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Fisheries Centre, University of British Columbia, Canada

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

Edited by
Tony J. Pitcher, Cameron H. Ainsworth and Megan Bailey

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CONTENTS

Page

Ecosystem Simulation Models For The Bird's Head Seascape, Papua, Fitted to Field Data

Cameron Ainsworth, Divya Varkey and Tony Pitcher

  - Ecopath parameterization

- Methods

  - Ecopath parameterization

  - The 1990 Raja Ampat model

  - Ecospace parameterization

Results

Discussion

Appendix A: EwE parameterization

Appendix B: EwE results

The migrant anchovy fishery in Kabui Bay, Raja Ampat, Indonesia: catch, profitability and income distribution

Megan Bailey, Christovel Rotinsulu, and U. Rashid Sumaila

Results

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A Research Report from Fisheries Ecosystem Restoration Research & the Fisheries Economics Research Unit

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DIRECTORS FOREWORD

This Report presents two contributions of very unequal length on the fisheries of Raja Ampat, in Eastern Indonesia. The second of these is devoted to a neat account of the economics of an anchovy fishery which developed without being monitored by official statistics, as probably most small-scale fisheries do throughout the world. It is also, apparently, a profitable fishery, and this again, raises questions about the usual neglect of small-scale fisheries.

It is, however, the first of these contributions which I want to elaborate on, as it connects very deeply to my personal trajectory. In 1975 and 1976, I worked in western Indonesia, with a freshly-minted Master of Fisheries, in an 'aid' project devoted to the development of trawl fisheries of the Java Sea and adjacent areas. I did not know then much about fisheries in general, and tropical fisheries in particular, but I realized, upon seeing my very first multi-species trawl haul wiggling on deck that it would be impossible to estimate, using 'classical methods' (i.e., those I had been taught), the parameters of growth, natural mortality, etc., required for the (single-species) models that were then in vogue for the management of fisheries.

This realization was the start of my personal research program, devoted to identifying pattern in the growth and mortality parameters across a number of species, which could be used to infer their likely value in the absence of local data, and of methods for their estimation, given a minimum of such data. This program, which coincided with that of many fisheries scientists at the time (including T.J. Pitcher, one of the authors of the contribution commented upon here) was rather successful, as reflected in this very Report.

Raja Ampat, in Eastern Indonesia is near the centre of the world's marine biodiversity, but it is, by any other standard, an extremely peripheral area, notably as science goes. It could be inferred, therefore, that, as the phrase goes, "nothing is known on [whatever] in the area".

But this is not so. An amazing amount of data is available on virtually all areas of the world, including areas as 'remote' as Raja Ampat, even if we go back as far as the 17th century. The point is to know where to find these seemingly dead data, and to make them alive again. One way to do this is through the compilation and analysis of observations by the naturalists of successive historic expeditions, and the narrative of travellers, as illustrated in an earlier report on the same area by 'Deng' Palomares and 'Sheila' Heymans[*]. The other approach to overcoming the dictum that "nothing is known…", documented in this Report, is to combine locally available, but scattered data (which always exits) with general patterns on the distribution, feeding and production of fish and invertebrates, derived from databases such as Fishbase.

Reading this document, I have a sense that the work we did the last thirty years actually was useful: we now have the tools to build realistic models, and to propose practical schemes for the management of about any marine ecosystem in the world. Not bad. These tools work only when in good hands, but clearly, this is here the case. I conclude, therefore, by congratulating the authors for a job well done.

Daniel Pauly
Director, Fisheries Centre

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[*] Maria Lourdes D. Palomares and Johanna J. Heymans 2006. Historical Ecology of the Raja Ampat Archipelago, Papua Province, Indonesia. Fisheries Centre Research Reports 14(7): 64 pp.

EXECUTIVE SUMMARY

A growing awareness of the decline in ecosystem health and the depletion of resources world-wide has led researchers to explore the use of ecosystem-based management (EBM), an approach that integrates ecological, social, and economic goals, and explicitly recognizes humans as key components within an ecosystem. EBM is still in its infancy, and a number of research projects have been launched to try to increase understanding, develop EBM tools, and attempt to mitigate or even reverse at least the worst of the present trends.

One such study is within the Coral Triangle, spanning eastern Indonesia, parts of Malaysia, the Philippines and Papua New Guinea, where the highest coral reef biodiversity on earth has been measured. At the heart of the Coral Triangle is the Bird's Head Seascape, off the west coast of Papua Province, Indonesia. This is still a relatively remote and pristine area, home to about 75% of the world's reef-building coral species, and over 1,000 fish species. The Raja Ampat archipelago, where Alfred Wallace made a home in the 1830s, has attracted the interests of conservation groups and scientists, and has been selected as one of the top conservation priorities in the world. The high level of biodiversity has lead to a growing marine tourism sector, and the newly decentralized government is trying to develop the area sustainably for the 31,000 inhabitants. Following a proposal, funding was generously provided by the David and Lucile Packard Foundation to researchers and scientists from Conservation International (CI), The Nature Conservancy (TRC), the World Wildlife Fund (WWF), the State University of Papua (UNIPA), and the Fisheries Centre, University of British Columbia, for a project entitled, "Toward Ecosystem-Based Management in the Bird's Head Functional Seascape of Papua, Indonesia". Three teams at the Fisheries Centre are working to provide a synthesis of key ecological, economic and historical components, supporting field teams from UNIPA, TNC, CI and WWF who are sampling and collecting data. This report represents the second of UBC's contributions to the Bird's Head Seascape EBM project[†].

The first paper in this report, from the Fisheries Ecosystems Restoration Research group, describes the developement of a 98-functional group ecosystem simulation model (Ecopath with Ecosim, EwE) for Raja Ampat, fitted to local time series abundance and CPUE data, and driven by local climate changes. Fine-scaled local models for three areas (Kofiau Island, Misool Island, and the Dampier Strait) are also included. Several novel approaches have been added to this model, including a new algorithm for estimating diets based on fish gape size, body depth and habitat co-occupation. These EwE models will be further refined with data from the field teams on diets and fisheries, and with the results of interviews with fishers on percieved changes in the Raja Ampat ecosystem. The aim is to use the models to develop optimal management scenarios in order to provide EBM advice that can be appraised by stakeholders in the Raja Ampat archipelago.

Illegal, unreported, and unregulated (IUU) fishing is now widely recognized as undermining management goals. The second paper in this report, from the Fisheries Economics Research Unit, uses field observations to estimate the unreported and unregulated catch of anchovies in Kabui Bay, Raja Ampat. The estimates include uncertainty, revenues, costs and the apparent profitability of the fishery. Results suggest that fisheries managers in Raja Ampat could consider capturing some of the fishery rent. The UBC team hopes to provide an IUU estimate for all of Raja Ampat upon the completion of the project, and the anchovy estimate will contribute to this.

Tony J. Pitcher, Cameron H. Ainsworth and Megan Bailey
Vancouver, May 2007

[†] The first contribution was: Palomares, M.L.D. and Heymans, J.J. (2006) Historical Ecology of the Raja Ampat Archipelago, Papua Province, Indonesia. Fisheries Centre Research Reports 14(7): 64 pp.

ECOSYSTEM SIMULATION MODELS FOR THE BIRDS HEAD SEASCAPE, PAPUA, FITTED TO DATA

Cameron Ainsworth, Divya Varkey and Tony Pitcher
Fisheries Ecosystems Restoration Research, Fisheries Centre,
University of British Columbia, 2202 Main Mall, Vancouver, BC, Canada, V6T 1Z4

Abstract

Ecopath with Ecosim models are described for the marine ecosystem of the Raja Ampat (RA) archipelago in Papua province, eastern Indonesia. The models are based on literature and output data emerging from the Birds Head Seascape Ecosystem Based Management (BHS EBM) project, a joint Packard-funded initiative between TNC, CI, WWF and UBC. A new diet allocation algorithm is developed for use in tropical ecosystems, based on predator gape and prey body size. The algorithm predicts feeding relationships in order to make better use of FishBase diet information. Time series of catch, effort and catch-per-unit-effort are developed from governmental fisheries statistics assembled in the field. A historic model, representing 1990 AD is developed based on this time series information, and a 16-year dynamic Ecosim simulation is fitted to agree with time series. The model incorporates four mediation functions to capture key non-trophic interactions important in reef ecosystems. A primary production anomaly is developed that would help explain the difference between observed and predicted biomass dynamics from 1990 to 2006. The anomaly shows a non-significant negative correlation with sea surface temperature. An equilibrium analysis and various challenges to Ecosim are used to test the behaviour of the model. Policy optimizations are conducted to sketch the potential trade-off frontier between economic and ecological harvest benefits available in RA. Ecospace maps are designed for RA and sub-area models of Kofiau Island and Dampier Strait. Some comments are made regarding future developments of the UBC spatial modelling component of the BHS EBM project.

INTRODUCTION

This report presents the methodology used to create Ecopath with Ecosim (EwE) and Ecospace ecosystem models of the Raja Ampat Islands in Papua, Indonesia, and provides a preliminary analysis of ecosystem functioning and resource potential of coral reefs. The models created here are based on scientific data emerging from the research project "Towards Ecosystem-Based Management in the Bird's Head Functional Seascape of Papua, Indonesia", being conducted jointly by The Nature Conservancy (TNC), Conservation International (CI), World Wildlife Fund (WWF), and the University of British Columbia (UBC).

Ecosystem models are being developed for the RA region at various spatial scales. These temporal and spatial dynamic models capture biotic and abiotic interactions in the ecosystem. By accurately representing ecological processes on coral reefs, they will help us to improve our understanding of reef ecosystem behaviour. The models can be used to assist ecosystem-based marine policy; with them we can design sustainable fishing strategies that maximize economic benefits while protecting coral reef communities. Fishing policies developed with these tools can be made robust against various future climate scenarios, and the risk and uncertainty surrounding harvest recommendations can be evaluated and quantified. Importantly, the spatial models are able to forecast the effects and benefits of spatial management schemes, such as the

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Cite as:[‡] Ainsworth, C.H., Varkey, D. and Pitcher, T.J. (2007) Ecosystem simulation models for the Bird's Head Seascape, Papua, fitted to data. Pages 6–172 in Pitcher, T.J., Ainsworth C.H. and Bailey, M. (eds) Ecological and Economic Analyses of Marine Ecosystems in the Birds Head Seascape, Papua, Indonesia: I. Fisheries Centre Research Reports 15(5): 184 pp.

application of marine protected areas (MPAs). The models are built within a flexible framework that can be continually modified and improved as new data becomes available. The work presented here should provide a starting point for further study of ecosystem-based management (EBM) strategies helpful to the management of the Bird's Head Functional Seascape (BHS).

Ecopath with Ecosim (EwE)

We have used the family of modelling tools, Ecopath with Ecosim (EwE) and Ecospace to represent the food web of Raja Ampat and simulate trophic interactions of interest to fisheries and conservation. Invented by Polovina (1984) and advanced by Christensen and Pauly (1992, 1993), Walters *et al.* (1997, 1998) and Christensen and Walters (2004a) among others, EwE is a mass-balance trophic simulator that acts as a thermodynamic accounting system. Summarizing all ecosystem components into a small number of functional groups (i.e., species aggregated by trophic similarity), the box model describes the flux of matter and energy in and out of each group, and can represent human influence through fishery removals and other ways. There are now dozens of published articles that use EwE to describe ecosystems, test hypotheses and demonstrate innovative applications useful for EBM (see review in Christensen and Walters, 2005). EwE has been used in actual fisheries management, but to a limited extent. Reviews and criticisms of the EwE approach are provided by Fulton *et al.* (2003), Christensen and Walters (2004a), and Plagányi and Butterworth (2004).

An EwE model is presented here for the marine ecosystem of Raja Ampat (RA) as it appeared in 2006 AD. The model utilizes BHS EBM project information and data from literature sources. New methodologies are developed to make the best use of FishBase data. For example, a new diet allocation algorithm determines likely prey items based on predator gape-size and processes FishBase diet data to the level of functional groups.

An Ecopath model of RA representing the system in 1990 AD is created based on the 2006 model. Relative functional group biomass and catch is estimated for these years based on Indonesian governmental statistics, and ecosystem dynamics are tuned to agree with the historic trends from the years 1990-2006. The data fitting process attempts to capture ecosystem responses to fishing and climate that occurred over the last 16 years. The dynamic Ecosim model utilizes advanced features such as mediation functions, which capture critical animal behaviours and allow us to represent important non-trophic relationships present in the coral reef environment. A primary production time series anomaly is determined that may explain the discrepancy between the observed and predicted catch and biomass trends. The anomaly is compared to various environmental indices. Insight gained can potentially improve our understanding of regional climate and its affect on marine production.

A comprehensive review of model behaviour is performed using the equilibrium analysis facility in Ecosim. This routine describes the exploitation status of commercial functional groups, allowing us to judge the accuracy of the baseline model condition against our knowledge of the ecology and fishing history of the region. The analysis generates catch and biomass curves equivalent to those used by classical fisheries methods. Diagnostic challenges are presented to the model to test its performance - extreme combinations of fishing practices that reveal the behaviour and stability of the model. By presenting these early diagnostic outputs in this report, we hope to the draw attention of local experts and enlist their help to establishing realistic model behaviours.

Basic policy optimization is conducted using the tuned Ecosim model, and the socioeconomic/ecological tradeoff frontier is mapped to reveal the sustainable production potential of the ecosystem. This application should demonstrate the power of policy optimizations in EwE, although the specific values and estimates of resource potential will continue to change as our understanding of the RA ecosystem improves.

Initial efforts to produce spatially explicit models are described here. Habitat maps, based on data collected in the BHS EBM project, provide a foundation for the Ecospace models of RA and two smaller-scale models: Kofiau Island and Dampier Strait. Basic parameterization of the Ecospace models is described. Finally, we discuss our goals and the current direction of the spatial modelling component for the BHS-EBM project.

Raja Ampat Islands

The RA archipelago extends over 45,000 km^2 and consists of approximately 610 islands including the 'four kings', Batanta, Misool, Salawati and Waigeo (COREMAP, 2005). Erdmann and Pet (2002) provide a summary of the major oceanographic features occurring in the Raja Ampat archipelago. 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 percent of the world's known coral species (Halim and Mous, 2006).

Fisheries by native peoples of Papua have likely persisted for centuries; although there is evidence that long-term 'chronic' exploitation of coral reefs had an early impact on reef health in many places throughout the world (Pandolfi *et al.*, 2003). However, record keeping typically begins long after the major depletion of reef resources occurs (Bellwood *et al.*, 2004). This is the case in Indonesia and many other countries that manage coral reef resources. The gradual or early declines may therefore go unnoticed thanks to the shifting-baseline syndrome (Pauly, 1995) in which each generation of scientists and resource users accept a lower standard of abundance as normal. It is therefore difficult to estimate the loss of potential productivity that has occurred, especially since there are few pristine areas remaining with which to form a baseline comparison. The use of ecosystem models does allow us to predict unexploited biomass levels for critical species, but accurate predictions depend on the quality of the models, and the models can only be vetted against time-series catch and abundance data. Unfortunately, quantitative data is limited in RA, and much of the knowledge we have about ecosystem changes comes in the form of local ecological knowledge (LEK) from scientists and inhabitants.

Currently, the main marine commodities in the RA archipelago include skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*) and Spanish mackerel (*Scomberomorus commerson*), but significant artisanal fisheries also exist for reef-associated fish and invertebrates. Indonesia is known to have suffered a rapid depletion in recent decades of near-shore fish stocks and coral reef animals, especially sharks, tunas and reef-associated fish (Tomascik *et al.*, 1997). The pressures on the reef systems in Eastern Indonesia can only be expected to increase as the human population grows. Overfishing has reduced the average life span of some marine species (Myers and Worm, 2003). Consequently, marine ecosystems may be increasingly unstable and responsive to environmental fluctuations (Hughes *et al.*, 2005). The effect is likely to be pronounced in coral reef environments, where large and influential predators and herbivores are targeted (Hughes *et al.*, 2003). Increased system volatility could potentially be a long-lasting effect if the constant antagonism of fisheries asserts an evolutionary pressure towards early maturation and high turnover rates in exploited species.

Challenges to management of coral reefs now centre on the serious issues of overexploitation (Pandolfi *et al.*, 2003), land-based pollution (McCullock *et al.*, 2003), disease outbreaks (Kaczmarsky *et al.*, 2005) and outbreaks of coralivores such as the crown of thorns starfish (*Acanthaster planci*) - a source of mass mortality in corals (Chesher, 1969). Loss of coral cover from these stressors has far reaching impacts throughout the food web, and may result in a long-term loss of fish biodiversity (Wilson *et al.*, 2006).

