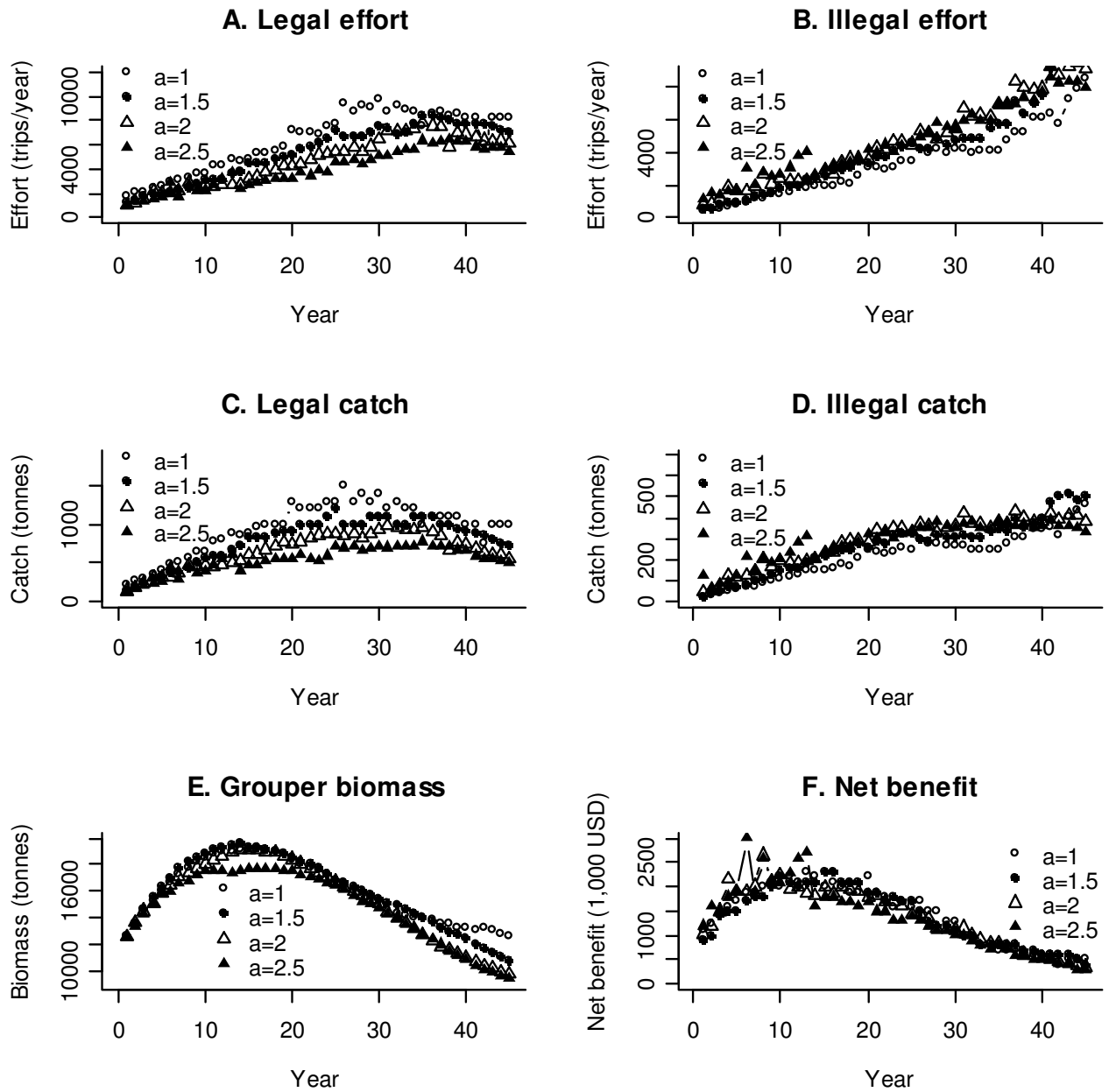


Figure 5. Grouper simulations run for varying α .

Baseline simulation

The baseline scenario is one which assumes the status quo of zero monitoring and enforcement continues in Raja Ampat for the next 45 years. Under this scenario, the fishery yields US \$62.45 million in total net present value (NPV) over the 45 years (Table 11). Figures 6A and 6B show the effort and catch profiles for the baseline solution. Over 45 years a total of 42,380 tonnes of grouper are caught, averaging 941 tonnes annually. More effort is allocated to, and more catch is taken by, legal methods in all years, although effort converges near year 45. The price of illegally-caught grouper is higher, and the cost lower, and yet fishers are spending more effort fishing with legal gears. The higher catchability of legal methods assumed in this model is what most likely drives the large amount of legal effort. The decrease in legal effort, and increase in illegal effort, at the end of the simulation, is probably driven by the ‘end of the world’ scenario, as described earlier. Grouper biomass increases at the start of the simulation, but after reaching its maximum

at about year 20, the biomass starts to decrease for the remaining time steps (Figure 6C). Figure 3.6D shows the net benefits attained from grouper fishing over 45 years.

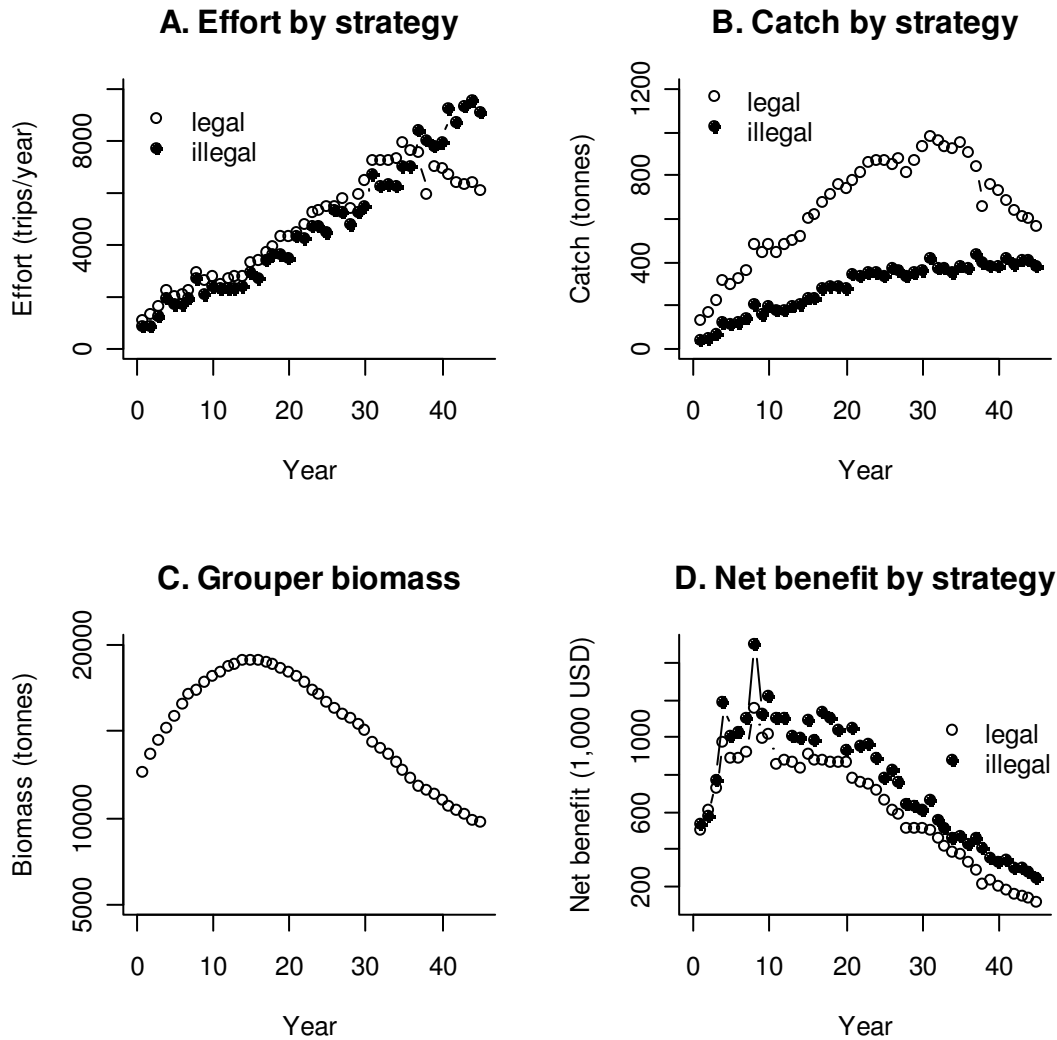


Figure 6. Grouper baseline simulations, no monitoring and enforcement.