Project Synthesis

The BHS EBM project contains 17 major scientific components. The wide diversity of information resulting from these projects can readily be incorporated into various aspects of Ecopath, Ecosim and Ecospace; and novel methodologies are under development that will allow us to use, for the first time in the EwE, the sort of highly resolved biogeographic information emerging from BHS EBM studies. Generally, data collected for the RA region will help to make the EwE models, presented here in a preliminary and generic form, more relevant to the local context. The resulting suite of EBM tools should be able to test specific ecological and socioeconomic hypotheses relevant to the management of coral reef ecosystems in RA. Importantly, the unique opportunity provided by this project, to collate and integrate data resulting from multidisciplinary studies, will strengthen our understanding of coral reef ecology, improve EBM tools, and increase scientific dividends resulting from the BHS EBM project.

TNC reef health monitoring ongoing at Kofiau, Boo and Misool Islands among other sites (see Mous and Muljadi, 2005) is intended to provide coral cover and biomass data for important species of herbivorous fish and large piscivorous fish. Results from this analysis were not available in time for this report; the final reef monitoring report for Kofiau Island is expected in December 2006 (P. Mous. TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia, pers. comm.). The biomass estimates we are currently using for herbivorous fish and large piscivorous fish species are based on reef transect data from sites near Weigeo Island (COREMAP, 2005). Unless the updated biomass information is very different from current estimates, integrating this new data should be straight forward, and should not require extensive reworking of the models. It will, however, allow us to produce more accurate site-specific versions of the model representing the various field sites. Depending on the precision and extent of the data, it may also help up in developing scenarios for the novel EwE sub-routine now under development, Ecolocator (contact: C. Ainsworth, UBC Fisheries Centre. 2202 Main Mall, Vancouver BC. Canada. Email: c.ainsworth@fisheries.ubc.ca).

The CI seascape connectivity analysis may provide us with an independent check of Ecospace dispersal parameters and advection patterns. In EwE, dispersion represents the tendency of populations to shift or expand their occupied range. It is not necessarily related to swimming ability or speed of movement, but more closely reflects the fidelity of individuals to their natal habitats, or the ability of planktonic propagules to travel and settle new areas. Populations that display genetic homogeneity across the study area may therefore be assumed to have higher rates of dispersion, while heterogeneous populations may reveal the action of isolating biogeographic effects. At the time of this report, connectivity data is forthcoming.

Interviews conducted in the Seascape reproduction study, which identifies and monitors spawning aggregation sites (SPAGS), may provide critical habitat data for Ecospace that will allow us to accurately represent source-sink dynamics of major commercial fish populations. This information may influence our expectations of the ecological and economic merit of spatial management schemes (Sanchirico *et al.*, 2006). Adding to this output, oceanographic data resulting from the SPAG vial release program may help us to track advection currents and predict areas of larval settlement. This may prove to be an important factor, both in determining sustainable exploitation levels, and in the siting of marine protected areas, as mortality during settlement may be a bottleneck for some reef fish species (Doherty *et al.*, 2005; Hughes *et al.*, 2005). At the time of this report, the SPAGS studies had failed to confirm the existence of any large spawning aggregations sites on Kofiau Island; but further studies are planned for SE Misool.

The WWF Seascape migration and dispersal analysis for turtles is expected to provide habitat and movement information for Ecospace (contact: L. Pet-Soede. Jl. Raya Puputan No. 488, Renon Denpasar, Bali, Indonesia). The TNC fish stomach content analysis study will provide valuable diet information directly usable by Ecopath, and should supplement (or render obsolete) the current diet allocation used to parameterize the EwE food web (contact: P. Mous, TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia). The CI socioeconomic study will provide cost and price information essential to the socioeconomic optimization facilities in Ecosim (contact: A. Dohar, CI. Jl.Gunung Arfak.45.Sorong, Papua, Indonesia). The historical ecology study can provide us with more accurate model baselines with which to parameterize fisheries indicators in Ecosim (contact: S. Heymans, UBC Fisheries Centre. 2002 Main Mall, Vancouver, Canada). The TNC marine resource utilization survey has generated aerial photographs of RA, providing useful habitat data and allowing us to estimate fishing effort distribution; this will be useful for validating Ecospace (contact: P. Mous, TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia). Analyses using MARXAN to assess the conservation potential of protected areas will guide the Ecospace research and provide candidate closure scenarios for socioeconomic evaluation (contact: M. Barmawi, TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia). Results from the historical ecology study and aerial photography are currently being assessed for integration into the models; results from other project components are forthcoming.

First field trip

The UBC synthesis model Post-Doctoral Fellow, Cameron Ainsworth, traveled to Papua and Bali in Feb. 20 – Apr. 19, 2006. The purpose of the trip was to meet key personnel involved with the BHS EBM project, collect data from Indonesian repositories, gather preliminary information and literature which had been assembled by project partners, and collect early data resulting from the project. The first week was spent in Bali liaising with researchers from TNC, CI and WWF. Meetings were held with senior project staff from the partner organizations in which we planned the strategic direction of the spatial modelling effort and discussed ways to incorporate project information into the models. We agreed on the general outputs that are expected from the modelling, and determined what outputs might assist the regional management of RA marine fisheries. Contributing to those meetings were Peter Mous (TNC), Lida Pet-Soede (WWF), Jos Pet, Muhammad Barmawi and Abdul Halim (TNC). Cameron Ainsworthwas briefed on the state of major research projects, and collected preliminary GIS data that had been collated, and interview materials from the perception monitoring study.

Traveling to Sorong, Papua provided the opportunity to discuss specific model requirements with experts knowledgeable in the ecology and fisheries of RA. Functional group structure and fleet design were discussed at length. By representing the most critical functional elements in the ecosystem, we hoped to provide a suitable basis for the models that was capable of capturing important processes. The basic structure of the model was designed so that it could provide outputs that would be relevant to the management process and hold resonance with managers, policy makers and the public.

The extensive field experience of TNC and CI scientists, divers and research staff was invaluable to model design. Particularly, their knowledge of coral reef animals and their habits, biogeographic and oceanographic features laid the foundation for the Ecopath and Ecospace models especially. Although many researchers contributed to the early design of the models, Peter Mous, Andreas Muljadi and Obed Lense provided particularly valuable assistance in designing the functional group structure and fisheries. We also acknowledge the contributions of Chris Rotinsulu, Reinhard Poat, Anton Suebu, Adityo Setiawan and other researchers in TNC and CI Sorong offices. Throughout this report, specific contributions are acknowledged as personal communications.

In Sorong we visited the offices of the Sorong Regency Fisheries Office (Departemen Kelautan dan Perikanan, DKP), the Raja Ampat Regency Fisheries Office, the Trade and Industry Office (Departemen Perinustrian dan Perdagangan) and the Agricultural Quarantine Office (Badan Karantina Pertanian). Cameron Ainsworthalso had the opportunity to talk with student researchers from the State University of Papua (UNIPA), who were in the process of collecting information for the socioeconomic evaluation study (CI).

A week spent in Deer Village on Kofiau Island allowed familiarization with the artisanal fishing methods, to witness fishing operations and to interact with residents. Penny Goodwyn, a student researcher from the University of Canberra provided valuable translation assistance. Opportunity to snorkel and SCUBA dive was provided, and we also released spawning aggregation (SPAG) tracking vials at a suspected grouper aggregation site (Gebe Island) to study local currents and larval settlement patterns. Some data were collected from the marine use monitoring study.

Returning to Bali, researchers from UBC, TNC, CI, and WWF participated in a modelling coordination workshop, April 10-14 in Sanur. The model format was presented for review: structure, data sources and preliminary parameters were vetted. The local knowledge and scientific experience of Mark Erdmann helped set the direction of the UBC modelling study. Presentations by the UBC modelling study and socioeconomic study, as well as TNC, CI and WWF staff helped to coordinate team members.

Ecopath parameterization

Raja Ampat model

The Raja Ampat model describes the region from 129o 12' E and 0o 12' N to 131o 30' E and 2o 42' S (Fig. 1.1). This large-scale model includes all the waters of Raja Ampat. The functional groups represent reef-associated fish identified by McKenna *et al.*, (2002b), as well as pelagic and deepwater fish occurring in Eastern Indonesia. In order to be included in the model, a fish species had to be listed both under the 'Indonesia' country code in FishBase (FishBase country code 360) and the 'Papua New Guinea' code (FishBase country code 598). That information is found on the "DemersPelag" (habitat) field of the "Species" table in the FishBase database.

Kofiau model

The Kofiau Island Ecospace model extends from 129o 14' E and 1o 5' S in the north-west corner to 130o 1' E and 1o 20' S in the south east corner (Fig. 1.2). Kofiau was selected as a study area for a small-scale model based on a number of advantages. Firstly, it is the most well developed TNC RA field site in the BHS EBM project. The permanent field office in Deer Village is staffed throughout the year, and there are many marine experts on site and in Sorong that have extensive knowledge of its ecology and biogeography. Secondly, the process of data gathering is furthest along at this location. At the time of this report, reef fish abundance counts have been made in transect studies; however, the data is not yet available. Community interviews for the resource use assessment are underway, the SPAG vial release program has so far only been conducted at Kofiau, and MPA site selection using MARXAN is also furthest advanced for this area (P. Mous, TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia). Thirdly, this site provides an excellent example of the valuable reef habitat that is associated with RA, and is responsible for the biodiversity and beauty of the coral triangle. For example, Wambong Bay on Kofiau Island has the highest number of fish species ever recorded from a single site (208) (Allen, 2000).

The small-scale model representing Kofiau Island is primarily a coral and reef-fish model that has been expanded to include important pelagic elements. Reef fish species in the Kofiau Island model are based on the 940 species identified by McKenna *et al.*, (2002b) to species level. The species list for the Kofiau model was expanded to include key pelagic species occurring around Kofiau Island such as tunas (Scombridae), sardines and herrings (Clupeidae), wolf-herring (Chirocentridae), anchovies (Engraulidae), flying fish (Exocoetidae) based on expert communications (Andreas Muljadi, Obed Lense, Reinhart Poat, Adityo Setiawan. TNC-CTC. Jl

Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413; Chris Rotinsulu. CI. Jl Arfak No. 45. Sorong, Papua, Indonesia 98413, pers. comm.).

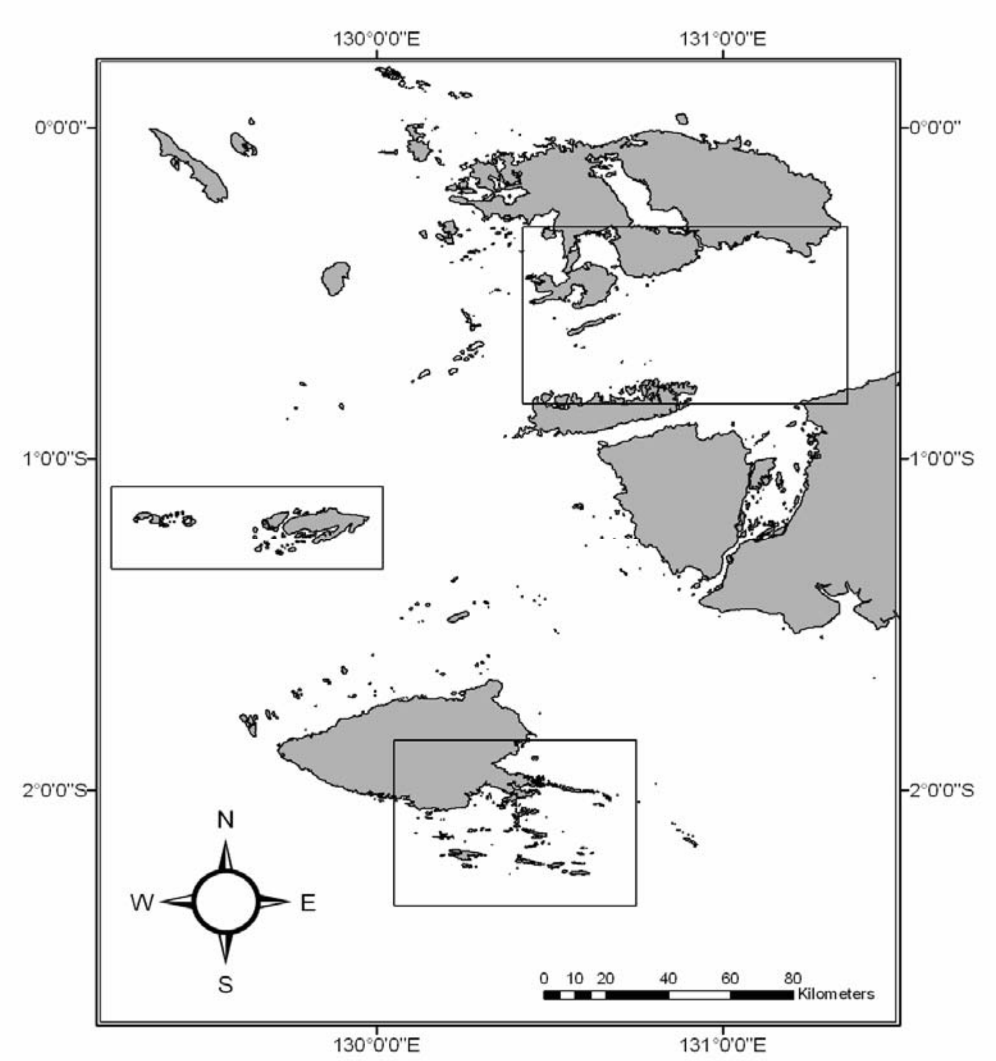


Figure 1.1 - Area represented by Raja Ampat (RA) model. RA model is delimited at 1290 12' E and 00 12' N at the northwest corner and 1310 30' E and 20 42' S at the southeast corner. From north to south, inset rectangles show areas described by Dampier Strait, Kofiau Island and SE Misool Island models.

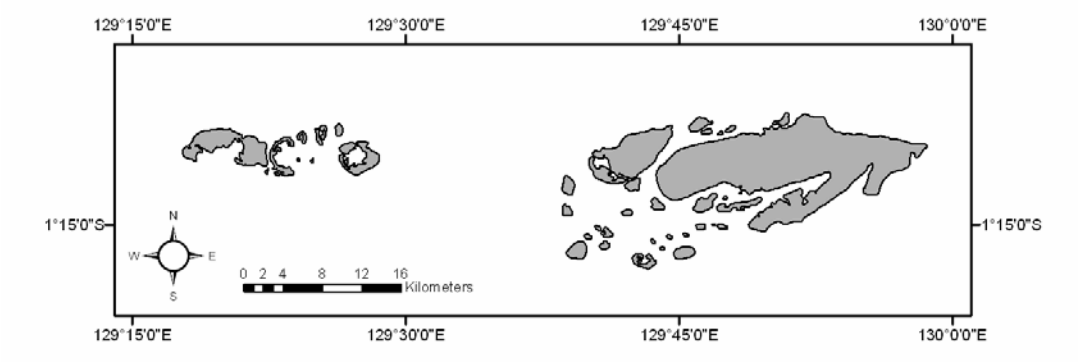


Figure 1.2 - Area described by Kofiau Island model. Kofiau Island model is delimited at 1290 14' E and 10 5' S at the northwest corner and 1300 1' E and 10 20' S at the southeast corner.

The pelagic species list also includes species mentioned in Venema (1997). Individual parameters were set for each of the 940 reef fish species in the model. Fish families were then divided into functional groups. The fishing fleet in the model represents near shore and artisanal gear types; the foreign fishing fleet, which operates in RA, is excluded.

Dampier Strait model

The Dampier Strait model extends from 130o 25' 12'' E and 0o 18' S at the northwest corner to 131o 21' 36'' E and 0o 50' S at the southeast corner. The model includes Waisai Bay in the northwest and incorporates a large extent of the southern coast of Weigeo Island, including Gam Island and Kabui Bay (Fig. 1.3). Mayalibit Bay, a shallow enclosed body of turbid water occupying a south-central position of Weigeo Island, was excluded from the model as it likely ecologically distinct from the deeper and faster flowing Dampier Strait (Mark Erdmann. CI. Jl. Dr. Muwardi. 17 Renon Denpasar, Bali, Indonesia, pers. comm.). The modelled area is bounded by the convoluted shore of Batanta Island in the south. Dampier Strait is an important and productive area in Raja Ampat that sustains a major artisanal fishery for anchovy due to a region of strong upwelling.

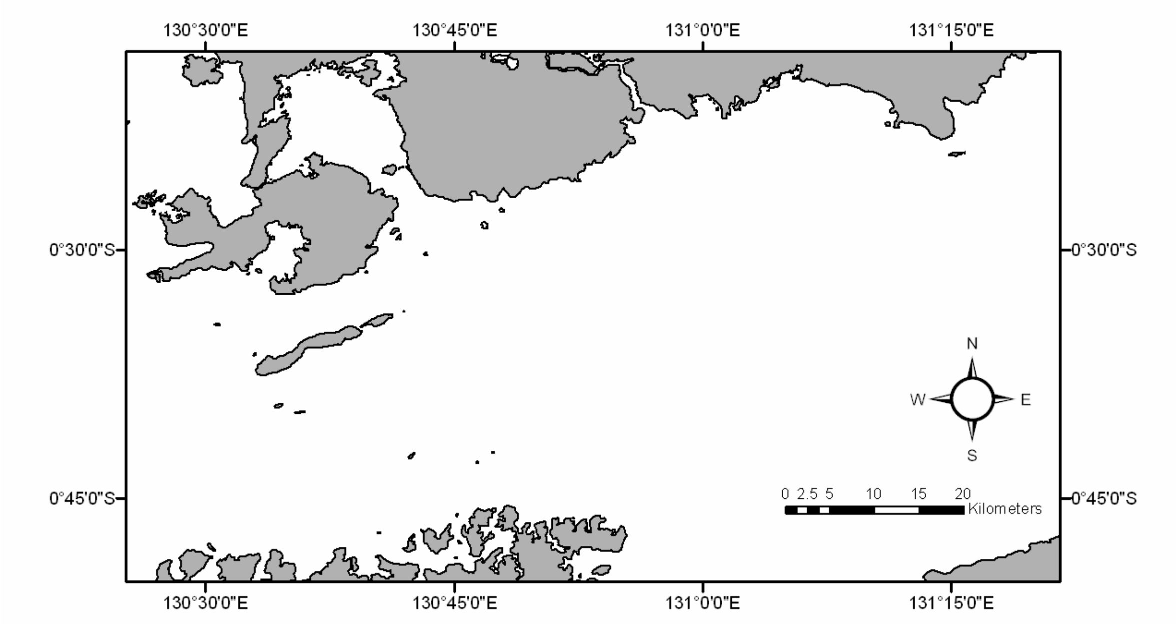


Figure 1.3 - Area described by Dampier Strait model. Dampier Strait model is delimited at 130o 25' 12'' E and 0o 18' S at the northwest corner and 131o 21' 36'' E and 0o 50' S at the southeast corner.

METHODS

Ecopath (Mass Balance)

Ecopath (Polovina, 1984; Christensen and Pauly, 1992) operates under two main assumptions. The first assumption is that biological production within a functional group equals the sum of mortality caused by fisheries and predators, net migration, biomass accumulation and other unexplained mortality. Eq. 1.1 expresses this relationship:

$$B_i \cdot (P/B)_i = Y_i + \sum_{j=1}^{n} B_j \cdot (Q/B)_j \cdot DC_{ij} + E_i + BA_i + B_i (P/B)_i \cdot (1 - EE_i) \qquad (1.1)$$

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); and
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;

The second assumption is that consumption within a group equals the sum of production, respiration and unassimilated food, as in eq. 1.2.

$$B \cdot (Q/B) = B \cdot (P/B) + (1 - GS) \cdot Q - (1 - TM) \cdot P + B(Q/B) \cdot GS \tag{1.2}$$

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. Intermediate values represent facultative consumers.

Ecopath uses a set of algorithms (Mackay, 1981) to simultaneously solve n linear equations of the form in eq. 1.1, where n is the number of functional groups. Under the assumption of mass-balance, Ecopath can estimate missing parameters. This allows modelers to select their inputs. Ecopath uses the constraint of mass-balance to infer qualities of uncertain ecosystem components based on our knowledge of well-understood groups. It places piecemeal information on a framework that allows us to analyze the compatibility of data, and it offers heuristic value by providing scientists a forum to summarize what is known about the ecosystem and to identify gaps in knowledge.

Ecosim (dynamic simulations)

Ecosim (Walters *et al.*, 1997) adds temporal dynamics. It accounts for the biomass flux between groups using coupled differential equations derived from the first Ecopath master equation (eq. 1.1). The set of differential equations is solved using the Adams-Bashford integration method by default. Biomass dynamics are described by eq. 1.3.

$$\frac{dB_i}{dt} = g \sum_{j=1}^{n} f(B_j, B_i) - \sum_{j=1}^{n} f(B_j, B_i) + I_i - (M_i + F_i + e_i) \cdot B_i \tag{1.3}$$

where dB_i/dt represents biomass growth rate of group (*i*) during the interval d_t;
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). It is modified by the predator-prey vulnerability parameter assigned to the interaction.

Variable speed splitting enables Ecosim to simulate the trophic dynamics of both slow and fast growing groups (e.g., whales/plankton), while multi-stanza pools (Christensen and Walters, 2004a) allow us to represent life histories and model ontogenetic dynamics. The multi-stanza routine back-calculates juvenile cohort abundance based on the adult pool biomass and on life stage mortality rates, employing a Deriso-Schnute delay difference model. For a complete description of the multi-stanza routine see Walters *et al.* (2000).

Predator-prey vulnerabilities

The principle innovation in Ecosim considers risk-dependant growth by attributing a specific vulnerability term for each predator-prey interaction. The vulnerability parameter is directly related to the carrying capacity of the system. Each predator-prey trophic interaction is assigned a vulnerability coefficient, from one to infinity. The figure is unitless and it describes the maximum increase in predation mortality allowable on that feeding interaction. By assigning a low value, we imply a donor driven density-dependant interaction. In foraging arena theory (Walters and Juanes, 1993; Walters and Korman, 1999; Walters and Martell 2004), the prey can remain hidden or otherwise inaccessible during periods of high predator abundance. Predators are never satiated and handling time or physiological constraints do not limit predation mortality (Essington *et al.*, 2000). By assigning a high value, we imply a predator driven density-independent interaction, in which predation mortality is proportional to the product of prey and predator abundance (i.e., Lotka-Volterra). This implies a high flux rate for prey species in and out of vulnerable biomass pools.

Strict bottom-up control in Ecosim may produce unrealistically smooth changes in prey and predator biomass that fail to propagate through the food web (Christensen *et al.*, 2004), and can impart an unrealistic degree of resilience to the effects of fishing (Martell *et al.* 2002). Strict top-down control may cause rapid oscillations in biomass and unpredictable simulation behaviour (Christensen *et al.*, 2004; Mackinson, 2002) and will often produce a complex response surface that is difficult to work with under policy optimizations (Cheung *et al.*, 2002; Ainsworth, 2006). In the absence of better information, many modelers assume mid-range vulnerabilities to temper the dynamics (Okey and Wright, 2004).

The preferable parameterization method is to fit the model's dynamic behaviour to time series of catch or biomass by altering the vulnerabilities manually, or with the assistance of automated routines in Ecosim (Christensen *et al.*, 2004). Data fitting is done here using the available time series that we collated from governmental fisheries statistics. Future revisions to this model will incorporate time series abundance information recently collected in community interviews (contact: C. Rotinsulu. CI. Jl Arfak No. 45. Sorong, Papua, Indonesia 98413), and catch and effort data collected by the CI socioeconomic analysis (contact: A. Dohar, CI. Jl. Gunung Arfak.45.Sorong, Papua, Indonesia).

Mediation factors

Ecosim offers the capability to represent non-trophic effects that have a strong influence on food web dynamics. Using mediation functions, the vulnerability of a given prey to a given predator can be affected according to the biomass density of a third mediating group. This can be used to capture important behavioral aspects of populations and more accurately simulate ecosystem functioning.

The most common types of mediation models applied in Ecosim include facilitation and protection. An example of facilitation is seen when pelagic piscivores like tuna drive small pelagics to surface waters, increasing their vulnerability to avian predators (e.g., Dill *et al.*, 2003). This is known as 'competitor facilitation' because birds compete with tuna for a common prey type. Similarly, small pelagics may be corralled into tight aggregations as an anti-predator defense in response to fish or marine mammal predation. This may increase their vulnerability to other types of predators that attack dense prey schools, such as diving birds. Dayton (1973) provides a different example of competition facilitation in which urchins, taking insecure footholds to avoid predation by sea stars, are dislodged through wave action and made available to anemone predators. Strand (1988) provides another example concerning inter-specific foraging associations; where nuclear-follower behaviour improves hunting success in certain reef species. Protection effects occur when structure-forming species, such as reef-building corals, provide shelter for reef dwelling fish or invertebrates. Elimination of the biotic structure by grazing corallivorous fish or crown of thorns starfish for example may regulate the survival of fish and invertebrate species taking refuge within the reefs.

Four mediation functions have been entered into the BHS-EBM models. The first function describes a major facilitation effect, in which tunas (both 'skipjack tuna' and the 'other tuna' group) corral small pelagics and anchovy near to the surface, and make them more vulnerable to predation by birds. The mediation function is entered so that the vulnerability of the prey groups increases in linear proportion to the biomass of tuna, up to a maximum increase of 2X the baseline vulnerability. The mediating groups, skipjack tuna and other tuna, contribute equally to this effect. Prey groups subject to this mediation effect are adult and juvenile anchovy, and adult and juvenile small pelagics.

The second mediation function represents a major protection effect, in which hermatypic (reef-building) scleractinian corals confer protection against predators to the following groups: small and medium reef-associated fish, sub-adult groupers, sub-adult snappers, juvenile and sub-adult Napoleon wrasse, juvenile coral trout and octopus. The function is modeled so that the vulnerability of the prey species changes in inverse linear proportion to coral biomass. All the predators of these prey species are affected equally. The vulnerabilities of these small reef fish are free to increase to a maximum of 2X the baseline value (during periods of low coral biomass) and can decrease to near 1 (during periods of high coral biomass).

The third mediation function represents a minor protection effect, in which cleaner wrasse improves the health of large reef-associated fish. This effect is applied to the adult stanzas for groupers, snappers, large reef-associated fish, coral trout and Napoleon wrasse. The effect is modelled so that vulnerability of the large reef fish to their predators changes in inverse linear proportion to cleaner wrasse biomass. All the predators of these large reef fish species are affected equally by this mediation effect. Vulnerabilities may increase to a maximum of 1.5 times the baseline value (during periods of low cleaner wrasse biomass), and they may decrease to a minimum of 0.5 times the baseline value (during periods of high cleaner wrasse biomass). By using the mediation functions, we are making the assumption that cleaner wrasse improve the health of large reef fish populations, and that this allows them to avoid predation.

The fourth mediation function represents a minor protection effect, in which mangroves and sea grasses provide protection to juvenile groupers and snappers. The effect is weighted so that the vulnerabilities of these juvenile reef fish species increases to all their predators as the biomass of mangroves and sea grasses goes down; i.e., in inverse linear proportion. The vulnerabilities are allowed to increase to 1.5X the baseline value, or decrease to 0.5X the baseline value. The mediating groups, mangroves and sea grasses, do not affect the predator-prey interactions equally; mangroves have a stronger affect than sea grasses on the order of 3:1.

We have chosen to use simple linear effects for all of the mediation functions pending review by experts. However, it may be difficult to differentiate the relative effects of behavioural interactions with those of trophic cascades (Carpenter and Kitchell, 1993; Walters *et al.*, 1997). Even if animal behaviour and ecology is well understood, it may be difficult to prescribe mediation functions based on empirical data, as there are currently significant limitations in the mediation routine.

The increase in vulnerabilities is currently restricted to maximum of 2X the baseline value, regardless of the biomass of the mediating group(s). This limitation was less of a concern when the routine was originally integrated into Ecosim, but since the release of Ecopath V5.1 the definition of the vulnerability parameter has changed. It is now set for each predator-prey interaction from 1 to infinity (Christensen and Walters, 2004a). When vulnerabilities are low, as in donor-driven interactions, a relative increase of 2X has a much larger affect than when vulnerabilities are high. If the same mediation effect is applied to numerous trophic interactions, it may be difficult to forecast the relative impact on each group.

A second limitation in the routine is that each predator-prey interaction can be governed by only one mediation function. Therefore, we are currently forced to choose only the most influential mediating effect for any given predator-prey interaction. We cannot, for example, model the protection that coral reefs impart on a reef fish population, while simultaneously representing the advantage conferred on them by cleaner wrasse. In the present models, cleaner wrasse are assumed to be more important to the adult reef fish stanzas, while reef protection is assumed to be more important to sub-adult or juvenile stanzas. This limitation will be resolved with the upcoming release of EwE V6.0 in September 2007.

Ecospace (dynamic spatial simulations)

Ecospace (Walters *et al.* 1998) models the feeding interactions of functional groups in a spatially explicit way. A simple grid represents the study area, and it is divided into a number of habitat types. Each functional group is allocated to its appropriate habitat(s), where it must find enough food to eat, grow and reproduce - while providing energy to its predators and to fisheries. Each cell hosts its own Ecosim simulation and cells are linked through symmetrical biomass flux in four directions; the rate of transfer is affected by habitat quality. Optimal and sub-optimal habitat can be distinguished using various parameters such as the availability of food, vulnerability to predation and immigration/emigration rate. By delimiting an area as a protected zone, and by defining which gear types are allowed to fish there and when, we can explore the effects of marine protected areas (MPAs) and test hypotheses regarding ecological function and the effect of fisheries. Previous authors have used Ecospace in this capacity (e.g., Walters *et al.*, 1998; Beattie, 2001; Pitcher and Buchary, 2002a/b; Buchary *et al.*, 2002; Pitcher *et al.*, 2001; Salomon *et al.*, 2002; Sayer *et al.*, 2005).

Ecopath parameterization

Functional group designations

Ninety-eight functional groups are used to represent the marine ecosystem of Raja Ampat. These include mammals, birds, reptiles, fish, invertebrates, plants, zooplankton, phytoplankton, and non-living groups such as fishery discards and organic detritus (Table A.3.1). The models have been designed to serve at various spatial scales. Ideally, smaller area models, such as the one representing Kofiau Island, would have a group structure especially suited to represent coral reef organisms and their interactions, while the larger area RA model should consider pelagic and deep-water species in more detail. However, to keep the various models comparable, identical group structures are used. A compromise solution is therefore used that tends to emphasize reef communities, while providing the basic level of functionality necessary to assist management of pelagic and deep-water resources. .

High-order food web dynamics are carefully represented in the BHS EBM models in order to provide reliable forecasts concerning the impacts of fisheries on coral reefs. Important predatory, herbivorous and commercial fish tend to be allotted into highly specialized functional groups, while basal organisms are generally aggregated. At 98 functional groups, these are complex models, but we believe that this approach is necessary in order to provide sufficient resolution to capture important processes occurring on coral reefs.

Fish groups

Because of the enormous amount of differentiation in life-history, morphology and feeding guilds that appears within coral reef fish families, delineating functional groups by fish family or clade is impractical and may be unwise. Through evolutionary convergence, similar niche specializations can be present in unrelated taxa; or, a single fish family may include multiple functional niches. The specific group structure in a EwE model is largely subjective and should be tailored to satisfy specific requirements of the investigation. Therefore, most of the functional groups developed for the preliminary Raja Ampat ecosystem models are based on the functional role that the fishes play in the ecosystem, with additional groups configured to allow the representation of important commercial, social and ecological interests. The important specializations were determined based on the ecological literature available for coral reef ecosystems (e.g. Bellwood *et al.*, 2004) and through expert communication.

There are 1203 fish species represented in the RA model. The common and scientific name of each species is presented in Table A.1.1 along with their assigned functional group. The fish species are apportioned into 57 functional groups; of which 30 represent unique species or species groups. The remaining functional groups correspond to various juvenile, sub-adult and adult life history stages included in the model to represent ontogenetic feeding, mortality and behaviour.

Fish functional groups may be designed to represent specific functional roles (e.g., grooming by cleaner wrasse, algae mediation by herbivorous echinoids), to represent species of commercial interest (e.g., skipjack tuna, groupers) or to cover the wide diversity of fishes in aggregated species groups (e.g., large reef-associated fish). Fish have been allocated into functional groups based also on body size (e.g., small, medium and large groups), feeding guild (e.g., planktivorous and piscivorous) and habitat (e.g., pelagic, demersal, reef-associated). The rationale behind functional group designation is provided in Table A.3.1.

Reef fish

Reef fish functional groups were established based on Bellwood *et al.* (2004) and Ayre and Hughes (2004), and modified based on expert opinion (T. Pitcher, UBC Fisheries Centre. 2204 Main Mall. Vancouver, BC; P. Mous, TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia; A. Muljadi, Reinhart Poat, Obed Lense TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413). The groups were revised again following the TNC, CI, WWF, UBC Modelling coordination workshop (Sanur, Bali, Indonesia April 10-14). McKenna *et al.* (2002b) identified 940 species of coral reef fish present in Raja Ampat. Although all of these species are associated with reefs to some degree, the species were subdivided into pelagic and demersal based on the comment field in the FishBase Ecology table.

Where a single fish species could suitably fit into several aggregate functional groups, it was usually assigned to the most taxonomically specific group. For example, kawakawa tuna (Euthynnus affinis) are large and piscivorous, and so could fit into the piscivorous 'large pelagic' functional group. Instead, kawakawa is slotted into the more exclusive 'other tuna' functional group. Similarly, the group 'large planktivorous fish' includes planktivorous species that are both reef-associated and pelagic, but these were kept apart from those larger aggregate groups to highlight their uncommon feeding mode.