Optimal solution

The optimal solution assumes that the government is trying to completely eliminate cyanide fishing. With the elimination of the cyanide fishery for grouper, the total NPV over the 45 years is US \$52.87 million (Table 11). With the total elimination of the illegal fishery, the value of the grouper fishery is worth almost US \$10 million less over the 45 years.

The optimal solution assumes that the price of legal caught fish does not change with the elimination of the illegal fishery. If we assume that in the optimal scenario fishers receive 50% more for their catch, resulting in a price of US \$6195/tonne, then the total NPV of a totally legal fishery would be US \$65.38 million. This is only marginally higher than the baseline scenario. This increase of US \$2.93 million, if averaged over the 45 year period, could mean a difference of an estimated US \$65,000 annually.

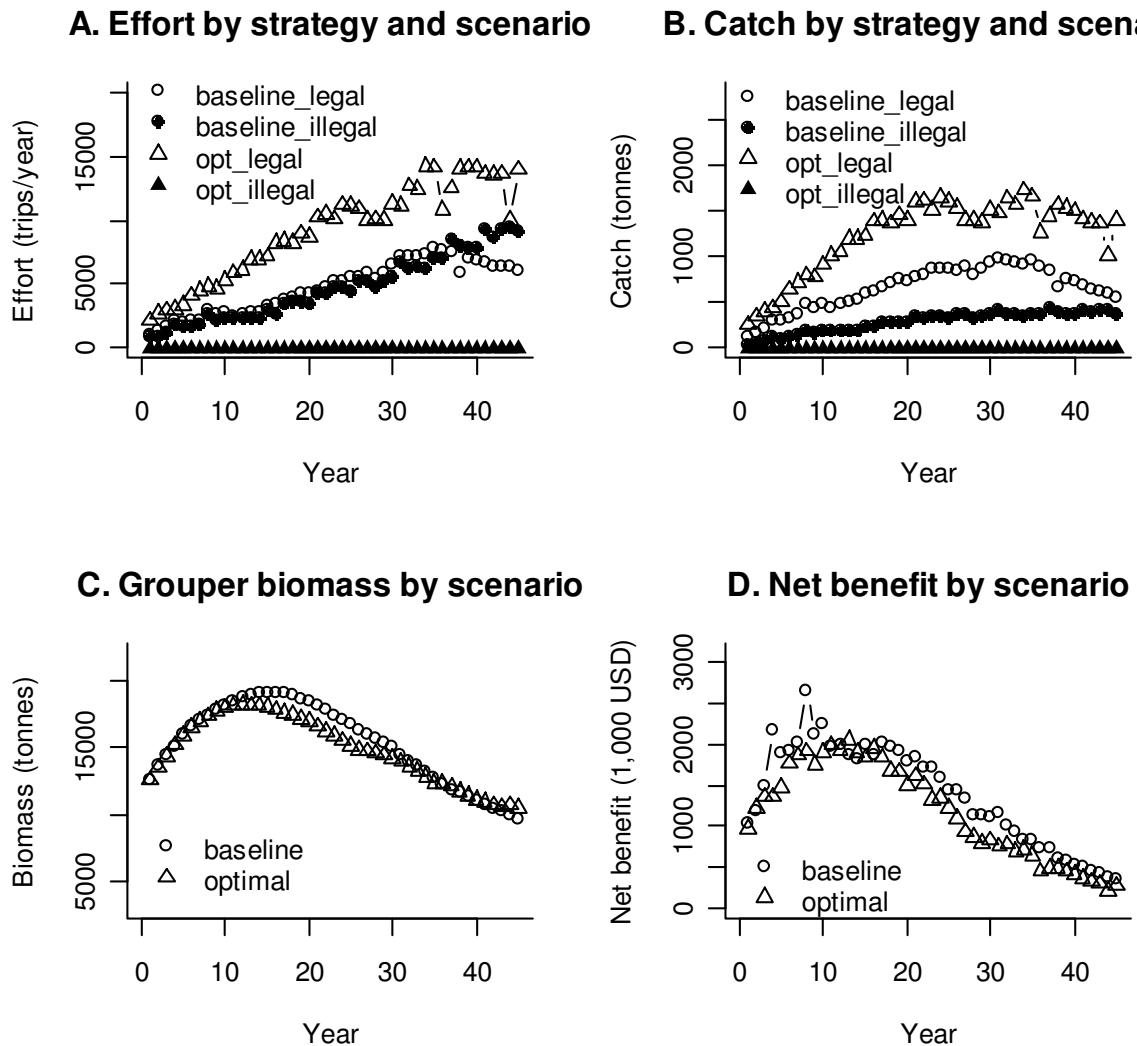


Figure 7. Grouper baseline and optimal simulations.

Table 11. Grouper baseline and optimal simulation net present value (NPV) in million USD.

Simulation	Legal NPV	Illegal NPV	Total NPV
Baseline	27.80	34.65	62.45
Optimal	52.87	0	52.87
Difference	25.07	-34.65	-9.58

marked improvement in grouper biomass in the optimal solution (Figure 7 C).

Figure 7 compares the baseline and optimal solution. Figure 7A and 7B show the optimal effort and catch profiles. Over the 45 years, the total grouper catch is 42,380 tonnes in the baseline scenario and 55,578 tonnes in the optimal solution. There does not appear to be a

To attain the optimal solution, there are several combinations of detection probability (ρ) and fine amount (Fee) the government can offer as incentives. Table 12 presents these possibilities. Essentially, the government can have a high detection probability (by investing in monitoring) but fine fishers a relatively small amount, or they can have a low detection probability but fine apprehended fishers a relatively large amount

Table 12. Grouper optimal detection probability (ρ) and fine (Fee) combinations

ρ (%)	Fee (USD)
10	10,100
15	6,750
20	5,050
25	4,040
30	3,370

Discounting

As explained in the discounting section of the snapper model results, the value of the discount rate (used to express benefits to be received in the future into benefits today) can greatly effect how resources are utilized. Table 13 shows the catch, NPV and biomass in year 45 for increasing discount rates in the baseline scenario. A higher discount rate appears to lead to a lower biomass (Table 13). Generally, a higher discount rate leads to a larger grouper catch, but this is only true up to a discount rate of 7%. It may be that with a higher discount rate, more catch is taken at the beginning of the simulation, leading to a lower biomass and less future catches. As expected, higher discount rates result in lower NPV of the fishery.

Table 13. Grouper baseline simulation run with increasing discount rates.

Benefit type	Discount rate			
	0*	4	7	10
Legal catch (t)	19,493	20,973	29,500	22,785
Illegal catch (t)	9,418	10,612	12,800	13,194
Total catch (t)	28,911	31,545	42,380	35,979
Illegal catch (%)	33	34	30	37
Legal NPV(\$•10 ⁶)	79.92	35.95	27.8	17.87
Illegal NPV (\$•10 ⁶)	120	54.43	34.65	29.36
Total NPV(\$•10 ⁶)	200	89.38	62.45	47.23
Biomass (t), year 45	19,000	17,100	9,700	8,054

* This is actually the limit as δ goes to 0, to allow convergence (Clark 2006).

Sensitivity analysis

Intrinsic rate of growth

The intrinsic rate of growth, r , is a biological parameter quantifying how rapidly a population grows in the absence of limiting factors. Table 14 shows the results of the sensitivity analysis with the low and high values used in the simulation given on either side of the main value used in the model. We expect the influence of changes in r to be similar to what we would find in changes to the value of the carrying capacity, K . A higher r value implies a more productive population, thus providing for larger catches and value through the 45 years (Table 14). It is very interesting to note, however, that a more productive stock appears to result in larger losses in NPV associated with the elimination of cyanide fishing (Table 14).

Table 14. Sensitivity analysis for grouper model: Intrinsic rate of growth.

Result	Simulation	Intrinsic rate of growth		
		Low (0.09)	Model (0.18)	High (0.36)
Biomass (t), year 45	Baseline	10,200	9,700	14,783
	Optimal	8,728	10,500	14,874
Total catch (t)	Baseline	22,860	42,380	78,000
	Optimal	30,265	55,578	94,198
NPV (\$•10 ⁶)	Baseline	32.86	62.45	115.4
	Optimal	24.97	52.87	89.66
Difference in NPV (\$•10 ⁶)	-	-7.89	-9.58	-25.74
Relative profitability	-	0.76	0.85	0.78

DISCUSSION

The perverse incentives to fish using explosives and cyanide are apparent in this analysis. In both scenarios, effort is allocated to these fishing methods due to their apparent profitability, although in the snapper fishery, more effort is allocated to illegal methods, while in the grouper fishery, more effort is allocated to legal gears. Even with changes in parameter values, as explored in the sensitivity analysis, the baseline simulations show why these destructive fishing gears are common in Raja Ampat.

BLAST FISHING FOR SNAPPER

In this analysis, the artisanal snapper fishery is estimated to be worth between US \$2.85 and \$6.53 million over the next 45 years. The elimination of explosives on the reef could result in a higher stock biomass, and fairly consistent catches through time. It appears that the optimal solution is perhaps a desirable one for the regency government. The costs associated with the monitoring and enforcement program are obviously an important consideration for the government. Of course any amounts collected from apprehended fishers could potentially be used to help fund the program.

The recent rise in tourism⁵⁴ and pearl farming⁵⁵ in Raja Ampat has resulted in a perceived decrease in the number of blasts occurring in the area. The presence of dive operations out on the water, as well as armed guards present at the farms, could potentially act as effective enforcers, perhaps decreasing the government's management costs.

Several possible combinations of detection probabilities and fisher fines were presented. Although it is not the authors' intention to suggest which combination is best, it is important to note that the potential for bribes in developing countries is often large (Owino 1999; Thyl De Lopez 2003). As such, it might be in the government's best interest to invest heavily in monitoring. If government staff members are well paid to begin with, then perhaps the incentive for accepting bribes will not threaten the integrity of a management program.

CYANIDE FISHING FOR GROUPER

Grouper populations have decreased throughout Indonesia (Halim 2003). Researchers in Raja Ampat have suggested that the amount of cyanide fishing has also been decreasing in the area⁵⁶. Evidence suggests that the price of live-caught grouper is still high, although less than before the Asian financial crisis of 1997 (McGilvray and Chan 2002), and the costs of cyanide have not increased in the area. Furthermore, the current inability of managers to charge cyanide fishers with a crime would imply that fishers are not fishing less due to the risk of being apprehended or fined. Therefore, less effort using cyanide may be a result of smaller grouper stock sizes resulting in smaller catch per unit effort associated with this gear and target species. Cyanide fishing tends to target grouper spawning aggregation sites (SPAGS), thus possibly leading to recruitment overfishing (Cesar et al. 2000). The Raja Ampat ecosystem-based management (EBM) project has a component study researching grouper SPAGS and preliminary reports suggest that they have been all but eliminated in Raja Ampat⁵⁷.

Elimination of the cyanide fishery in Raja Ampat does not seem to yield significant benefits, either biologically, as grouper biomass still declines through time, or economically, as the NPV is actually lower in the optimal solution. However, if a price function could be added into the model to allow price to change with the elimination of the illegal fishery, then perhaps there may in fact be an economic incentive to eliminate cyanide fishing. This implies that perhaps the high prices given to fishers who can provide live reef fish are an overwhelming incentive. The government may be better off supporting alternative capture methods for the live reef fish trade. For example, grouper mariculture has been shown to be a potentially viable option in Indonesia (Halim 2003). During the first author's field visits to several fishing villages in Raja Ampat, several grouper pens were seen in operation. These pens are used to hold any live fish that are caught with nets or traps until a vendor comes to purchase them from the village.

CONCLUSION

The use of destructive fishing gears threatens fisheries, marine biodiversity and ecosystem services worldwide (Pauly 1989; Pet-Soede and Erdmann 1998; Cesar et al. 2000; Halim and Mous 2006). In Raja Ampat, with artisanal fisheries currently valued at US \$7 million (Dohar and Anggraeni 2007), it seems evident that ensuring sustainable fishery yields through time should be a priority for the government, not to mention conserving ecosystem services through time. And although sustainable fisheries management

⁵⁴ Eddie Frommenwiler, owner and operator of the Pindito liveaboard boat, personal communication.

⁵⁵ Mark Erdmann, Conservation International, personal communication.

⁵⁶ Mark Erdmann, Conservation International, personal communication.

⁵⁷ Christovel Rotinsulu, Conservation International, personal communication.

requires several components, the elimination of illegal fishing is certainly an important one (FAO 2001). The current analysis suggests that if the present-day situation continues, with no monitoring and enforcement by the government, the use of explosives and cyanide in Raja Ampat may lead to a decline in snapper and grouper populations and catches over time.

As the government wishes to use the fisheries sector to increase the standard of living for regency citizens (Wanma 2002), sustainability of the artisanal sector is vital. Munro (1992), explained, in general economic terms, that the present day investment in a stock of capital will benefit a society by increasing the society's productive capacity in the future. By increasing snapper and grouper stocks today, in part by eliminating destructive fishing methods as shown in the snapper analysis, the Raja Ampat regency could be ensuring a flow of benefits to the community through time. Furthermore, other commercially targeted fish, such as trevally and fusiliers, as well as the prized Napoleon wrasse, would most likely benefit from reduced destructive fishing methods.

What is also important to consider, as was highlighted in the section regarding the relative impact of destructive fishing (the value of a), is that destructive fishing not only jeopardizes fish stocks, but the very ecosystems that commercial species depend on (Pauly 1989; Cesar et al. 2000). The fact that economic valuation analyses generally ignore amenity values, such as ecosystem services, can often lead managers to disregard the potential benefits from ecosystem restoration (Berman and Sumaila 2006). If a valuation study could be done to model the potential ecosystem benefits of eliminating cyanide fishing, then that may offer an economic incentive that does not seem apparent in this model, which only examined the change in value of the grouper fishery itself.

Ecosystem-based management (EBM) explicitly recognizes the impacts that fishing has on the ecosystem (Ward et al. 2002). This analysis has attempted to incorporate this component of EBM, by assuming that the impact of destructive fishing is greater than that of legal fishing methods. The traditional village clans in Raja Ampat, which are responsible for marine management (Halim and Mous 2006), need to be included in fisheries sector planning and educated on the destructive nature of, and lost revenue due to, the frequent use of destructive methods. An ecosystem model has been developed for Raja Ampat (Ainsworth et al. 2007). The effort profiles simulated in this analysis can be fed into this model in order to predict what types of ecosystem effects could be expected in Raja Ampat based on the use of destructive gears to catch snapper and grouper. In this way, a single-species model may lead to ecosystem-wide predictions, which would be a great contribution to the field of fisheries economics.

ACKNOWLEDGMENTS

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CHAPTER 4

ECOSYSTEM-BASED MANAGEMENT: THE INFLUENCE OF A PROJECT IN RAJA AMPAT, PAPUA, INDONESIA⁵⁸**Divya Varkey, Tony J. Pitcher and Cameron Ainsworth***Fisheries Ecosystems Restoration Research, Fisheries Centre, University of British Columbia,
2202 Main Mall, Vancouver, BC, Canada, V6T 1Z4***ABSTRACT**

The Bird's Head Seascape Ecosystem-Based Management (BHS EBM) project is a joint Packard-funded initiative between The Nature Conservancy (TNC), Conservation International (CI), World Wildlife Fund (WWF) and the University of British Columbia (UBC). The first two years of the project were based in the Raja Ampat Regency in Papua province, Indonesia, a region of incredible marine biodiversity. The project came into existence with the intentions of the partner NGOs and the Regency government to develop environmentally sound ecosystem-based policies for the management of marine resources. This paper evaluates the expected progress from the successful implementation of the project. The evaluation is based on previously-published criteria in implementing ecosystem-based fishery management (EBFM): overall principles (5 attributes); criteria for success (6 attributes); and implementation steps (12 attributes). The results show that a considerable improvement in management might be expected with the successful implementation of the BHS EBM project.

INTRODUCTION

There is now substantial interest in establishing frameworks for ecosystem-based fisheries management (EBFM); in fact legislative requirements in some countries are beginning to demand the inclusion of principles of ecosystem-based management (EBM) (Hall and Mainprize 2004), while numerous international conventions also require this type of holistic view (Garcia et al. 2003). The interest and faith in management methods rooted in principles of EBFM has led to an increase in the number of projects designed according to principles of EBM. Before embarking on a project, during a mid-term evaluation or after completion of a project, stakeholders, scientists and managers may find it interesting to evaluate the progress towards EBM as a result of the project. This paper evaluates the marine management scenario before and after the implementation of the Bird's Head Seascape Ecosystem-Based Management (BHS EBM) project.

Raja Ampat Regency in Eastern Indonesia's Papua Province is an interesting and appropriate site for a case study for two reasons. The BHS EBM project is highly collaborative: three environmental NGO partners (CI, TNC's Southeast Asia Center for Marine Protected Areas, and WWF-Indonesia) are involved in a science-based initiative in partnership with local stakeholders to explore ecosystem processes that are relevant to management (Conservation International 2005). The second reason is that Indonesia scored lower than a failing grade in all of the three categories of the present analysis. Thus, we assumed that no factors external to the project contributed to the changes observed during the 2 year period of the BHS EBM project. We evaluated the status of EBFM in the area prior to the inception of the project and the status expected after successful implementation against the same three sets of the listed attributes described below.