Planktivorous fish

Obligate and facultative planktivorous species are included in the planktivorous functional groups. Where quantitative diet information is unavailable from the FishBase Diet table, assigning fish to planktivorous functional groups may require a judgment call based on qualitative information as contained in the FishBase Species, Fooditems and Ecology tables. For a species to be included into a planktivorous functional group a prominent mention of planktivory is required in diet remarks on the Species table. A comment such as 'eats mainly zooplankton' is assumed to indicate planktivory. The Ecology table provides a simple diet classification in its 'Mainfood' and 'Feeding type' fields. Positive indicators for planktivory include the entry 'zooplankton' in the 'Mainfood' field, and 'selective plankton feeding' or 'filtering plankton' in the 'Feeding type' field. The Fooditems table lists prey items in order of importance, and a prominent mention of a planktivorous prey item is said to qualify the species for a planktivorous EwE group. In addition, species may be designated as planktivorous without specific mention of planktivory if their specified prey items are among the more common planktivorous taxa (e.g., copepods, euphausiids, ostracods) and if their diet does not contain a large portion of non-planktonic components.

Subdividing habitat type and feeding guilds by fish size

Fish size was based on maximum length, converted to TL (see Section 2.5.1 - Length-length conversions) since an L_{max} could be found for 96.3% of species (FishBase; Allen, 2000). The size distributions of 'pelagic fish', 'reef-associated/demersal fish' and 'planktivorous fish' are presented in Fig. 2.1. The functional groups 'pelagic fish' and 'reef-associated/demersal fish' consist of 133 and 674 species respectively. The pelagic habitats categorized by FishBase include 'pelagic' and 'benthopelagic' zones, while the demersal habitat includes the 'demersal' zone. Fish occurring in the 'bathypelagic' or 'bathydemersal' zones (i.e., occurring at depths > 200m) are considered to be deep-water species.

These groups, aggregated by habitat type, were further divided into either 2 or 3 size categories (e.g., small, medium and large). The size category for each species was determined by comparing their length against the length of other species occurring in their habitat. Fish species that are present in the 'planktivorous' functional groups, for example, were divided into small, medium or large size categories based on a comparison against other reef-associated fish (in the case of reef-associated planktivores) or pelagic fish (in the case of pelagic planktivores).

They were not compared strictly to other planktivores, but to all sympatric species. This method was preferred in order to maximize the number of species serving as a comparison. There are eleven sharks in the Raja Ampat model; these are divided based on L_{max} into 'small sharks' (five species < 200 cm) and 'large sharks' (six species > 200 cm).

Bioeroders

Bioerosion is the process whereby certain species of fish, invertebrates, plants, fungi and bacteria cause mechanical and/or chemical erosion of calcareous skeletons of corals and other reef organisms through feeding and burrowing behaviour. It is known to be a major structuring force in coral reef ecosystems (Hutchings, 2002). Bioeroders can be classified into browers, who scrape or rasp the reef substrate feeding on epilithic algae or invertebrates, and grazers who consume much more reef material in search of endolithic prey (Holt, 2003). Bioeroders can have a positive impact on the reef community by oxygenating the reef substrate and removing dead coral to facilitate settlement and growth of new individuals, but they can also initiate a cascading destruction of the reef if chronic degradation weakens resistance to biological invasion or wave action.

In the BHS EBM models, bioeroding fish are classified into three functional groups based on Bellwood *et al.* (2004). Causing the least damage to reefs are the herbivorous 'macro-algal browers', selected so based on diet information and qualitative remarks in FishBase. More damaging are the 'scraping grazers', including members of Scaridae (parrotfish), Acanthuridae (surgeonfish), Monacanthidae (filefish), and Tetraodontidae (puffers). The functional group 'eroding grazers' is reserved for the two most damaging species of parrotfish, which use their specialized beak-like jaws and pharyngeal mill to process coral substrate: doubleheaded parrotfish (*Scarus microhinos*) and green humphead parrotfish (*Bolbometopon muricatum*). These species are thought to have a serious impact on reefs in RA (Adityo Setiawan. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, pers. comm.; Bellwood *et al.*, 2004).

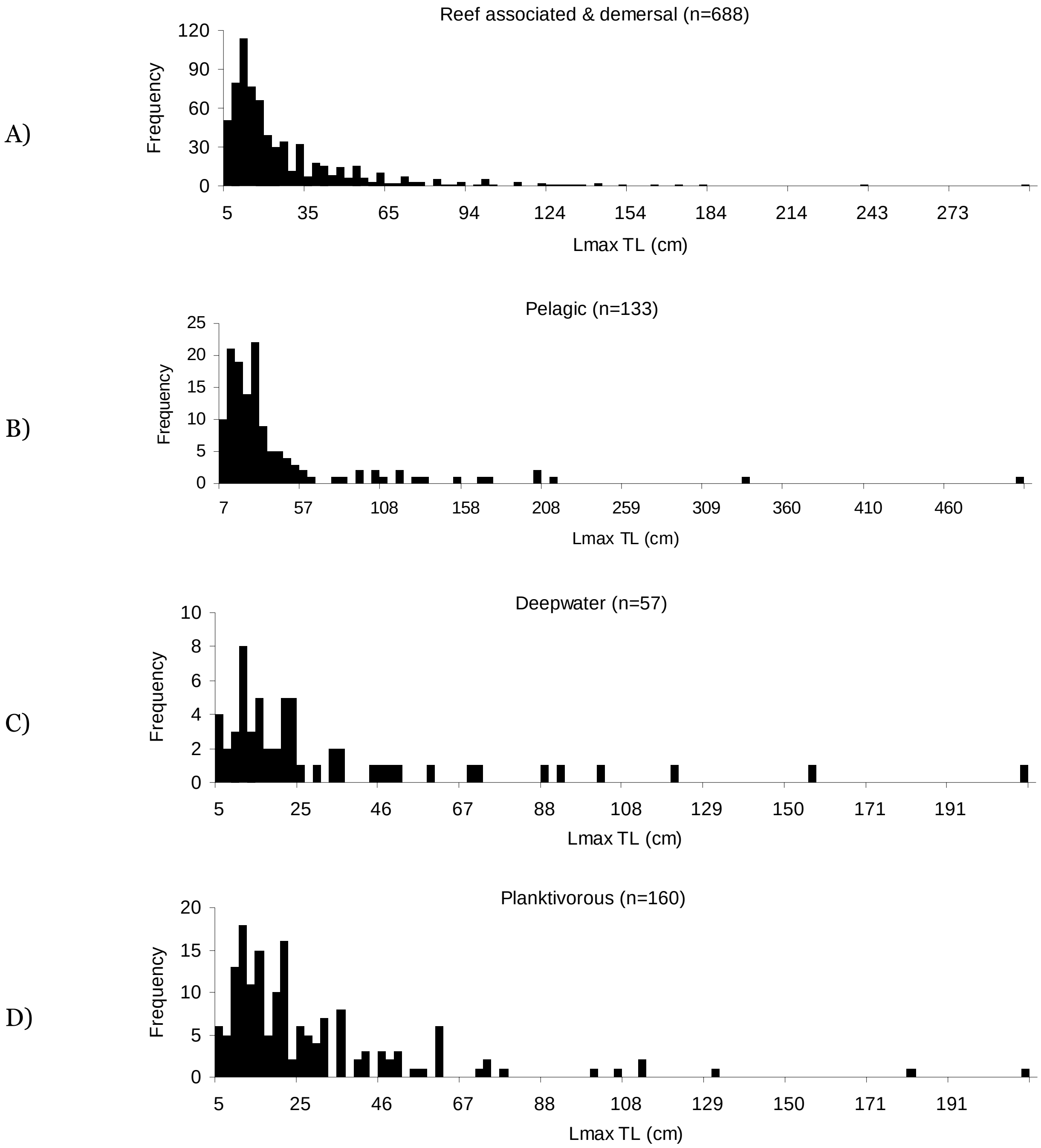


Figure 2.1 - Fish maximum length (L_{max}) distribution. Histograms based on total body length (TL). A-C) based on habitat type; D) based on feeding guild. Species are mutually inclusive.

The crown-of-thorns starfish (*Acanthaster planci*) was given its own functional group to describe the serious impact that these animals can have on reefs. As a dominant corallivore, periodic outbreaks of the sea star can have long-lasting impacts on the health of the coral reef community. Such outbreaks may be a direct or indirect consequence of human activities (Endean, 1969; Randall, 1972) but empirical evidence is scarce (Pratchett, 2005). Removal of large fish species (e.g., Lethrinidae, Napoleon wrasse *Cheilinus undulatus*) may also reduce the natural predation mortality on *A. planci* populations permitting outbreaks, although Sweatman (1995) could not confirm it empirically.

The activity of bioeroding species is captured through the diet matrix. They consume coral groups, including hermatypic scleractinian corals, non-reef building corals and soft corals, as well as calcareous algae. By used of mediation functions in Ecosim (see Section on Mediation factors) a realistic impact of bioeroders can be modelled, where removal of the substrate impacts the survival of juvenile fish by limiting their refuges and increasing predation mortality

Basic parameterization

The data needs of Ecopath can be summarized as follows. Four data points are required for each functional group: biomass (in $t \cdot km^{-2}$), the ratio of production over biomass (P/B; in $year^{-1}$), the ratio of consumption over biomass (Q/B; in $year^{-1}$), and ecotrophic efficiency (EE; unitless). Ecopath also provides an input field representing the ratio of production over consumption (P/Q; unitless), which users may alternatively use to infer either P/B or Q/B based on the other. Each functional group requires 3 out of 4 of these input parameters and the remaining parameter is estimated using the mass-balance relationship in eq. 1.1. A biomass accumulation rate may be entered optionally; the default setting assumes a zero-rate instantaneous biomass change. These Ecopath data points are referred to collectively in this report as the basic parameters. For a more thorough description of Ecopath data needs and parameter definitions please refer to Christensen *et al.*, (2004).

This section 'Basic parameterization' describes the general methodology used to assign fish functional groups their basic parameters using FishBase information. Section 'Functional group parameterization' addresses each group specifically, reporting where literature values and other special data sources were used to set the basic parameters. Most often, Q/B was set using the empirical formulae of Pauly (1986); a few species were set using Palomares and Pauly (1998) using tail aspect ratio as modified by Christensen *et al.* (2004). P/B was determined based on the sum of the natural mortality rate (M), estimated using the empirical formula of Pauly (1980), and some fishing mortality rate (F), which is an assumed fraction of M. As a guideline, heavily exploited species were assumed to have an F approximately equal to M, while moderately exploited species were assumed to have an F equal to M/2 or less.

Growth parameters

All growth parameters utilized from the FishBase PopGrowth table, including asymptotic length (L_∞), asymptotic weight (W_∞) and the von Bertalanffy growth constant (K) were selected among values in the temperature range 28 ± 2°C. An average value was taken for each species for values within this temperature range. When no growth parameters were available from within this range, an average value of all available parameters, regardless of the temperature, was used for the species. Some growth data is duplicated in other FishBase tables, for example W_∞ occurs in the PopGrowth table and the QB table. The growth constant K can occur in the FishBase PopGrowth table or the QB table. In all cases, growth data was taken from the PopGrowth table preferentially, then the 'QB' table, then the 'Species' table, as illustrated in Figs. 2.2 - 2.4.

Estimating asymptotic weight (W_∞)

The W_∞ parameter is utilized by the Q/B regression formula presented below (eq. 2.7), and it is also required by the multi-stanza routine. W_∞ is the asymptotic fish body weight in grams. Fig.

2.2 illustrates the method used to establish W_∞ for fish species. W_∞ is taken directly from FishBase, if it is available in the 'aveWinf' field of the PopGrowth table or the 'Winf' field of the QB table. Where no value is available from FishBase, the parameter is calculated from the length-weight (L/W) relationship (eq. 2.1), utilizing a and b growth parameters found respectively in the 'a' and 'b' fields of the FishBase PopGrowth table, and L_∞. L_∞ is taken preferentially from the 'aveLinf (TL)' field of the PopGrowth table.

$$W = a \cdot L^{b} \qquad (2.1)$$

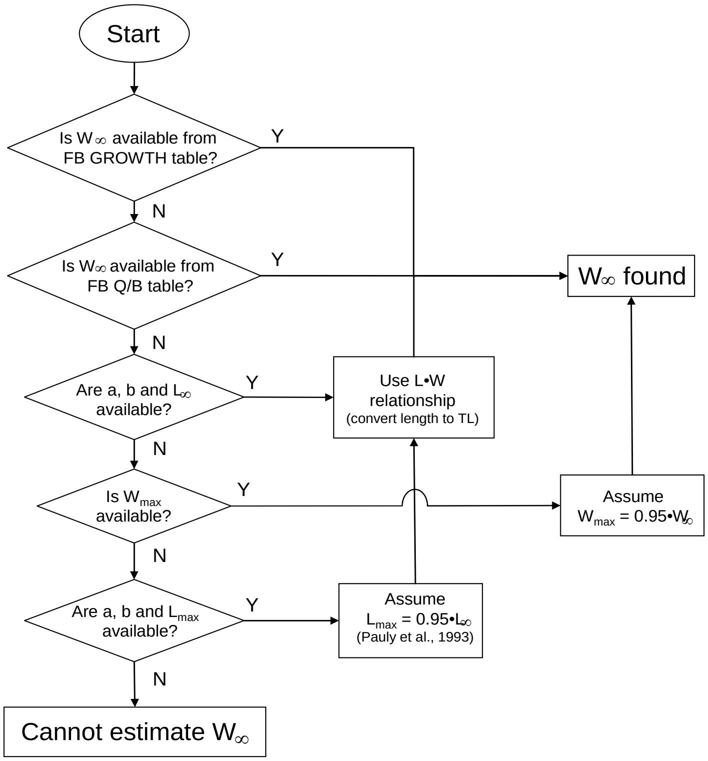
If any of these L/W parameters are unavailable, then W_∞ is instead estimated from the maximum weight (W_{max}), which occurs in the 'Max weight' field of the FishBase Species table, according to the assumption shown in eq. 2.2[§].

$$W_{max} = W_\infty \cdot 0.95 \qquad (2.2)$$

If W_{max} is unavailable, then L_∞ is estimated from L_{max}, which can be found in the FishBase PopGrowth table, according to eq. 2.3 as found in Pauly *et al.*, (1993), and the L·W relationship (eq. 2.1) is subsequently used to establish W_∞. A decision flow tree is presented in Appendix A.1 summarizing the data source used to calculate W_∞.

$$L_{max} = L_\infty \cdot 0.95 \qquad (2.3)$$

To maximize the number of species contributing data towards parameter values for aggregate functional groups, average family values for L·W parameters were calculated for some functional groups if there were example values for at least five species per family.



[§] If we assume eq. 2.3 is correct, then a more precise estimate is given by $W_{max}=W_\infty*0.86$

Figure 2.2 - Flow chart showing W_∞ parameterization method. All growth parameters are taken from areas occupying the temperature range 28 ± 2°C; where values were unavailable from within this temperature range, an average value was used for all available parameters regardless of temperature.

Length-length conversions

The empirical formula of Pauly (1980) for estimating M and the formula of Pauly (1986) for estimating Q/B both require L_∞ as measured in total length (TL). Entries for L_∞ in FishBase (in both Species and PopGrowth tables) are usually provided in TL. Where length measurement are given in other formats by the original data sources (e.g. in fork length (FL) or standard length (SL)), FishBase usually provides conversions to TL in the 'TLinfinity' field; no conversions are provided for maximum lengths found in the 'Species' table. When required, conversions were performed manually.

To convert FL to TL, the linear empirical relationships of Booth and Isted (1997) were used. For fish with forked tails, the relationship employed is based on panga (*Pterogymnus laniarus*), as in eq. 2.4:

$$FL = 0.901 \cdot TL - 0.6848 \tag{2.4}$$

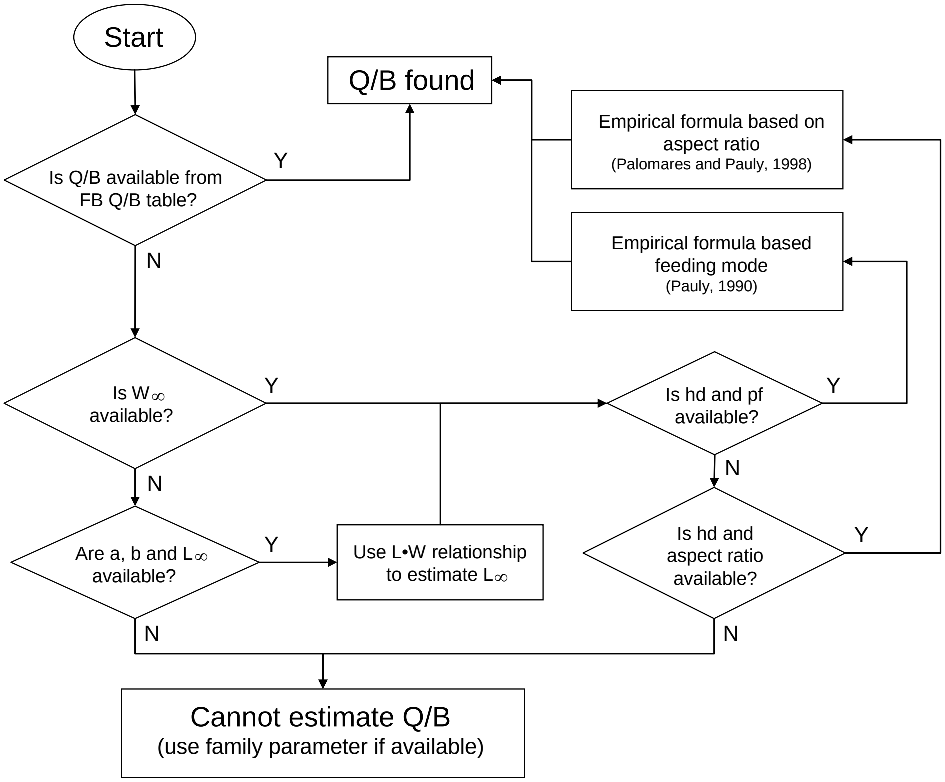


Figure 2.3 - Flow chart showing Q/B parameterization method. Feeding mode (pf) and diet composition (hd) parameters for empirical formulae were obtained from FishBase Ecology table (Herbivory and FeedingType fields, respectively), or set according to qualitative description of feeding habits in FishBase Species table.

For fish with emarginated tails, the relationship is based on the lesser gurnard (*Chelidonichthys quekerri*) as in eq. 2.5:

$$FL = 0.9454 \cdot TL + 3.6166 \tag{2.5}$$

All pelagic, benthopelagic and bathypelagic fish were assumed to have forked tails, while all reef fish, demersal and bathydemersal fish were assumed to have emarginated tails. Each FishBase species is demarked into one of these six habitat classifications according to habitat data indicated in the Habitat field of the FishBase Species table.

Where SL was provided, the conversion factor to TL was applied from Christensen and Pauly (1992) as in eq. 2.6.

$$TL = 1.1757 \cdot SL - 0.1215 \tag{2.6}$$

Estimating consumption rate (Q/B)

Q/B was taken preferentially from the literature or as estimated in FishBase. Estimates of Q/Bs from FishBase sources were accepted if the data is based on a study of similar temperature to Raja Ampat (28°C ± 2°C). For each fish species, the Q/B value was taken directly from FishBase, if available from the 'PopQB' field of the 'QB' table. Otherwise, an empirical relationship was used to estimate Q/B for each species. The empirical formula of Pauly (1986) based on feeding mode was preferred (eq. 2.7), using W_∞ as determined above.

$$Q/B = 10^{6.37} \cdot 0.0313^{(1000/T)} \cdot W\infty^{-0.168} \cdot 1.38^{Pf} \cdot 1.89^{Hd} \tag{2.7}$$

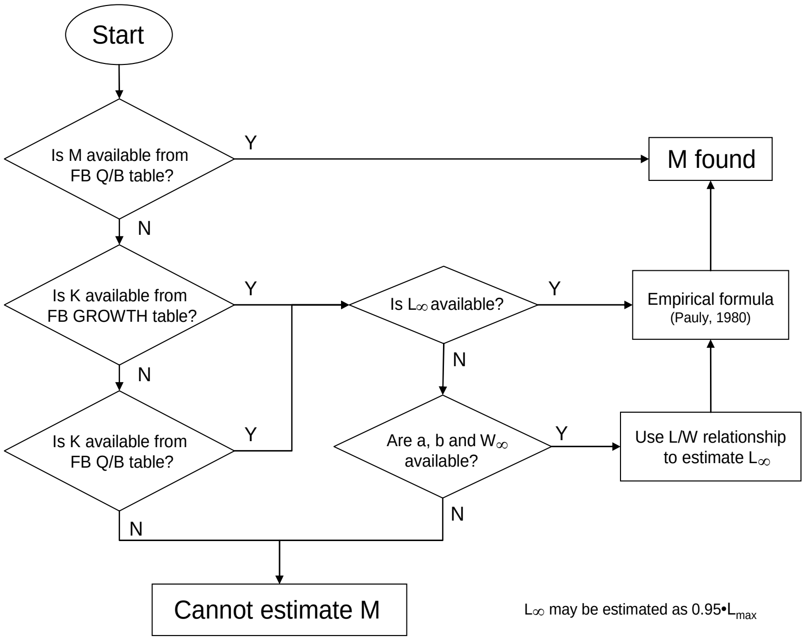


Figure 2.4 - Flow chart showing M parameterization method.

The mean annual temperature (T) is expressed as 1000 / (T°C + 273.1) where T°C is temperature in degrees Celsius (assumed 28°C). The feeding mode parameter (Pf) is set equal to 1 for predators and zooplankton feeders, and zero for other fish species as per Pauly (1986). The diet composition parameter (Hd) is set to 1 for herbivores, and 0 for omnivores and carnivores. Parameters Pf and Hd were set for each species based on qualitative feeding remarks located in MainFood, Herbivory2 and FeedingType fields of the FishBase Ecology table, and in the general comment field of the Species table.

If W_∞ could not be determined, then the empirical formula of Palomares and Pauly (1998) was used instead to estimate Q/B based on caudal fin aspect ratio (eq. 2.8). Here, aspect ratio (A) is defined as (tail height/area)^2; it is available from the AspectRatio field of the FishBase Swimming table. Parameters h and the d refer to the types of food consumed (i.e., for herbivores h=1, d=0; for carnivores h=0, d=0; for detritivores d=1, h=0 as defined by Palomares (1991) and reported by Palomares and Pauly (1998)). These binary values were set for each species based on diet information provided in the FishBase diet table or on comment fields (e.g., in the Species table).

$$Q/B = 7.964 \cdot 0.204 \log W\infty + 1.965\, T + 0.083A + 0.532h + 0.398d \qquad (2.8)$$

The decision tree in Fig. 2.3 demonstrates the parameterization method for the consumption rate (Q/B) of fish species. Q/B was set individually for all species and then averaged to obtain functional group parameters reported in Table A.3.2.

Estimating natural mortality (M) for fish

Natural mortality (M) is used to represent the P/B rate for species that are unexploited; for species with an annual catch, P/B is estimated as the sum of M and fishing mortality (F). Fig. 2.4 shows the decision tree used to parameterize M for fish species. Where available, the M value was taken directly from literature sources or from data tables in FishBase. Where an estimate could not be found, the regression equation of Pauly (1980) was used to determine M (eq. 2.9), which requires growth information: the von Bertalanffy growth constant (K) and the asymptotic length (L_∞). These values were obtained for most species from FishBase PopGrowth table. When L_∞ was unavailable, the maximum specimen length observed L_{max} was substituted, assuming that $L_\infty = 0.95 \cdot L_{max}$.

$$M = K^{0.65} \cdot L_\infty^{-0.279} \cdot T^{0.463} \qquad (2.9)$$

Daily ration

Marine mammals

The empirical equation for daily ration of marine mammals, modified from Innes *et al.* (1987) in Trites and Heise (1996), is used for estimating the consumption per unit of biomass (Q/B) as in eq. 2.10.

$$R = 0.1 \cdot W^{0.8} \qquad (2.10)$$

W is body weight in kg and R is the daily ration in kg·day^{-1}.

Birds

The empirical equation for daily ration for birds given by Nilsson and Nilsson (1976) in Wada (1996), is used for estimating the consumption per unit of biomass (Q/B) as in eq. 2.11,

$$\log R = -0.293 + 0.85 \cdot \log W \qquad (2.11)$$

W is the body weight in grams and R the ration in grams per day.

Ingestion rate in deposit feeders

An empirical model for the ingestion rate of aquatic deposit feeders and detritivores was used in the calculation of Q/B for sea cucumbers, as in eq. 2.12.

$$C = -0.381 \cdot W^{0.742} \qquad (2.12)$$

Consumption (C) is in mg·day^{-1} and dry weight (W) is in mg.

Estimating P/B of invertebrates

The P/B ratio for benthic invertebrate functional groups was obtained by an empirical model established by Brey (1995); it is presented in eq. 2.13.

$$\log P/B = 1.672 + 0.993 \cdot \log(1/A_{max}) - 0.0335 \cdot \log(M_{max}) - 300.447 \cdot - 1/(T+273) \qquad (2.13)$$

A_{max} is the maximum age in years, M_{max} is the maximum individual body mass in grams dry mass (g_{DM}) and T is the bottom water temperature in degrees Celsius.

Group maturity parameters

The multi-stanza routine in Ecopath (Christensen *et al.*, 2004) requires the following growth and maturity information: the von Bertalanffy growth constant K, recruitment power, relative biomass accumulation rate, the weight at maturity (W_{mat}) the asymptotic weight (W_∞) and the age at maturity. W_∞ was compiled at the species level for each fish functional group according to the methodology described in the above section. K was taken as a direct average of FishBase entries in the PopGrowth table. To calculate W_{mat} from FishBase length at maturity (L_{mat}) data, a length-weight relationship was employed as in eq. 2.1. For all multi-stanza groups, the adult stage is considered to be reproductive, and so the W_{mat} represents the average body weight at the transition (i.e., knife edge entry to the reproductive cohort is assumed).

For species that had multiple data values, the maturation parameters are taken as an average, regardless of geographic origin of the data points. Where a range of values is provided from a single publication, an average value was accepted. Maturity data is utilized for 148 reef-associated species and 122 pelagic/deepwater species.

Biomass density estimates

Biomass density estimates are based directly on COREMAP (2005) reef transect data for 26 reef-associated fish functional groups out of 48 in the models. Biomass estimates could be made for 17 additional reef-associated fish groups based on the subjective abundance rankings provided by McKenna *et al.* (2002b) (e.g., “common”, “rare”). Biomass weighting factors were assigned to each abundance ranking offered by McKenna *et al.* (2002b). The weighting factors were determined by comparing McKenna *et al.*’s (2002b) abundance rankings against biomass densities of known species estimated from COREMAP (2005). The biomasses of unknown species are extrapolated based on the weighting factors.

COREMAP abundance counts are based on reef resource inventory and line intercept transects (see Appendices 3 and 6 in COREMAP, 2005). The abundance data is converted into biomass by multiplying fish numbers by an average species weight. The average weight is calculated at the species level using an age-structured model. The model uses a Ricker recruitment relationship and von Bertalanffy growth function, and employs species-specific A and B length-weight parameters from FishBase, asymptotic length (L_∞) and growth constant (K). We assume a simple mortality schedule for each species based on whether the groups are heavily exploited, lightly exploited or unexploited. Species-level biomass estimates were compiled into the current functional groups (Table A.3.1), to provide biomass estimates for the groups. The biomass density estimates determined from COREMAP (2005) transects represents fish biomass on reef areas. Therefore, to calculate an average biomass density for the whole of RA, including offshore and deeper areas, the COREMAP (2005) biomass density was reduced to 1.75 % of the original reef area value. This ratio represents the reef area to marine area ratio for all of Indonesia used by Spalding *et al.* (2001).

Diet algorithm

Quantitative diet information was obtained from the FishBase Diet table for 255 out of 1196 species in the Raja Ampat model. 26% of the reef fish and demersal fish species had available diet information, while 17% of the pelagic and deep water fish species had data. Of the 30 fish groups present in the model, 23 had data on at least one representative species. The availability of diet information is summarized in Table 2.1.

Table 2.1 - Diet algorithm supporting parameters. Habitats assigned to EwE fish functional groups for prey item allocation algorithm. FishBase (FishBase); Raja Ampat (RA).

Fish functional group	Number of species in RA model	Species with FishBase diet data	Speices with diet data (%)	Habitat	Feeding mode
Groupers	46	8	17	reef-associated	swallows
Snappers	32	16	50	reef-associated	swallows
Napoleon wrasse	1	0	0	reef-associated	swallows
Skipjack tuna	1	1	100	pelagic	swallows
Other tuna	10	9	90	pelagic	swallows
Mackerel	9	3	33	pelagic	swallows
Billfish	5	2	40	pelagic	swallows
Coral trout	6	0	0	reef-associated	swallows
Large sharks	6	6	100	pelagic	bites
Small sharks	5	3	60	pelagic	bites
Whale shark	1	1	100	pelagic	swallows
Manta ray	1	1	100	reef-associated	bites
Rays	8	2	25	reef-associated	bites
Butterflyfish	57	29	51	reef-associated	swallows
Cleaner wrasse	3	3	100	reef-associated	swallows
Large pelagic	26	8	31	pelagic	swallows
Medium pelagic	9	1	11	pelagic	swallows
Small pelagic	75	0	0	pelagic	swallows
Large reef associated	212	80	38	reef-associated	swallows
Medium reef assoc.	175	38	22	reef-associated	swallows
Small reef associated	206	17	8	reef-associated	swallows
Large demersal	10	2	20	reef-associated	swallows
Small demersal	11	0	0	reef-associated	swallows
Large planktivore	52	15	29	either	swallows
Small planktivore	62	13	21	either	swallows
Anchovy	17	1	6	either	swallows
Deepwater fish	58	4	7	either	swallows
Macro-algal browsing	3	0	0	reef-associated	swallows
Eroding grazers	1	0	0	reef-associated	swallows
Scraping grazers	82	24	29	reef-associated	swallows
Detritivorous fish	7	0	0	reef-associated	swallows

Categories of prey items listed in the FishBase Diet table are imprecise (e.g., 'bony fish', 'benthic invertebrates') and there are formatting and spelling variations. The FishBase data has therefore been standardized. FishBase prey items are sorted into their corresponding EwE functional groups, either in equal proportions for non-fish prey items, or in specific proportions for fish prey items calculated using a diet allocation algorithm. The algorithm determines likely prey species for each predator based on habitat co-occupation and gape size/body depth limitations, determines the fractional contribution of each prey species according to a size-based vulnerability function, and aggregates the values to produce a predator-prey diet matrix at the functional group level suitable for EwE.

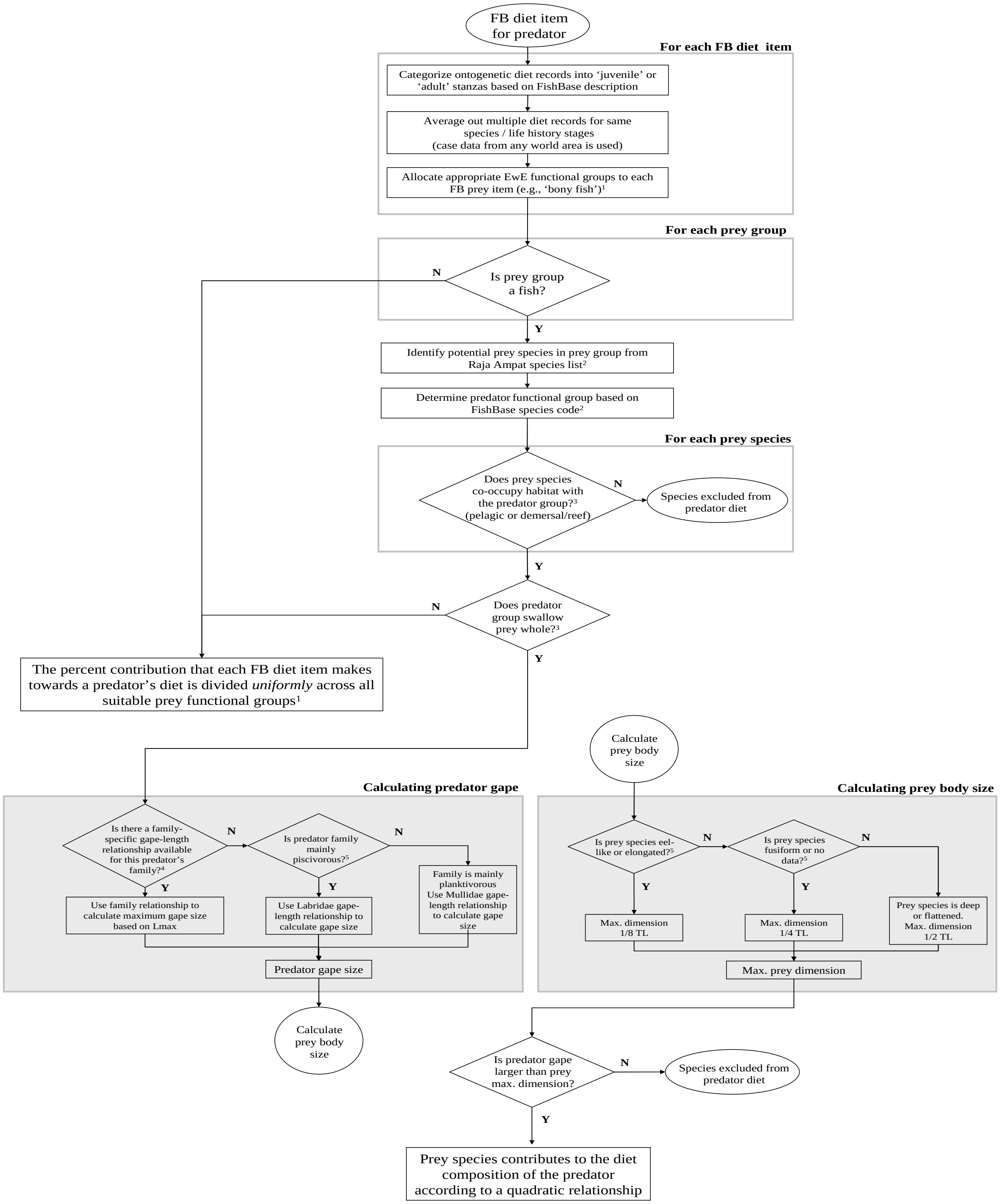


Figure 2.5 - Flow chart showing diet allocation algorithm. 1.) Table 2.2. 2.) Table A.1.1. 3.) Table 2.1. 4.) Karpouzi and Stergiou (2003). 5.) Table A.2.1.