⁵⁸ Cite as: Varkey, D., Pitcher, T.J., Ainsworth, C. (2008). Ecosystem-Based Management: The Influence of a Project in Raja Ampat, Papua, Indonesia. Pages 171-177 in Bailey, M., Pitcher, T.J. (Eds), Ecological and Economic Analyses of Marine Ecosystems in the Bird's Head Seascape, Papua, Indonesia: II. Fisheries Centre Research Reports 16(1): 186 pp.

METHOD

We have chosen to base our analysis on the Ward et al. (2002) framework which consists of three sets of attributes for ecosystem-based management: overall principles (5 attributes; Table 2, page 19 in Ward et al. 2002); criteria for success (6 attributes; Table 3, pages 19-20 in Ward et al. 2002); and implementation steps (12 attributes; Table 6, pages 50-51 in Ward et al. 2002). Fishery management in Raja Ampat before and after the implementation was scored against the three main sets of the listed attributes.

RESULTS AND DISCUSSION

Scores, including the lower and upper bounds allocated to each attribute are shown in Appendix Table 1. The scores for Indonesia were obtained from extensive material documenting Indonesia's compliance with the FAO (UN) Code of Conduct for Responsible fisheries (Pitcher et al. 2006)⁵⁹. Following the method outlined above, final ordination results are shown in Figures 1, 2 and 3.

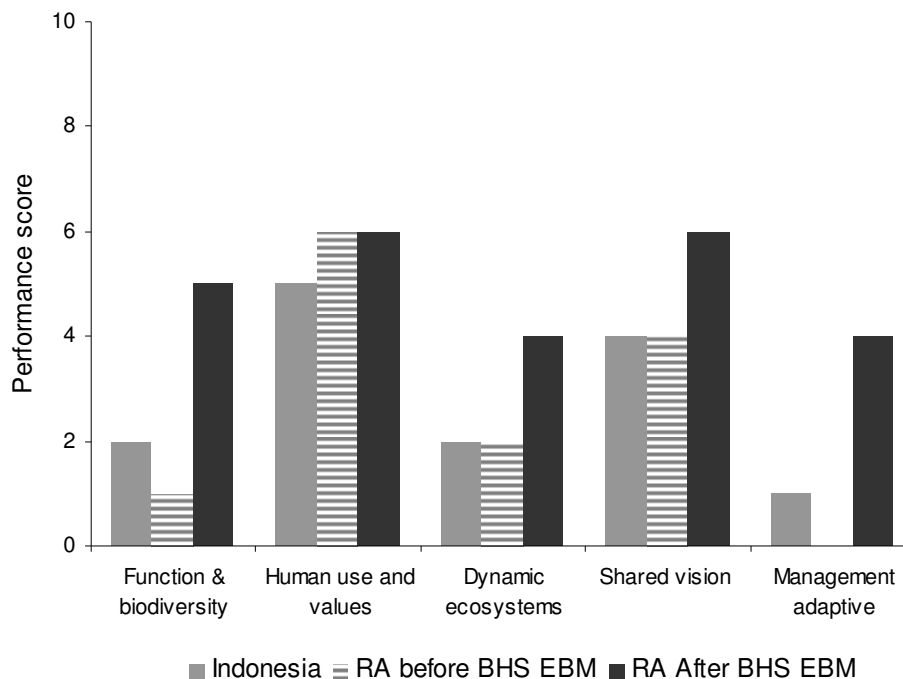


Figure 1. Scores for the five principles of EBM for Indonesia and Raja Ampat before and after the project implementation

⁵⁹ A more recent version of this is in preparation: Pitcher, T.J., Kalikoski, D., Short, K., Varkey, D., Pramod, G.. An evaluation of progress in implementing ecosystem-based fishery management for 33 countries.

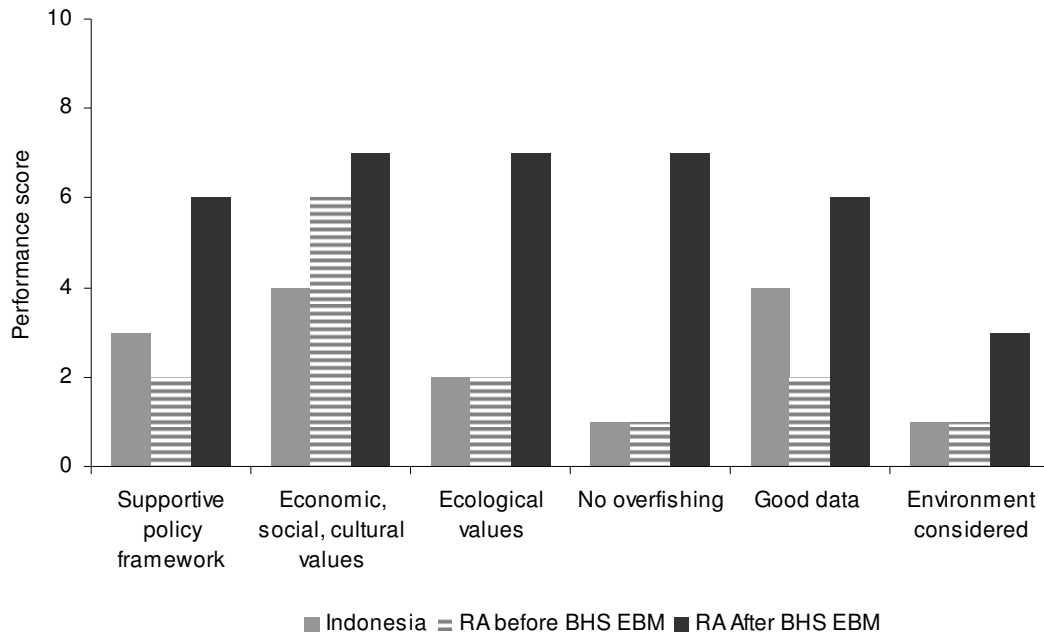


Figure 2. Scores for the six indicators of EBM for Indonesia and Raja Ampat before and after the project implementation

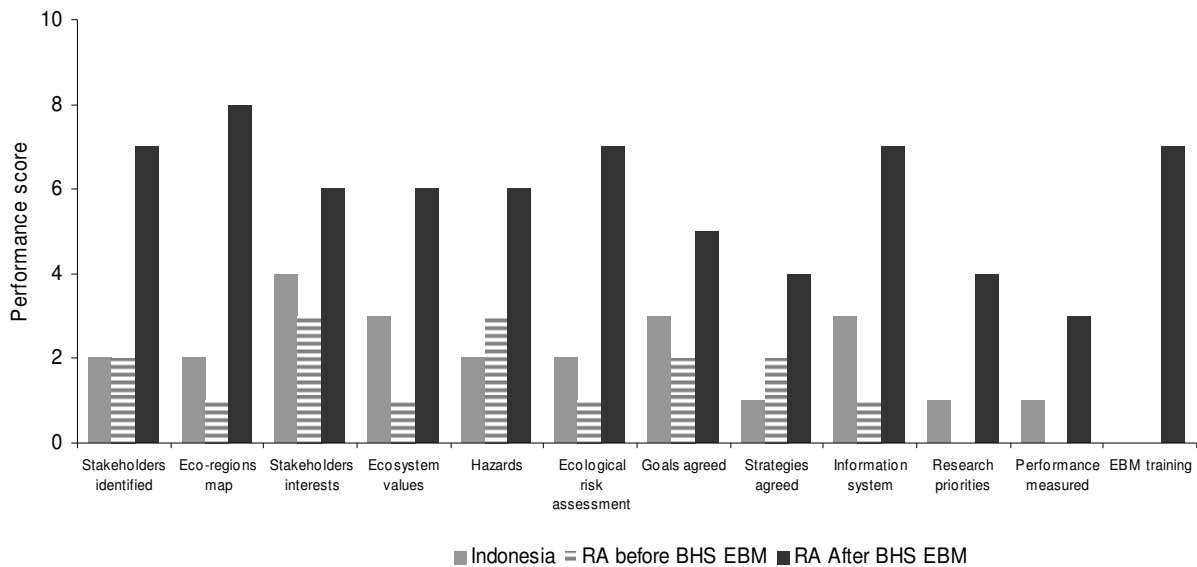


Figure 3. Scores for the twelve steps of EBM implementation for Indonesia and Raja Ampat before and after the project implementation

Before the BHS EBM project:

The ecosystem of Raja Ampat is in better shape than other parts of Indonesia, but no measures are in place to protect the system (McKenna et al. 2002). The people assume that the coral reefs will remain and support the population forever.⁶⁰ The role of habitat or species in an ecosystem context is not widely-appreciated. Despite a tradition of stewardship among the native people of Papua, traditional governance rights have become less prevalent since Suharto's regime. Management today exists as a conflict between

⁶⁰ Abdul Halim, The Nature Conservancy, personal communication.