The algorithm used to allocate prey fish species to predators is presented in Fig. 2.5. For each predator, the algorithm assigns appropriate functional groups to each prey item category as listed in FishBase; the group assignments are presented in Table 2.2. Ontogenetic FishBase diet records for predator fish are characterized into either adult or juvenile entries based on the data field 'SampleStage' in the FishBase Diet table. The FishBase entries 'larvae' and 'recruits/juv.' are assumed to refer to juvenile fish, while the entries 'juv/adults' and 'adults' are assumed to refer to adult fish. These data categories are used to parameterize adult and juvenile stanzas respectively for corresponding EwE predator fish functional groups. In some cases, adult and juvenile diet records were combined to provide an overall diet composition for certain Ecopath functional groups that are not differentiated into life history stages.

Table 2.2 - Fishbase prey items assigned to EwE functional groups. Relevant EwE functional groups are assigned to each prey item listed for Raja Ampat fish species in the FishBase Diet table. Groups 1-98 refer to Ecopath functional groups listed in Table A.3.1; Groups 99, 100 and 101 are diet import, juvenile fish and unidentified items respectively. Juvenile fish items were distributed evenly across juvenile prey fish groups, unidentified items were omitted from predator diets.

FB prey item	Relevant EwE groups
bony fish	10,11,12,13,14,15,16,17,18,19,20,21,22,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66
squids/cuttlefish	75
n.a./other benth. crustaceans	74,78,79,80,82,86,87,88
n.a./other mollusks	75,76,82,84,86,87,88
benthic algae/weeds	94,95
n.a./other plank. Crustaceans	74,90,91,92
mysids	91,92
stomatopods	90
n.a./other plank. crustaceans	74,90,91,92
bivalves	84
crabs	79,80
isopods	86,87,88
shrimps/prawns	74
n.a./other plank. Invertebrates	74,75,89,90,91,92
n.a./other plank. invertebrates	74,75,89,90,91,93
plank. copepods	90,92
n.a./other annelids	86,87,88
ascidians	85
euphausiids	90
gastropods	82,86,87,88
amphipods	86,87,88,90,91,92
benth. copepods	87,88
jellyfish/hydroids	89
sea birds	5
n.a./other mammals	1,2,3
octopi	76
sea stars/britte stars	87
n.a./other cephalopods	75,76
carcasses	97,98
n.a./other phytoplankton	93
insects	99
toads/frogs	99
fish eggs/larvae	100
n.a./others	101
n.a./other finfish	10,11,12,13,14,15,16,17,18,19,20,21,22,25,26,27,28,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66
n.a./other benth. Invertebrates	72,74,76,77,78,79,80,81,82,83,84,85,86,87,88
polychaetes	87,88
ostracods	86,87,90,91,92
n.a./other reptiles	6,7,8,9,99
diatoms	93
n.a./other benth. invertebrates	72,74
n.a./other echinoderms	74,76,77,78,79,80,81,82,83,84,85,86,87,88
chitons	87
non-annelids	86,87,88
n.a./other benth. Crustaceans	74,78,79,80,82,86,87,88
lobsters	78
sea urchins	83
sea stars/brittle stars	87
debris	97,98
cladocerans	91,92
sea cucumbers	83
hard corals	67,68,69
n.a./other polyps	67,68,69,70
sponges	85
dinoflagellates	90,92
blue-green algae	93

The diet allocation algorithm first eliminates potential prey species from the predator's diet if they do not occur in the same habitat as the predator. Predator habitat was determined at the functional group level as listed in Table 2.1. Predator habitat classification is divided into two categories, reef-associated/demersal and pelagic; it is based on the 'habitat' field of the FishBase Species table. Species categorized in FishBase as pelagic, benthopelagic or bathypelagic are assumed to occupy a 'pelagic' habitat, while reef-associated and demersal fish are assumed to occupy a 'reef-associated/demersal' habitat. Prey habitat types are similarly simplified from FishBase habitat entries, but at the level of species.

A minimum and maximize prey size is then determined for each predator based on mouth gape size. These may be important parameters governing population dynamics (Claessen *et al.*, 2002). In aquatic systems, the lower limit to the consumption relationship may be set by the encounter rate, the predator's ability to visually locate prey (Lundvall *et al.*, 1999) or to retain the prey after capture (Persson, 1987). The maximum limit may be determined by mouth gape size (Hoyle and Keast, 1988; Scharf *et al.*, 2000), or by changes in capture and handling efficiency (Christensen, 1996), changes in prey fish behaviour, prey visibility/camouflage (Lundvall *et al.*, 1999), nutritional content, toxicity and other factors. Both the minimum and maximum prey sizes may also be constrained by the precepts of optimal foraging (Emlen 1966; Schoener 1971). However, within this 'predation window', prey species are vulnerable.

Simple rules were used here to establish the predation window and the consumption rate of fish predators on fish prey. Predator functional groups that swallow their prey whole are assumed to be constrained through gape size limitations with respect to the size of prey they can consume. All of the predator fish functional groups are assumed to swallow prey whole except for the functional groups 'large sharks', 'small sharks', 'Manta ray' and 'rays' and their corresponding juvenile groups (Table 2.1). These groups feed by biting or tearing pieces off their prey, and so are assumed able to feed on larger fish than a gape-restricted species of similar size.

To determine the maximum gape size of swallowing predator species, family-specific gape-body length relationships were utilized from Karpouzi and Stergiou (2003) for Synodontidae, Scorpaenidae, Serranidae, Carangidae, Mullidae, Labridae and Scaridae. Calculating the gape size requires an estimate of body length standardized into TL (see Section 2.5.1 - Length-length conversions). For other predator families, the maximum gape size was determined by assuming a similar gape-body length ratio as Labridae, in the case of mainly piscivorous predator families, or Mullidae, in the case of mainly planktivorous predator families (see Table A.2.1). Each predator family was designated as being mainly piscivorous or planktivorous based on the predominant feeding mode seen in member species. The proportion of species within each family exhibiting piscivory is reported in Table A.2.1; this figure applies specifically to species present in RA. Member species are considered to be planktivorous under the same criteria used for assigning fish into planktivorous EwE functional groups (see Section 2.4.2 - Planktivorous fish). Briefly, the main food items must be planktonic as reported either quantitatively in the FishBase Diet table, or qualitatively as reported in the Ecology, Fooditems or Species tables.

The smallest body dimension of the prey species, i.e., the dimension limiting consumption by a potential predator, is determined in a separate calculation. The body morphology is assessed for each fish family based on representative members that have morphological information in FishBase. For 'eel-like' or 'elongated' fish familes, the smallest body dimension is assumed to be 12.5% of the maximum body length (L_{max} in TL, taken at the species level). For 'fusiform' fish or fish with no data, the smallest body dimension is assumed to be equal to 25% of L_{max}. For 'deep bodied' or 'flattened' fish, the smalled body dimension is assumed to equal 50% of L_{max}. Fish family body morphologies used by the algorithm are reported in Table A.2.1.

We assume that the predator-prey consumption rate follows a domed relationship that is dependant on the relative sizes of the species. The quadratic model used to predict the consumption is initialized so that the consumption rate is zero at the minimum and maximum prey sizes available to the predator, and it is highest in the mid-range. Eq. 2.14 shows the dome shaped quadratic function passing through (0,0) and (0,1).

$$Q_{ij} = -4 \cdot x^2 + 4x \qquad (2.14)$$

Q equals the relative consumption of predator (*j*) on prey (*i*), and x equals the smallest body dimension of prey species (*i*), divided by the gape size of predator (*j*).

A dome-shaped vulnerability function may be an appropriate model to describe prey mortality as a function of predator length (Lundvall *et al.*, 1999; Claessen *et al.*, 2002). Nevertheless, the relationship can be confused by the presence of refugia (Lundvall *et al.*, 1999), which may be an important factor on coral reefs with high substrate complexity. The lower limit to the predation window may have an especially influential impact on population dynamics through the effects of cannibalism (Claessen *et al.*, 2002; Persson *et al.*, 2000).

An alternative to the quadratic consumption rate equation may be to use a right-skewed relationship such as a beta distribution, so that a wide range of smaller prey sizes are accessible, but predation mortality falls quickly as prey size approaches the predator gape-size limit. This may be appropriate if the minimum prey size consumed by the predator does not tend to increase as fast as the maximum gape size, (e.g., Scharf *et al.*, 2000). Another prospective improvement to the algorithm may be to implement a monotonically increasing consumption rate function for smaller predators, or to employ a dynamic predation mortality function, whose peak shifts right with larger prey sizes (Lundvall *et al.*, 1999).

The diet algorithm in place also assumes that the availability of prey species is affected by prey abundance. 'Abundant' prey species identified by McKenna *et al.* (2002b) are assumed to incur 130% of the baseline predation mortality rate; 'common' prey incur 120%, 'moderately common' prey incur 110% mortality, 'occasional' prey suffer 90% mortality and 'rare' prey suffer 80% mortality. All other species are assumed to incur baseline predation rates (100%) and the prey-consumption ratios are normalized for each predator group so that the fractional sum of prey species equals 1. The consumption rate of a given predator on a given prey is therefore affected by both the relative sizes of the species, and the relative abundance of the prey species.

Another key assumption required by this algorithm is worth discussing. The assumption made is that, for both predator and prey, L_{max} can serve as an adequate proxy for L_{ave}, the average fish length in the population. However, if predator populations have been reduced significantly from unexploited levels, or if their age structure is shifted towards smaller fish by the influence of fisheries or other factors, then the algorithm will overestimate the range of prey sizes available to the predator. Conversely, if the prey population is reduced in size or average length, then the range of prey sizes available to predators will be underestimated.

If predator and prey populations are reduced in size or skewed from their unexploited age-structure by a proportionately equal amount, then the L_{max}: L_{ave} proxy may hold true. However, the further depressed the populations are, the more inaccurately will the algorithm predict the likely size range of prey consumed, since gape size and prey body length change non-linearly with length. Additional sampling work could help describe the current population age structure for critical species and address this potential source of error.

The output of the diet allocation algorithm has been modified during the process of balancing and tuning the model to time series data. The diet matrix used in the 2000 RA model is presented in Table A.3.6.

Fisheries

Gear types

The preliminary gear types included in the RA model were selected based on discussions with local fisheries experts and on Indonesian fishery records and publications (Departemen Pertanian. Jakarta; Subani and Barus, 1989; Andreas Muljadi, Obed Lense, Reinhart Poat, Arif Pratomo. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, pers. comm.). For the RA model, the gear structure is shown in Table 2.3.

The gear types include spear fishing, reef gleening, shore gillnets, driftnets, permanent and portable traps, spear diving (for fish and invertebrates), diving specifically for live fish, diving with use of cyanide and surface-supplied air, blast fishing using dynamite, trolling, purse seining, pole and line, set lines, lift nets, the foreign fleet and shrimp trawl. Three diving gear types are used to represent distinct fishing methods, markets, and commodity prices received for product. Blast fishing using explosives is known to occur throughout the archipelago, although BHS-EMB aerial surveys have not detected any (M. Barmawi; unpublished manuscript. TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia). The foreign fleet consists mainly of powered Philippino tuna vessels operating in deeper areas in the north of RA (A. Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, pers. comm.). The shrimp trawl fishery is located amost exclusively in the Arafura Sea, and only a small fraction of that area is considered by the RA models.

Catch time series

Fishery statistics were collected from several agency offices in Sorong: the Sorong Regency Fisheries Office (Departemen Kelautan dan Perikanan, DKP), the Raja Ampat Regency Fisheries Office and the Trade and Industry Office (Departemen Perinustrian dan Perdagangan). The data were collated into catch and effort time series, and converted into standard units for use in Ecosim. Catch and effort data from 1990 to 1999 are contained in the Sorong Regency Fisheries Office statistics as well as commodity prices; catch and effort data from 2000 to 2004 are contained in the Trade and Industry Office statistics. The Raja Ampat Regency Fisheries Office had additional fisheries export data for 2005. Export data was also acquired from the Sorong Quarantine Service for 2002 and 2004-2006. However, the data were not used because we could not reconcile those export figures with other information from the principal data agencies mentioned above. Information from the Quarantine Service is largely concerned with the activities of specific fishing companies, and so there may be potential for further socioeconomic analysis if the ambiguity can be resolved.

For the purposes of this preliminary report, the data series assembled from DKP and the Trade and Industry Office statistics seem to form a continuous and coherent time series of catch and effort. Trade and Industry Office data was received in hard copy, as was 2005 data from the RA Regency statistics office (DKP). Data from the Sorong Regency office (DKP) was received in electronic format as was data from the Quarantine office (Pos Karantina Ikan Sorong). For some species catch data was taken directly from other literature sources (e.g, Venema *et al.*, 1997). The collated time series catch data is presented in time series in Figs. A.3.1 and A.3.2.

Interpreting catch statistics

Assumptions must be made in order to translate imprecise and incomplete fishery statistics into useable series for the EwE models. In some cases, data from Indonesian governmental sources may contain statistical inaccuracies (Dudley and Harris, 1987) due to the complexity of catch reporting in tropical reef-based fisheries, and common resource limitations in the fisheries bureau. These problems can mean that we have to use some guesswork in some estimates of catch for Raja Ampat

Table 2.3 - Fishing gear types included in the Raja Ampat model. Source: (Andrease Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, pers. comm.). 1) Reef fish catch includes mainly fusiliers, rabbitfish, parrotfish and jacks; 2) Small pelagic catch includes mainly anchovy and sardine; 3) Hard shell invertebrate catch includes mainly shellfish and snails.

Gear type	**Indonesian name**	**Skipjack tuna**	**Other tuna**	**Groupers**	**Snappers**	**Napoleon wrasse**	**Reef fish 1**	**Mackerel**	**Demersals**	**Sharks**	**Small pelagics 2**	**Squid**	**Cucumbers**	**Octopus**	**Hard shell inverts. 3**
Spear fishing / harpoon	Aco / panah			▨	▨		▨		▨				▨	▨	
Reef gleaning	Balobe / Meting												▨	▨	▨
Shore gillnet	Jaring insang				▨		▨				▨				
Driftnets	Jaring hanyut						▨				▨				
Permanent trap	Sero			▨	▨		▨		▨		▨				
Portable trap	Bubu						▨		▨						
Diving spear and gleen	Molo / Menyelam			▨	▨								▨	▨	▨
Diving live fish	Molo / Menyelam			▨		▨									
Diving air supply (cyanide)	Molo / Menyelam			▨		▨									
Blast fishing	Bom			▨	▨	▨	▨		▨		▨		▨	▨	▨
Trolling with FAD	Pancing tonda	▨	▨					▨							
Purse seine with FAD	Rumpon	▨	▨					▨							
Pole and line with FAD	Rumpon	▨	▨					▨							
Set lines	Rawai	▨	▨	▨						▨					
Lift net	Bagan Apung										▨	▨			
Illegal foreign fleet	-	▨	▨					▨							

The species names recorded in the catch statistics varied slightly from year to year. Pelagic fish that were consistently included are anchovy, scad, trevally, sardines, mackerels, Spanish mackerels and tuna. Anchovy catch was allotted entirely to the adult anchovy EwE group. Based on expert communications, the most important scad in terms of biomass and harvest value in RA is the oxyeye scad (*Selar boops*) (Obed Lense, TNC-CTC, Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413), which occurs in the large planktivore group. All of the scad catch was therefore allotted to this group. There are nine trevally species in the RA model, and they all occur in the large reef associated group; the adult stanza therefore received 100% of the trevally catch. Sardine catch was apportioned to the adult small planktivore group. Mackerels and Spanish mackerel catch was attributed to the adult Mackerel functional group. Tuna catch was divided between the adult skipjack tuna group (92%) and the adult other tuna group (8%) in the same proportion as landings observed throughout Indonesia (Venema, 1997). The 'other' component was divided evenly among small, medium and large adult pelagic groups.

Demersal species reported in the catch statistics are: Leiognathids, threadfin bream, croakers, hairtails, *Polynemus* spp., catfishes, Emperor bream, groupers, snappers and others. Leiognathidae catch was allotted completely to the adult large reef associated functional group. However, no Leiognathidae (ponyfish) appear in the Raja Ampat species list provided by McKenna *et al.*, (2002b). According to IFDG (2001), these are a common catch in the Arafura Sea, indicating that the Sorong DKP statistics include landings from the Arafura Sea. Since the RA model only includes a sliver of the Arafura Sea, the landing density could well be overestimated for our geographic scope.

After having allocated DKP and Trade and Industry Office catch statistics into their most relevant groups, there was a quantity left over representing 'other' unidentified species. This quantity was divided between the functional groups that lacked explicit catch estimates, in the proportion suggested by the total number of species in each group. We therefore assumed that the catch of each species was equal, and that functional groups possessing many species, such as butterflyfish and the aggregate reef-associated groups, should receive a larger relative fraction of the undetermined catch component. The catch for 'other' reef associated fish was divided between butterflyfish, macro-algal browsing fish, eroding grazers, detritivorous fish and the aggregate groups: large, medium and small reef-associated fish.

There is a large amount of frozen catch recorded in the Trade and Industry Office statistics for the years 2000-2002. On average, the total frozen quantity is 13% of the total recorded catch. However, the frozen product is likely bycatch from shrimp trawl fisheries operating in the Arafura Sea (C. Rotinsulu. CI. Jl Arfak No. 45. Sorong, Papua, Indonesia 98413, pers. comm.). As this is outside of the study area, this amount was not included in the model.

Splitting catch between functional groups

Total catch was first determined for each functional group according to the methodology described above. Catches were then divided into juvenile, sub-adult and adult stanzas using ratios described in Section 2.5.11 - Functional group descriptions. Generally, juveniles are assumed to comprise 10% of the total fisheries catch for all reef associated and demersal groups, the remaining 90% is allotted to the adult and subadult stanzas. For each age class and functional group, the total calculated catch was divided among the 17 gear types in the model according to ratios presented in Table 2.4. Each functional group was slotted into one of six categories that define the principle gear types used to pursue it. Catches for each gear type category are divided among EwE fisheries in a unique proportion. Interactions marked as bycatch in Table 2.4 were assumed to catch half as much as directed landings. The final EwE landings matrix, including catch and bycatch, is presented in Table A.3.4.

We include bycatch in the catch matrix, rather than the discard matrix, because we assume that it is always sold. Discards are set as a small fraction of the total estimated catch for each EwE fishery. Blast fishing is assumed to discard a quantity of hermatypic scleractinian corals equal to 1% of their catch weight; trolling with FAD is assumed to discard a weight of birds equal to 1% of their catch; set lines are assumed to discard 1% of their catch weight in birds, green turtles and oceanic turtles combined; shrimp trawl is assumed to discard 50% of its catch weight in small demersals, deepwater fish, epifaunal detritivorous and carnivorous invertebrates.

A small discarding of crocodiles was added to account for incidental capture or hunting; this corresponds to about 20 animals per year from RA at 200 kg per animal.

Table 2.4 - Functional group catch distribution by gear type. Each functional group is assigned into one of six gear type categories (SPEL, DIVING, etc.). Catch for each group is distributed among 17 EwE fisheries according to unique ratios for each category. A.) Catch ratios used for each gear type category; tuna catch ratio is based on Indonesian trends (Venema, 1997). B.) Functional groups pursued by fisheries; D = Directed catch; B = Bycatch. Bycatch is assumed to catch half as much as directed catch. SKIP indicates all EwE fisheries catch an equal proportion.

A)

		EwE Fisheries																
Gear type	Gear name	Spear and harpoon	Reef gleaning	Shore gillnet	Driftnet	Permanent trap	Portable trap	Diving spear and glean	Diving live fish	Diving air supply cyanide	Blast fishing	Trolling with FAD	Purse seine with FAD	Pole and line with FAD	Set line	Lift net	Foreign fleet	Shrimp trawl
SPEL	Small pelagic gears			20%	20%	15%	15%				5%					25%		
DIVING	Demersal gear & diving	5%		10%		10%		10%	25%	25%	5%				10%			
INVERT	Invertebrate gears	19%	60%					20%			1%							
DEM	Demersal gears	19%		19%	19%	19%	19%				5%							
PEL	Pelagic gears			25%	20%	15%	15%									25%		
TUNA	Tuna gears											29%	8%	38%	12%		13%	

B)

Gear type	#	Group Name																	
DIVING	10	Ad. groupers	D				D		D	D	D	D				D			
DIVING	11	Sub. groupers	D				D		D	D	D	D				D			
DIVING	12	Juv. groupers	B				B					B				B			
DIVING	13	Ad. snappers	D		D		D		D			D							
DIVING	14	Sub. snappers	D		D		D		D			D							
DIVING	15	Juv. snappers	B		B		B		B			B							
DIVING	16	Ad. Napoleon wrasse								D	D	D							
DIVING	17	Sub. Napoleon wrasse								D	D	D							
DIVING	18	Juv. Napoleon wrasse										B							
TUNA	19	Skipjack tuna											D	D	D	D		D	
TUNA	20	Other tuna											D	D	D	D		D	
TUNA	21	Mackerel											D	D	D			D	
SKIP	22	Billfish											D						
DEM	23	Ad. coral trout	D		D	D	D	D				D							
DEM	24	Juvenile coral trout	B		B	B	B	B				B							
SKIP	25	Ad. large sharks														D			
SKIP	26	Juv. large sharks														B			
SKIP	27	Ad. small sharks														D			
SKIP	28	Juv. small sharks														B			
DEM	31	Ad. rays			D	D	D	D											
DEM	32	Juv. rays			D	D	D	D											
DEM	33	Ad. butterflyfish	D		D	D	D	D				D							
DEM	34	Juv. butterflyfish	B		B	B	B	B				B							
DEM	35	Cleaner wrasse			D	D	D	D				D							
PEL	36	Ad. large pelagic			D	D	D	D									D		
PEL	37	Juv. large pelagic			B	B	B	B									B		
PEL	38	Ad. medium pelagic			D	D	D	D									D		
PEL	39	Juv. medium pelagic			B	B	B	B									B		
SPEL	40	Ad. small pelagic			D	D	D	D				D					D		
SPEL	41	Juv. small pelagic			B	B	B	B				B					B		
DEM	42	Ad. large reef associated	D		D	D	D	D				D							
DEM	43	Juv. large reef associated	B		B	B	B	B				B							
DEM	44	Ad. medium reef associated	D		D	D	D	D				D							
DEM	45	Juv. medium reef associated	B		B	B	B	B				B							
DEM	46	Ad. small reef associated	D		D	D	D	D				D							
DEM	47	Juv. small reef asociated	B		B	B	B	B				B							
DEM	48	Ad. large demersal	D				D	D				D							
DEM	49	Juv. large demersal	B				B	B				B							
DEM	50	Ad. small demersal	D				D	D				D							
DEM	51	Juv. small demersal	B				B	B				B							
DEM	52	Ad. large planktivore	D		D	D	D	D				D							
DEM	53	Juv. large planktivore	B		B	B	B	B				B							
DEM	54	Ad. small planktivore	D		D	D	D	D				D							
DEM	55	Juv. small planktivore	B		B	B	B	B				B							
PEL	56	Ad. anchovy			D	D	D	D									D		
PEL	57	Juv. anchovy			B	B	B	B									B		
DEM	58	Ad. deepwater fish			D	D	D	D											
DEM	59	Juv. deepwater fish			B	B	B	B											
DEM	60	Ad. macro algal browsing			D	D	D	D				B							
DEM	61	Juv. macro algal browsing			B	B	B	B				B							
DEM	62	Ad. eroding grazers			D	D	D	D				B							
DEM	63	Juv. eroding grazers			B	B	B	B				B							
DEM	64	Ad. scraping grazers			D	D	D	D				B							
DEM	65	Juv. scraping grazers			B	B	B	B				B							
DEM	66	Detritivore fish			D	D	D	D				B							
SKIP	68	Hermatypic corals										D							
SKIP	73	Penaeid shrimps																	D
SKIP	74	Shrimps and prawns																	D
SKIP	75	Squid															D		
INVERT	76	Octopus	D	D					D			D							
INVERT	77	Sea cucumbers	D	D					D			D							
INVERT	78	Lobsters		D					D			D							
INVERT	79	Large crabs		D					D			D							
INVERT	80	Small crabs		D					D			D							
INVERT	82	Giant triton		D					D			D							
INVERT	83	Herbivorous echinoids		D					D			D							
INVERT	84	Bivalves		D															
SKIP	85	Sessile filter feeders		D															
INVERT	86	Epifaunal det. inverts.		D					D			D							
INVERT	87	Epifaunal carn.inverts.		D					D			D							

Effort time series

DKP statistics included a limited fishing effort series for the years 1994-1999. In order to produce a continuous effort trend suitable for Ecosim analysis, we have extrapolated fishing effort back to the year 1990 using linear regression. Similarly, effort was estimated for the years 1999-2006 by assuming a constant annual rate of increase. The average rate of increase is based on data for all available years; however, we limit the maximum effort increase at 5% per year in the absence of better information.

Table 2.5 - Gear effort assignments. See text for explanation of effort series.

EwE gear type	Relevant DKP effort categories
Spear and harpoon	POP
Reef gleaning	POP
Shore gillnet	GN
Driftnet	GN+TN
Permanent trap	TW
Portable trap	FT
Diving spear	NM+WO
Diving live fish	WI+WO
Diving cyanide	POP
Blast fishing	POP
Trolling	TR
Purse seine	WI+WO
Pole and line	PL
Set line	BL
Lift net	LB+LBR
Foreign fleet	IM
Shrimp trawl	WI+IM

Gear-effort categories identified in the statistics are as follows: hand line (HL), gill net (GN), lift bag net (LB), lift bag net in raft (LBR), troll (TR), trammel net (TN), pole and line (PL), bottom long line (BL), tidal weir (TW) and fish trap (FT). Boat-effort categories are: non-motorized (NM), wooden outboard (WO), wooden inboard (WI) and inboard motorboats (IM). In order to produce a relative effort series for each EwE fishing gear type, we assigned each EwE gear type to one or more appropriate gear-effort categories as listed in the statistics. The assignments are provided in Table 2.5. The effort of each EwE gear type is assumed to follow these categories. Where EwE gear type effort follows more than one DKP effort category the effort series used by EwE represents the average of the relevant DKP categories. For certain gear types, the effort increase from 1990 to 2006 was assumed to follow the population increase in Papua. The average annual population increase is recorded as 3.22% per year by Badan Pusat Statistik (BPS) Provinsi Papua for the years 1990-2000 (BPS, 2006). This assumption was used for the following artisanal fisheries: spear and harpoon, reef gleaning, diving with cyanide and blast fishing.

To produce an effort series at the level of functional groups requires some basic assumptions concerning the relative contribution made by each EwE gear type. The fishing effort exerted on a particular group is assumed to equal the weighted average of recorded efforts for all gear type that are catching it. Each gear type contributes to the weighted average in a proportion equal to the relative amount of catch claimed by that gear type.

In order to determine a CPUE trend for functional groups, both for use in parameterizing biomass values of the 1990 model and in fitting temporal dynamics, we simply divide the catch of each functional group estimated from DKP statistics (Section 2.5.10 - Catch time series) by the calculated effort series for each biomass pool. The resulting trends are provided in Fig. A.6.2.

Prices

For commercial functional groups in the model, an export price is determined from Trade and Industry Office statistics; these represent average ex-vessel prices for the years 2000-2004. Export prices are determined for groupers, Napoleon wrasse and octopus. Prices for export product are determined for a further 32 reef-associated functional groups based on generic price listings in the Trade and Industry Office statistics for ‘mixed fish’. The price of all these groups is assumed to equal by unit weight. Commodity prices for domestic sale were determined based on 1993-1994 information from the DKP (Sorong Regency Office). The value of products were divided into local prices (i.e., vended in Sorong market) and prices received at island markets, which are typically lower. These were averaged to produce an overall domestic price. Domestic prices were calculated for groupers, snappers, tuna, shrimp, shark fins, sea cucumbers, mollusks, squid, lobster and crabs. The prices of aggregate groups (i.e., large, medium and small reef-associated / demersal / planktivorous groups and others) are set based on the generic 'mixed fish' price entry. Prices in Venema (1997) were applied to tunas (export), crabs, jellyfish, seaweed and corals. Since we had catch estimates for both export and local consumption, prices were set for each commercial group as a realistic weighted average of export and domestic prices. Where catch data was lacking, the price of groups were assumed to be an average of export and domestic prices. Juvenile fish always received the local prices, as we assume that they were unsuitable for export. The price of small pelagics was modelled after anchovy. Small pelagics are assumed to be sold locally, as no export price was found. Market prices in the model are presented in (Table A.3.5).

Unreported catch

Most of the catch information available to us originated in Sorong or nearby cities, but fisheries catches occurring in smaller villages, especially those off the mainland, are subject to little or no observation (C. Rotinsulu. CI. Jl Arfak No. 45. Sorong, Papua, Indonesia 98413, pers. comm.). Therefore, the catch statistics presented in Fig. A.6.1 probably represent only a fraction of total fisheries catch, considering the disperse and artisanal nature of reef fisheries, and the minimal reporting infrastructure. Preliminary figures for unreported catch quantities have therefore been entered as placeholders into the model to allow a more accurate representation of energy flow in the system. As major reef predators are likely harvested in unreported fisheries, the trophic implications of the missing catch could be major. Artisanal and unreported catch estimates are now being developed by the CI socioeconomic analysis component of the BHS EBM project (contact: A. Dohar, CI. Jl.Gunung Arfak.45. Sorong, Papua, Indonesia) and the UBC team (e.g., see Bailey *et al.*, this volume for a contribution covering the unreported Waigeo anchovy fishery.)

Functional group descriptions

Mysticetae

The species of the cetacean suborder mysticetae occurring in RA were short-listed based on Kahn (2001) and Kreb and Budiono (2005). The estimated proportions of global abundance for the species found in FAO Area 71 were obtained from Kaschner (2004). However, the estimates from her model are not meant to be applied to small geographic areas such as RA, and the uncertainties involved are relatively high (K. Kaschner, Forschungs- und Technologiezentrum Westküste, Hafentörn, 25761 Büsum, Germany, pers. comm.). These were not used for the biomass estimates. Instead, the EE of the group was fixed at 0.025 and Ecopath was allowed to estimate the biomass as 0.033 $t{\cdot}km^{-2}$.

Mysticete P/B is calculated as the average of r/2 (Schmitz and Lavigne, 1984), where r is the intrinsic rate of growth, for Sei whale, Minke whale and Fin whale. P/B is estimated to be 0.0583 $year^{-1}$. The r/2 method was also used as a measure for mammal P/B in Guénette (2005).

The average body weight of 6 baleen whale species is taken from Trites and Pauly (1998) (*Balanoptera musculus*, *Balanoptera borealis*, *Balanoptera edeni*, *Balanoptera acutorostrata*, *Balanoptera physalis* and *Megaptera novaeangliae*). To calculate Q/B, the feeding ration of is determined using the relationship in Innes *et al.* (1987) as modified by Trites and Heise (1996); Q/B is then averaged among species to obtain a value of 4.850 $year^{-1}$.

Piscivorous and deep-diving odontocetae

The species of odontocetae visiting the area were short-listed based on Kahn (2001) and Kreb and Budiono (2005). The estimated proportion of the global abundance of the species that can be found in FAO Area 71 were obtained from Kaschner (2004) but the uncertainties involved were relatively high (K. Kaschner, Forschungs- und Technologiezentrum Westküste, Hafentörn, 25761 Büsum, Germany, pers. comm.), these were not used for the biomass estimates. The EE of the group was fixed at 0.0025 and Ecopath was allowed to estimate the biomasses for piscivorous and deep-diving odontocetae as 0.052 and 0.091 t·km^{-2}, respectively.

The P/B for piscivorous odontocetae is calculated as the average of r/2 (Schmitz and Lavigne, 1984), where r is the intrinsic rate of growth, for *Stenella longirostris*, *Tursiops truncates*, and *Stenella attenuate* to be 0.0325 year^{-1}. The P/B for deep-diving odontocetae is calculated as the average of r/2 for *Physeter macrocephalus* and *Ziphius cavirostris* (after Guénette, 2005) to be 0.02 year^{-1}.

The average weight of 13 piscivorous odontocetae species are taken from Trites and Pauly (1998) and Noren and Williams (2000) (long nosed spinner dolphin, *Stenella longirostris*; bottlenose dolphin, *Tursiops truncates*; pan-tropical spotted dolphin, *Stenella attenuate*; Fraser's dolphin, *Lagenodelphis hosei*; Risso's dolphin, *Grampus griseus*; common dolphin, *Delphinus* spp.; rough toothed dolphin, *Steno bredanensis*; Indo-Pacific humpbacked dolphin, *Sousa chinensis*; Irrawady dolphin, *Orcella brevirostris*; melon headed whale, *Peponocephala electra*; Pygmy killer whale, *Feresa attenuate*; dwarf sperm whale, *Kogia simus*; pygmy/dwarf sperm whale, *Kogia* spp.,). That source also provides the body weights of 5 deep-diving odontocetae species (sperm whale, *Physeter macrocephalus*; false killer whale, *Pseudorca crassidens*; Cuvier's beaked whale, *Ziphius cavirostris*; short finned pilot whale, *Globicephala macrorhynus* and orca, *Orca orca*).