the village head and the fisheries department. Furthermore there is no cooperation between different sectors (i.e. mining, fisheries, tourism etc). Local chiefs often receive payment and allow fishing in waters that traditionally belong to the village (Goram 2007). Recently, there is recognition of damage from destructive fishing practices⁶¹, with more fishers having adopted destructive fishing methods under the influence of fishers from outside Raja Ampat. There is no assessment of the fish catches or the fish stocks; there is also a large amount of unreported catch (e.g., Bailey et al. 2008; Varkey, D., Ainsworth, C., Pitcher T.J., Goram J. Illegal, Unreported and Unregulated catch in the Raja Ampat islands, Indonesia and its implications for the Regency government. Submitted to Marine Policy), and hence it is impossible to ascertain the level of fishing for practice of adaptive management or to even perform basic stock assessment. No information system exists; however, the government is planning an inventory of the fishing vessels in the area⁶². The best maps of the region that existed prior to the BHS EBM project were the nautical charts made by Dutch expeditions. Environmental externalities are recognized but not a part of consideration in management. Human use values are recognized and the people connect deeply with the ocean. They also understand that fishers from outside Raja Ampat engage in rampant use of destructive fishing methods as they have little respect for Raja Ampat waters (D. Varkey, personal observation). The major management goal supported by local communities is to prevent entry of outside fishers into Raja Ampat waters. The local fishers in general do not understand ecosystem interactions and their values. The fisheries department probably understands what EBFM is, but does not have the same clout as the more profitable ventures (e.g. mining) (D. Varkey and C. Ainsworth personal observation)

Expected outcomes from the BHS EBM project:

Many information gaps have been filled during the project. An aerial survey was conducted to determine the number of fisheries operations in the Regency (Barmawi 2006). A rapid appraisal was conducted on the demographics of the Regency for a deeper understanding of exploitation demand from the resource (Djuang 2007). Careful evaluation of the fisheries and the other economic sectors has been done in the project (Dohar and Anggraeni 2006). The Atlas of Raja Ampat (Firman and Azhar 2006) is a clear inventory of habitats and eco-regions built during the project, future use of the information has been made easy by construction of Geographic Information System (GIS) format files⁶³. The ecosystem model that was built during the project integrated information from different sources, quantified interactions between different ecosystem components and described habitats of species and the patterns of resource use (Ainsworth et al. 2007; Ainsworth et al. this volume). The model estimated the maximum sustainable yields of the important fish and invertebrate groups. Study on the anchovy fishery (Bailey et al. 2008) revealed unreported catches that were subsequently used to ascertain the actual fisheries extraction from the system (Varkey, D., Ainsworth, C., Pitcher T.J., Goram J. Illegal, Unreported and Unregulated catch in the Raja Ampat islands, Indonesia and its implications for the Regency government. Submitted to Marine Policy). Several scenarios were analyzed to study the direct and indirect effects of destructive fishing and overfishing (Ainsworth et al. 2008b). Risk assessment of fisheries was done using an ecosystem model; the model can thus be used for adaptive management. Research questions were suggested by the participating NGOs and studied in detail (Ainsworth et al. 2008b), including analysis of spatial management options (D. Varkey unpublished manuscript). Studies on the institutional roles and traditional marine tenure helps to identify people who wield power in fisheries management decisions. The Papuan council, CI, TNC, and the Indonesian Navy are collaborating on a monitoring program for Raja Ampat (Rabu 2006). The findings will be communicated to the people via local newsletters like the CI tabloid (Rabu 2006), posters and booklets. Training manuals prepared by the University and the NGO teams will be used to give training and education. The information from the field surveys and the model will be used to design an EBM plan (Sumule and Boli 2006). The BHS EBM project also interviewed several hundred fishers and community members, collating socioeconomic information and collecting a large amount of local environmental knowledge concerning fisheries and the ecology of Raja Ampat. Analysis prepared by Ainsworth et al. (2008) utilized the information, which in some cases extends back 30 years, to demonstrate that there has been shifting baselines among communities as to what constitutes an abundant ecosystem, and suggested that serious fishery depletions have occurred in Raja Ampat.

During the course of the project, residents in Kofiau stated that they had observed improvements in catch around their villages after following guidelines issued by the TNC. 'Overfishing' will decrease if the MPAs

⁶¹ Jacinta Djuang. Conservation International, personal communication.

⁶² Becky Rahawarin, Kepala Dinas Perikanan dan Kelautan (DKP), personal communication.

⁶³ Muhammad Barmawi, The Nature Conservancy, unpublished files.

are successful in limiting the impact of outsiders. The NGOs conduct regular surveys for information at the village level, but the Regency lacks capacity for independent review. The NGOs plan and conduct review and performance assessment regularly⁶⁴. The project is making efforts to collaborate with the Local Papuan Council, a council of local leaders on issues of marine management and design of policy framework. During the implementation of the project MPAs were declared to keep fishers from outside Raja Ampat out of the fishing grounds. It is difficult to consider environment externalities for management even after the project has been implemented. Another main benefit to the project has been due to the high level of integration that TNC and CI have had at the community level. The presence of local field offices in rural areas has facilitated a high degree of cooperation between NGO staff and villagers, which has stimulated a sense of cooperation and helped increase the profile of environmental issues and EBFM challenges in the area.

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⁶⁴ Jacinta Djuang, Conservation International, personal communication.

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APPENDIX

Table 1. Scores, lower and upper bounds for Indonesia and Raja Ampat Regency before and after the implementation of the BHS EBM project. Scores for Indonesia are taken from (Pitcher et al. 2006), and (Pitcher et al. in prep).

Area	Indonesia			Raja Ampat Before BHS EBM Project			Raja Ampat After BHS EBM Project		
	Score	min	max	Score	min	max	Score	min	max
Five Principles of EBM									
Function & biodiversity	2	0	2	1	1	3	5	4	7
Human use and values	5	4	7	6	5	8	6	5	8
Dynamic ecosystems	2	0	3	2	0	3	4	3	6
Shared vision	4	3	6	4	2	4	6	3	7
Management adaptive	1	0	2	0	0	1	4	2	6
Six indicators of EBM									
supportive policy framework	3	0	4	2	0	3	6	4	7
economic, social, cultural	4	3	6	6	4	7	7	4	8
ecological values	2	1	3	2	1	3	7	4	7
no overfishing	1	0	2	1	0	2	7	4	7
good data	4	3	5	2	0	2	6	3	7
environment considered	1	0	2	1	0	1	3	2	4
Twelve Steps Implementing EBM									
stakeholders identified	2	1	6	2	1	4	7	5	8
Eco-regions map	2	1	6	1	1	2	8	8	10
stakeholders interests	4	3	7	3	1	3	6	5	8
ecosystem values	3	0	5	1	0	2	6	4	6
hazards	2	0	4	3	2	4	6	3	6
ecological risk assessment	2	0	2	1	0	2	7	6	9
goals agreed	3	0	3	2	0	3	5	3	7
strategies agreed	1	0	1	2	1	2	4	3	6
information system	3	3	5	1	1	4	7	6	8
research priorities	1	0	2	0	0	3	4	3	7
performance measured	1	0	2	0	0	2	3	1	4
EBM training	0	0	1	0	0	0	7	5	8

CHAPTER 5

ECOLOCATOR USER'S GUIDE⁶⁵

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INTRODUCTION

EcoLocator is a modelling tool that displays the biomass distribution of species and species groups in a study area based on highly resolved site-specific habitat information and our knowledge of species ecology. The visualization tool can be used to display biomass data from field sampling or predictions from complex population models like Ecopath with Ecosim (EwE: Polovina, 1984; Christensen and Pauly, 1992; Walters et al., 1997; Christensen and Walters, 2004) and Ecospace (Walters et al., 1999). EcoLocator can add functionality to other ecosystem analysis tools by providing a graphics capability or increasing their useful spatial resolution. Images and animations made with this software can enhance the interpretability of simulation results, and make scientific models more accessible to non-specialists.

Dynamic species biomass data is inputted into EcoLocator for one or more functional groups. The model predicts the distribution of populations and projects a coded colour pattern onto a habitat map, where warm colours indicate areas of high biomass concentration and cool colours indicate areas of low concentration. The distribution is calculated based on a cross-sectional pattern of species abundance, entered by the user on a sketchpad, and a habitat area that is sketched onto a map. The abundance cross-section pattern describes the biomass concentration between the habitat edge and certain 'node' cells, which indicate central areas occupied. The inputs for abundance pattern and habitat areas are highly flexible in their definitions. They may correspond to a variety of physical or oceanographic features important in species distributions; for example, as related to bathymetry or coral reef-cover. Habitats definitions can be shared across functional groups or tailored to represent a wide variety of organisms.

PROGRAM OPERATION

INPUTTING BIOMASS DYNAMICS INTO ECOLOCATOR

After running the application (EcoLocator.exe) the main form appears from which the user can select an input CSV file containing biomass dynamic information. The active file name is displayed at the bottom of the form on the status strip. The input data represents a biomass time series for one or more functional groups. It can be based on EwE or Ecospace predictions; for example, it may correspond to a particular Ecospace cell or output region (see section "Application to Ecospace").

The required format of the input CSV is demonstrated in Table 1. There are two header rows indicating the names and pool codes of functional groups. The leading column provides the year or time step used by Ecospace. EcoLocator can accept a maximum of 200 functional groups.

⁶⁵ Cite as: Ainsworth, C. (2008). EcoLocator User's Guide. Pages 179-186 in Bailey, M., Pitcher, T.J. (Eds), Ecological and Economic Analyses of Marine Ecosystems in the Bird's Head Seascape, Papua, Indonesia: II. Fisheries Centre Research Reports 16(1): 186 pp.

Table 1. Format for EcoLocator input CSV file. Values are biomass in t-km⁻².

Title	Mysticetae	Pisc. odonto.	Deep odonto.	Dugongs	...
pool code	1	2	3	4	...
1990	3.32E-02	5.19E-02	9.14E-02	5.89E-02	...
1991	3.31E-02	5.18E-02	9.09E-02	4.99E-02	...
1992	3.31E-02	5.17E-02	9.09E-02	4.86E-02	...
...

APPLICATION TO ECOSPACE

EcoLocator requires a biomass value for each functional group and time step represented. The value corresponds to the total biomass in the EcoLocator study area. When used to represent Ecospace results, the study area can correspond to a defined Ecospace 'output region' (see Christensen *et al.*, 2005). Output regions may be used to represent management areas, habitat types or even individual cells. Although Ecospace (in EwE V5) can output biomass dynamics automatically into a CSV file, it can only provide summary statistics for the entire Ecospace map. In order to recover the average biomass density (or other statistic) for a particular output region, the user must manually collate the information by pressing the 'Results' button on the 'Run Ecospace' tab following a spatial-dynamic simulation. By using the drop-down box on the results form, the user can cycle through output regions, copying and pasting the biomass vector of functional groups into a separate file for input into EcoLocator.

CREATING OR LOADING AN ECOLOCATOR MAP FILE

Once a CSV file is loaded containing biomass dynamics, the user can select 'New map' on the drop-down menu to open a new map design form. The blank form appears as in Fig. 1. The form contains a map panel, a biomass distribution panel and controls governing land and map-edge behaviour. The user can save the current map design form or load saved forms under the 'File' dropdown menu. The file is saved using an ECL extension.

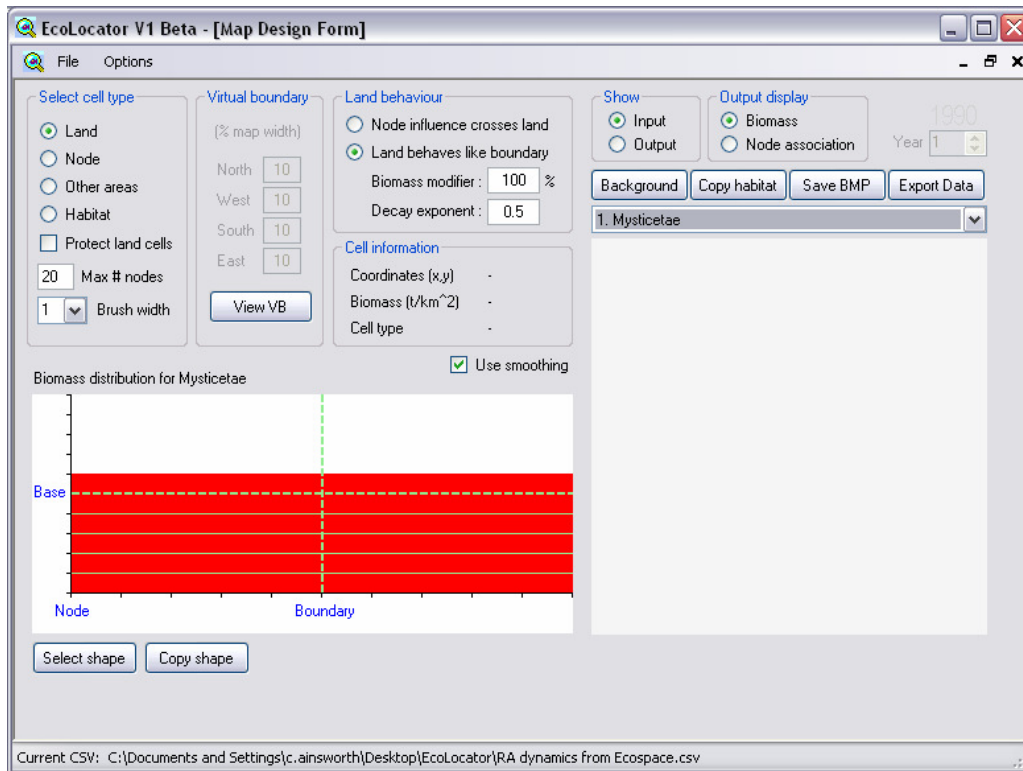


Figure 1. Blank map design form.

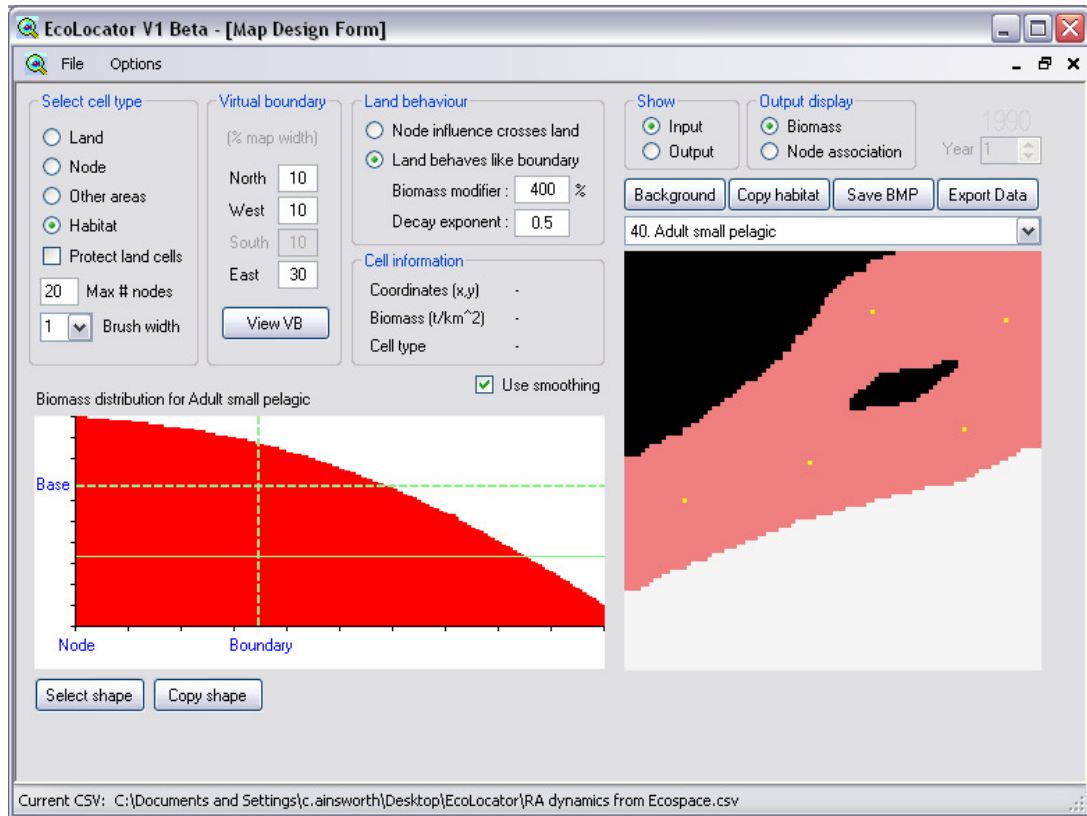


Figure 2. Completed map design form

Habitat areas appear pink. They are sketched in for each functional group or copied from another group using the 'Copy habitat' button. The habitat area will normally represent the area occupied by the functional group during the initial (baseline) year in the CSV input file. The habitat area can be used to represent some physical or oceanographic feature that defines a preferred habitat for the group (e.g., a coral reef, shallow or deep areas, sheltered areas, etc.).

Node cells in yellow are drawn inside habitat areas. In general, the more nodes that are used, the more homogeneous the predicted distribution will become. The maximum number of nodes is initially set to 20 to reduce computation time, but it can be increased. Fig. 2 shows a completed habitat map for the functional group 'Adult small pelagic'.

VIRTUAL BOUNDARY

Wherever a habitat area crosses the map edge, a virtual boundary is required for the cell biomass calculation. The example in Fig. 2 uses a virtual boundary equal to 10% of the map width (the default value) for the north and west map edges. It uses 30% for the east edge. The virtual boundary can be visualized by pressing the 'View VB' button; this calls the virtual boundary display form (Fig. 3).

BIOMASS DISTRIBUTION PANEL

The red area in the biomass distribution panel represents the cross-sectional biomass density of the functional group from node to boundary ('boundary' refers to the interface of habitat and non-habitat cells). The relative biomass concentration at the node is set at the X-intercept; the relative concentration at the boundary is set at the vertical dotted line. The position of the vertical dotted line can be dragged left or right, to increase or decrease the scale of the X-axis. Dragging the line right increases the precision of the biomass differential displayed. Dragging the line left allows the user to define the biomass concentration in more distant cells from the node. The rightmost pixel on the red distribution panel indicates the relative biomass density that is assigned to cells lying further away from node than can be described in the panel.

The position of the horizontal dotted line defines the area of occupation at baseline biomass levels. In the example in Fig. 2, the area of occupation will extend beyond the boundary by approximately one half of the node-boundary distance, with the highest concentration occurring close to the node. If biomass is increasing in the inputted CSV time series, the area of occupation will expand further away from the node as the user advances the display year.

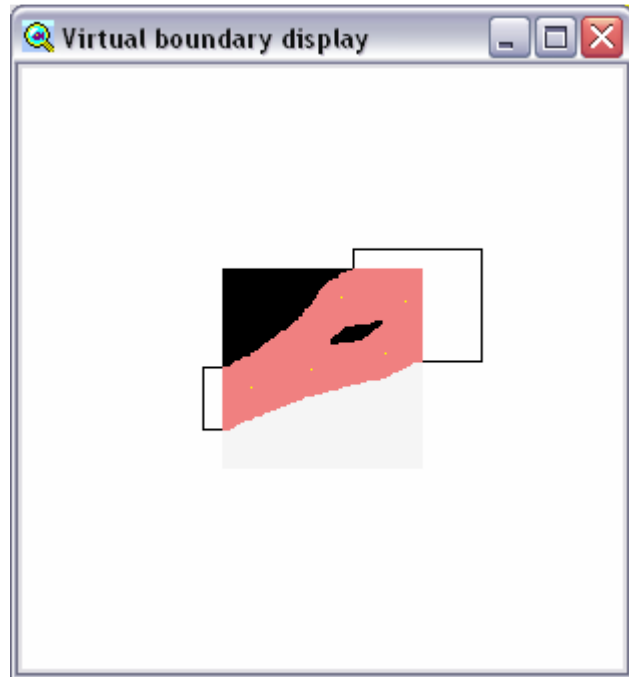


Figure 3. Virtual boundary display form.

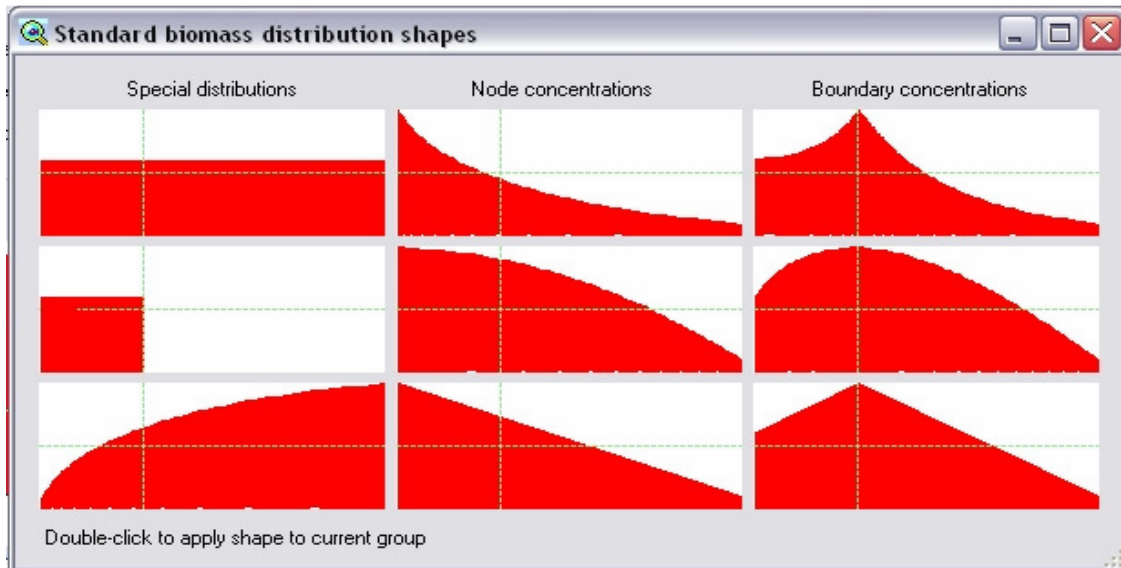


Figure 4. Standard biomass distribution shapes.

The solid green lines lying horizontally below the dotted line indicate the area of occupation at 2 times the baseline biomass, 3 times, etc., moving downwards. Dragging the dotted line downwards increases the

precision of the biomass differential displayed. Dragging the dotted line upwards increases the total range of biomass concentrations that can be displayed. For highly variable groups such as plankton, the horizontal dotted green line should be brought close to the top of the panel to allow a wider range of biomass concentrations to be represented. The display year (or time step) is set using the up/down counter control in the top right corner of the form.

The biomass distribution can be sketched manually to represent a wide variety of population structures and ecological niches, or it may be selected from pre-defined shapes (Fig. 4). These are accessed using the 'Select shape' button below the biomass distribution panel. Hovering the mouse over the various shapes provides explanation and examples for the use of each shape (Table 2). Biomass distribution shapes may also be copied from other functional groups using the 'Copy shape' button.

Table 2. Name, description and suggested uses for pre-defined biomass distribution shapes. Table entries correspond to the shapes in Fig. 4.

Special distribution	Node concentrations	Boundary concentrations
<p>Uniform distribution</p> <p>Used for groups present in all water cells.</p> <p><i>Recommended for:</i></p> <p>Highly mobile pelagic groups, plankton and detritus.</p>	<p>Concave node distribution</p> <p>Resists diffusion. Used for groups that concentrate in the centre of their habitat and encroach into other areas only during periods of high abundance.</p> <p><i>Recommended for:</i></p> <p>Small fish species / juveniles that avoid exposed areas. Habitat can represent protective areas like coral reefs or mangroves.</p>	<p>Concave boundary distribution</p> <p>Resists diffusion. Used for groups that congregate near the perimeter of their habitat area and encroach on other areas only during periods of high abundance.</p> <p><i>Recommended for:</i></p> <p>Planktivorous fish occupying the edge of coral reefs and areas of water/nutrient exchange.</p>
<p>Knife-edge distribution</p> <p>Used for groups that can occur only in habitat cells.</p> <p><i>Recommended for:</i></p> <p>Reef-building corals (where habitat is based on reef area). Cryptic species that occur only in reef habitat (e.g., moray eels).</p>	<p>Convex node distribution</p> <p>Easily diffuses. Used for groups that concentrate in the centre of their habitat but readily occupy other areas under favourable conditions.</p> <p><i>Recommended for:</i></p> <p>Herbivorous fish occupying the centre of reef area habitats; deep water fish and invertebrates occupying deep water habitats.</p>	<p>Convex boundary distribution</p> <p>Easily diffuses. Used for groups that congregate near the perimeter of their habitat area, but may forage in a wider zone.</p> <p><i>Recommended for:</i></p> <p>Large piscivorous fish, adult fish and sharks that hunt on the outside of reefs (e.g., in deeper areas).</p>
<p>Outside boundary distribution</p> <p>May be used to exclude groups from a commonly applied habitat area (e.g., coral reef). Can be used as an alternative to creating a unique habitat for a single group.</p> <p><i>Recommended for:</i></p> <p>Groups avoiding prohibitive habitats.</p>	<p>Linear node distribution</p> <p>Used for groups that concentrate in the centre of their habitat but occupy other areas during periods of high abundance.</p> <p><i>Recommended for:</i></p> <p>Herbivorous fish occupying the centre of reef areas, small fish and juveniles.</p>	<p>Linear boundary distribution</p> <p>Used for groups that congregate near the perimeter of their habitat area.</p> <p><i>Recommended for:</i></p> <p>Large piscivorous or planktivorous fish.</p>

LAND BEHAVIOUR CONTROLS

By default, the land-habitat interface behaves like a boundary cell. However, the user can enter a special modifier to increase or decrease the biomass of the group in cells close to land. Two parameters control the land's influence on the biomass distribution: the biomass modifier and the decay exponent. The biomass modifier specifies the biomass concentration in the cells directly adjacent to land. At 100%, land cells behave like boundary cells (default). Values larger than 100% indicate that this group concentrates near land (e.g., intertidal or nearshore species); a biomass modifier less than 100% may be used for species that do not occur close to shore. The decay exponent describes how far from land the effect extends. A value of 0.5 (default) indicates that the biomass modifier effect reduces with the square root of the distance to the evaluation cell. The appropriate decay exponent will depend on the ecology of the organism, and on the spatial scale of the study area. Equation 1 describes the land effect:

$$W = 100 + \frac{BM - 100}{d^{DE}} \quad (1)$$

BM is the biomass modifier in percent, DE is the decay exponent and W is the biomass weighting factor. The species group modelled in Fig. 2 will show a strong presence near land.

Alternatively, the user can select 'Node influence crosses land'. In this case, land cells are ignored and biomass calculations will depend on a boundary location defined on the far side of the land. This feature may be used if the spatial scale of the EcoLocator map is large. In this case, land influence becomes less important.

BIOMASS CALCULATIONS

The biomass concentration in any map cell is calculated based on the relative distance of that cell to a node, and the relative distance from that node to a boundary cell. The relevant boundary cell for the calculation will lie in direct line with the node and evaluation cell. When multiple nodes are used, the biomass concentration for any given map cell may be influenced by several nodes. A node may influence a map cell if the straight-line path between them is uninterrupted by non-habitat cells or land cells. The cell biomass is calculated with respect to each pertinent node, and a weighted average is taken so that closer nodes influence the biomass calculation more strongly. Node influence decreases linearly with distance. The influence of each node is restricted to its own continuous habitat area. This is necessary to avoid discontinuities in the biomass concentration. Cells without direct access to nodes inherit a neighbor's list of valid nodes for use in biomass calculations.

It is possible to visualize the influence of nodes throughout the map by selecting 'node association' in the 'Output display' box (Fig. 5). Cells that are influenced by many nodes will appear as either dark red, if they have direct connectance to a node, or dark blue if the nodes are inherited from a neighbour cell. Cells that are influenced by fewer nodes will appear as light red or light blue. A colour key is provided.

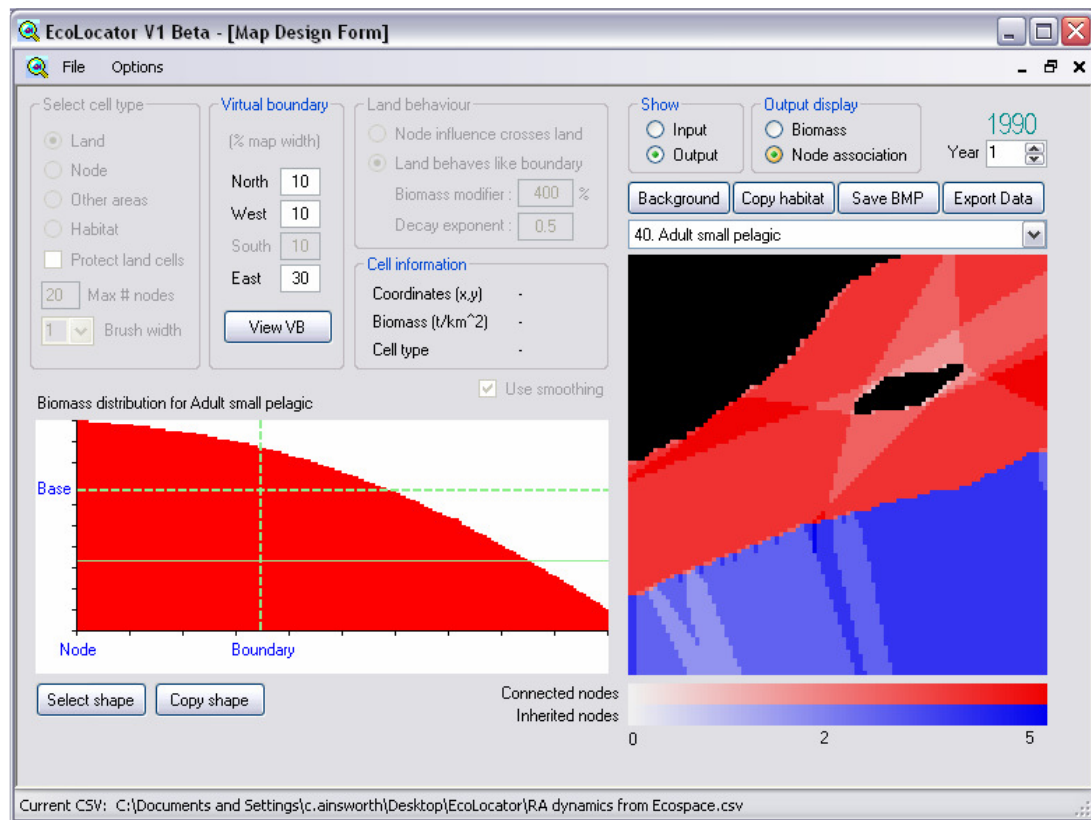


Figure 5. Colour coded node association shown on habitat map.

The final biomass value for each map cell can be calculated with or without a smoothing factor. Smoothing is enabled by default. When this feature is turned on, biomass for each cell will be adjusted to the average of its adjacent cells (up to 8).

OUTPUT

Selecting the 'Output' radio button begins biomass computations and will produce an output like Fig. 6. Advancing the simulation year using the up/down counter control prompts EcoLocator to recompute biomass based on the next time step in the CSV file. Biomass is displayed on the output map using the colour index defined at the bottom right. Passing the mouse over a map cell will provide quick information in the 'Cell information' group box. The biomass output for the whole map can be exported to a CSV file for graphing in another application using the 'Export Data' button. Finally, the map image can be exported as a bitmap file using the 'Save BMP' button; note: this feature can export either the input or output map image.

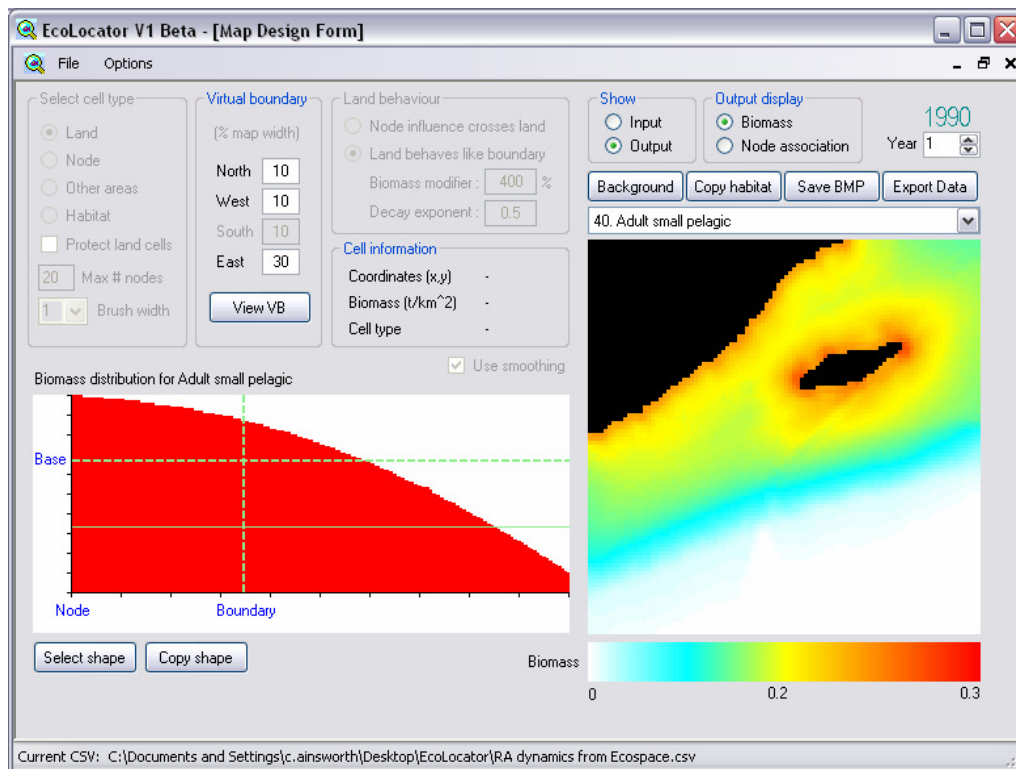


Figure 6. EcoLocator results.

SUPPORT, LIABILITY AND COPYRIGHT

EcoLocator may be copied and distributed freely for non-commercial purposes. It is an open source code application; source code in Visual C++.net can be obtained from the author (c.ainsworth@fisheries.ubc.ca). Software support is also available through the author. We encourage you to inform us of any models created using this software, or of any bugs encountered. The author and the University of British Columbia accept no liability for the use of this software.

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