For both piscivorous and deep-diving odontocetae, Q/B is based on the feeding ration determined using the relation given by Innes *et al.* (1987) as modified by Trites and Heise (1996); individual Q/B is averaged among species to obtain a Q/B value of 14.476 year^{-1} and 8.531 year^{-1} for piscivorous and deep-diving odontocetae, respectively. However, these values produce a very low P/Q value ~0.001, and so consumption rates were ultimately reduced for both groups, so that the EE value matched the one employed for Mysticetae. The resulting Q/B values are 6.1 year^{-1} and 3.6 year^{-1}, for piscivorous and deep-diving odontocetae, respectively.

Dugongs

The biomass of dugongs was calculated based on a population estimate in Torres Strait by Marsh *et al.* (1997) (i.e., 24,225 individuals in 30,561 km^{-2} survey area). The mean size of an individual is assumed to be 400 kg based on the weight range reported to be between 250 kg and 600 kg by Blanshard (2001). The biomass is thus estimated to be 0.317 t·km^{-2}. This estimate is scaled to the shelf area in RA, assuming that these animals occur on the shelf, to obtain the final biomass estimate 0.054 t·km^{-2} used in the model. The maximum rate of increase in dugong population is approximately 5% per annum (Marsh *et al.*, 1997). The P/B is calculated to be equal to r/2 = 0.025 year^{-1}, where r is the intrinsic rate of growth.

The average value of 400 kg was also used to calculate the ration based on the empirical relation given by Innes *et al.* (1987). The Q/B was calculated to be 11.012 year^{-1}. Another estimate by Goto *et al.* (2004) places consumption of captive dugongs at 14% of their body weight, before maturity, and 7% after maturity. This leads to Q/B estimates of 51.1 year^{-1} and 25.6 year^{-1} for dugong before and after maturity. The values are considered to be too high in relation to the estimated production rate, and so the lower alternative is used.

Birds

The biomass for the birds in the RA model is estimated to be 0.366 t·km^{-2}. The value based on the biomass of 11 species (black-naped tern, *Sterna sumatrana*; brown noddy, *Anous stolidus*; bridled tern, *Sterna anaethetus*; crested tern, *Sterna bergii*; brown booby, *Sula leucogaster*; red-footed booby, *Sula sula*; great frigatebird, *Fregata minor*; white-tailed tropicbird, *Phaethon lepturus*; red-tailed tropicbird, *Phaethon rubricauda*; sooty tern, *Sterna fuscata*; masked booby, *Sula dactylatra*) from the Banda sea (Karpouzi, 2005). The extent of Banda Sea was obtained from (Britannica, 2006). The estimated value is high compared to Opitz (1993), who used a biomass density for seabirds of 0.015 t·km^{-2} for a Caribbean reef.

P/B for Leach's storm petrel (*Oceanodroma leucorhoa*) 0.381 year^{-1} is used as P/B for the group in the model based on Russel (1999). This value is low compared to the production rate for birds in French Frigate Shoals by Polovina (1984) 5.4 year^{-1}; the same value was used for Caribbean coral reefs by Opitz (1993) and also Vidal and Basurto (2003) for Bahía de la Ascensión.

The Q/B was determined by first calculating the ration using the empirical formula given by Nilsson and Nilsson (1976) in Wada (1996), and then averaging the values for 11 species (i.e., the same species that were used to calculate biomass). A weighted average was used based on relative biomass of each species to obtain the group Q/B, which is equal to 63.95 year^{-1}. This high value is comparable to Polovina's (1984) estimate for Hawaiian reefs of 80 year^{-1}.

Reef-associated, Green and Oceanic turtles

The turtles are grouped into three functional groups based on their habitat and feeding habits: Reef associated (hawksbill turtle, *Eretmochelys imbricate*; loggerhead turtle, *Caretta caretta*); green turtle (*Chelonia mydas*) and oceanic turtles (leatherback turtle, *Dermochelys coriacae*; olive ridley, *Lepidochelys olivacae*; flatback turtle, *Natator depressus*).

The total biomass of turtles is approximately 0.02 t·km^{-2} (Alias, 2003), this was scaled in a ratio (1:2:2) for reef associated, green turtles and oceanic turtles. Mast and Hutchinson (2005) estimated the leatherback population to be about 650 nesting females in the BHS. Studies of sea turtle nesting site at Jamursba Medi Beach in Raja Ampat estimated 2983 Leatherback nests, 171 green turtle nests, 13 Hawksbill nests and 77 Olive Ridley nests (Putrawidjaja, 1997). These estimates could be used for partitioning the biomass estimate into the three functional groups, however at present, the ratio was maintained at (1:2:2) until better estimates becomes available from additional sites and nesting seasons. Biomass values are therefore 0.004, 0.008 and 0.008 t·km^{-2} for reef associated, green and oceanic turtles, respectively. The latter two groups were overfished in the initial model from the effects of set line discarding, and so a biomass accumulation rate was allowed of -0.02 year^{-1}.

The survival of loggerhead turtle was estimated as 0.8613 year^{-1} by Chaloupka and Limpus (2002). The P/B is calculated using the relation ($M = -\ln S$) to be 0.1493 year^{-1}. The survival estimate of green turtle, 0.984 year^{-1} is obtained from Mortimer *et al.*, (2000) and P/B is calculated, using the same method, as 0.053 year^{-1}. Opitz (1993) used a higher production rate for marine turtles on Caribbean reefs, 0.2 year^{-1}. The P/B estimate for green turtles is used for oceanic turtles in the absence of better estimates. Survivorship estimates were obtained for adult female turtles. The values were not used in the calculation of P/B, but they are informative about the proportion of hatchlings that reach the adult stage: 0.93 year^{-1} for flatback (Parameter and Limpus, 1995); 0.61 year^{-1} for green turtle (Bjorndal, 1980,); 0.43 year^{-1} for Kemp's ridley (Marquez *et al.*, 1982b); 0.48 year^{-1} for olive ridley (Marquez *et al.*, 1982a) and 0.81 year^{-1} for loggerhead (Frazer, 1983).

A Q/B value of 3.5 year^{-1} was used for all the turtle groups; the value taken from a trophic model for the coastal ecosystem of the West Coast of Penisular Malaysia (Alias, 2003).

Crocodiles

The biomass of crocodiles is estimated to be 5.75E-3 t·km^{-2} based on population estimate of 55 animals (Kushlan, 1980) and individual weight of 230 kg (Pritchard, 1978) in Florida Bay; the area is assumed to be about 2200 km^{-2} (Healy, 1996). However, the value is uncertain. Due to diet matrix conflicts, Ecopath was ultimately allowed to estimate crocodile biomass as 1.33E-3 t·km^{-2}. The estimate of P/B (0.408 year^{-1}) is based on Davis and Odgen (1994); the estimate of Q/B (6.5 year^{-1}) is based on estimates for American crocodile, *Crocodylus acutus*, from Day *et al.* (1990).

In the RA Ecospace model, crocodiles are restricted to shallow water habitat (<10 m). This habitat type implicitly represents marine and brackish environments. Crocodiles are limited to these areas using dispersal parameters that are strictly prohibitive to movement. In the small scale models for Kofiau and SW Misool estuaries are entered as an explicit habitat type; crocodiles are restricted to these regions.

There is no directed catch entered in Ecopath for crocodiles, but there is a small amount of discarding, 0.0001 t·km^{-2}. This is about 4.5 tonnes for all of RA, or about 20 animals per year at 200 kg per animal. Although we expect very little crocodile catch from the study area, it is known to occur. A large male specimen was killed by villagers on Kofiau Island in February of 2006 (C. Ainsworth, pers. observation). For safety reasons, the villagers attempt to kill every crocodile they encounter, according to their accounts. We therefore entered this as a discard in Ecopath, so no monetary catch value will be recorded.

Groupers

Groupers are divided into three functional groups representing life history stages: adult, subadult and juveniles. These groups incorporate information from 46 species and 16 genera of family Serranidae (Table A.1.1). Grouper biomass is calculated from COREMAP (2005) abundance counts, adjusted for the relative reef area in RA using the reef area to marine area ratio for all of Indonesia (Spalding *et al.*, 2001). Abundance counts are converted to biomass using an average individual weight obtained from an age-structured model (see Section 2.5.8 - Biomass density estimates). Biomass density is estimated to be 0.257 t·km^{-2}. This amount is split by Ecopath among the three life history stages according to the mortality schedule in Table A.3.3. Ontogenic parameters used by the multi-stanza routine represent species-level averages for RA species determined with FishBase maturity data. Biomass accumulation rate is set at -2% per year.

The COREMAP (2005) abundance counts suggested a high biomass density in sites near Weigeo Island, 0.256 t·km^{-2}. This value has been scaled to represent the average biomass density in RA, according to the relative marine area to reef area ratio in Spalding *et al.* (2001). The adult, sub-adult and juvenile stanzas receive 72%, 22% and 6% of the biomass respectively by employing the multi-stanza parameter estimates (Table A.3.3). When similarly scaled for reef area in RA, Wolanski's (2001) estimate of "Large groupers" biomass is 0.035 t·km^{-2}; Kongchai *et al.*, (2003) estimated only 0.0025 t·km^{-2} for the Gulf of Thailand. Allen *et al.*, (2005) provided grouper densities for East Andaman Sea of approximately 0.032 t·km^{-2} (this value was converted to weight using length-weight parameters for RA serranids).

The P/B of adult groupers was set at 0.225 year^{-1} after 5 RA species of genus *Epinephelus* (Grandcourt, 2005). Subadult and juvenile groupers was set at 0.4 and 1.2 year^{-1}, respectively to provide a realistic age distribution as quantified by Ecopath's multi-stanza routine. Opitz (1993) used a production value for large groupers of 0.37 year^{-1}. The Q/B of adult groupers was determined to be 9.086 year^{-1} using the empirical regression of Pauly (1986) based on the average of 41 grouper species out of 46. Q/B of subadult and juvenile groups is estimated by Ecopath as 13.224 and 26.908 year^{-1}, respectively.

Groupers are pursued by all three diving gear types in the model, as well as blast fishing, spear and harpoon and permanent traps. Cyanide fishing, which supplies premium live fish to the Hong Kong market, has also resulted in the loss of valuable reef-associated species like Napoleon wrasse (*Cheilinus undulatus*) and giant grouper (*Epinephelus lanceolatus*) due to overexploitation (Erdmann and Pet-Soede, 1996; Mous *et al.*, 2000). Total catch was estimated for this group based on DKP statistics as 0.022 t·km^{-2}, or approximately 990 tonnes annually for all of Raja Ampat. 50% of the total grouper catch was allotted to the adult functional group; 40% was attributed to sub-adults and 10% to juveniles. Adult groupers were lightly exploited in the initial RA model, and catch was increased to represent the impact of unreported catches occurring in this group. Assuming that grouper catches reported in Sorong constitute 40% of the entire RA catch provides the following fishery indicators from Ecosim's equilibrium analysis: F_{msy} estimate of 0.21 year^{-1}, F_{2006} of 0.094 year^{-1} and MSY of 0.027 t·km^{-2}. This MSY value is an average for all of RA, but when corrected to represent only the reef area this value equates to roughly 1.35 t·km^{-2}. This amount compares well with the 'typical' grouper MSY estimate offered by Jennings and Polunin (1995) of 1 t·km^{-2}. We assume that there is no discarding of this valuable species group.

Snappers

Snappers are divided into three functional groups representing life history stages: adult, subadult and juveniles. These groups incorporate information from 32 species and 9 genera of family Lutjanidae (Table A.1.1).

The biomass for snappers was determined from COREMAP (2005) abundance counts. Abundance counts are converted to biomass using an average individual weight obtained from an age-structured model (see Section 2.5.8 - Biomass density estimates). Biomass density is estimated to be 0.152 t·km^{-2}. This amount is split among the three life history stages by Ecopath according to the mortality schedule in Table A.3.3, with adults, sub-adults and juveniles stanzas receiving 53%, 27% and 20% respectively. Ontogenetic parameters used by the multi-stanza routine represent species-level averages for RA species determined with FishBase maturity data. Biomass accumulation rate is set at -10% per year.

The P/B ratio of adult snappers is set at 0.4 year^{-1}. This represents the average M of 17 species of family Lutjanidae from independent sampling studies, 0.3 year^{-1} (Marcano, et al, 1996; Burton, 2001; Burton, 2002; Newman *et al.*, 1996; Newman, 2002; Newman *et al.*, 2000; Kamukuru *et al.*, 2005, Wilde and Sawynok 2004), but the value has been increased by one third to account for fishing mortality. This value is not too different from the one used to represent snappers in EwE models by Vidal and Basurto (2003) and Arreguín-Sánchez *et al.* (1993); their value is 0.49 year^{-1}. They did not use age stanzas, and so their value implicitly includes younger age classes and should be higher. The sub-adult production rate was set higher relative to adults at 1.1 year^{-1}, while the juvenile production rate was set at 1.47 year^{-1}. These production rates reflect the M estimate for 18 RA snapper species based on the empirical equation of Pauly (1980); but the values have been increased by 50% and 100% respectively to represent additional predation mortality incurred by the immature stanzas (as well as any fishing mortality). These rates generate a realistic age-biomass distribution under the species-specific growth and mortality values obtained from FishBase, in which the majority of biomass is concentrated in the adult and sub-adult stanzas. The consumption rate of adult snappers, 7.105 year^{-1} is based on the empirical equation of Pauly (1986); this uses species-specific information for 29 species of RA snappers out of 32, and represents an average species value. It is slightly higher than the consumption rate used to model snappers in the Mexican Caribbean, 5.6 year^{-1} by Vidal and

Basurto (2003).

Snapper catch is estimated from DKP and Trade and Industry Office statistics as 0.031 t·km^{-2}. This represents average catches between 2000-2005. 45% of the total snapper catch was allotted to the adult functional group; 45% was attributed to sub-adults and 10% to juveniles. This catch quantity includes an estimate of unreported artisanal catch equal to 50% of the reported value. Snappers are represented in the RA model as fully exploited, with an F_{2006} of 0.15 year^{-1}, which is close to the F_{msy} (0.21 year^{-1}). MSY is predicted to be 8.4 kg·km^{-2} for RA, or about 0.479 t·km^{-2} on coral reefs.

Napoleon wrasse

This functional group represents only Napoleon wrasse (*Cheilinus undulatus*), which is a conspicuously large reef fish species in family Labridae. It is also commonly referred to as humphead wrasse or double-headed Maori wrasse, among other names (Allen, 2000). The functional group is divided into adult, subadult and juvenile stanzas.

A biomass value for this species could not be calculated based on the reef transects in COREMAP (2005) because *Cheilinus* is only reported to the genus level (four other *Cheilnus* are also present in the model in the medium and large reef associated groups). However, Donaldson and Sadovy (2001) suggested that Napoleon wrasse is uncommon wherever it occurs, and Russell (2004) suggested a typical density of 10 fish per hectare in reef environments and a maximum density of 20 fish per hectare. Since there is a heavy fishery on Napoleon wrasse in RA, we assume that the standing biomass should fall toward the lower end of that possible range. Ten fish per hectare equates to 2 t·km^{-2} on reefs; and when corrected for reef area a possible overall biomass density in RA is determined as 0.035 t·km^{-2}. This amount was split into adult (33%), subadult (57%) and juvenile groups (10%) using the mortality schedule in Table A.3.3.

The P/B of adult Napoleon wrasse is set at 0.5 year^{-1}. It is based on the M regression formula of Pauly (1980), but the M value (0.25 year^{-1}) was then doubled to estimate P/B and account for fishing mortality. A similar P/B value was used for sub-adults, but juveniles were set higher at 1.2 year^{-1} to represent additional predation mortality suffered by the immature stanzas. Sampling data for *C. undulatus* suggests that the natural mortality rate may be lower, 0.11 year^{-1} (Eckert, 1987). However, the contribution of fishing mortality to total mortality is in question, and we have therefore made a precautionary assumption that F is at least equal to M. Q/B rate for adults is set at 8.9 year^{-1}, and the rates for immature stanzas were calculated according to the mortality schedule in place. A consumption rate could not be found for *C. undulatus*, and so this value was designed to represent a slightly lower consumption rate than of groupers. This is appropriate since Napoleon wrasse is among the largest reef-associated fish species, therefore consuming less per unit body mass.

This species is subject to a live reef food fishery supplying high value export product (Mous *et al.*, 2000). The export of Napoleon wrasse is regulated by CITES Appendix II, of which Indonesia is a signatory. The fishery in RA is conducted primarily by surface air supplied divers who may use cyanide to stun the fish, and it is also pursued by reef bombing operations (Andreas Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, pers. comm.). Catch of Napoleon wrasse is estimated from DKP and Trade and Industry Office statistics. It represents an average of the years 2000-2005. The value was doubled from the official sources to represent unreported artisanal catch. However, the total catch estimate remains small at only 2.07 kg·km^{-2}. It is divided between age stanzas: 45% was attributed to the adult functional group, 45% to sub-adults and 10% to juveniles. With this small amount of catch, Ecosim predicts that F_{2006} equals 0.085 year^{-1}, which is short of F_{msy} (0.23 year^{-1}). MSY in RA is predicted to be 1.8 kg·km^{-2} for adults, and approximately 5.3 kg·km^{-2} for adults and sub-adults together. This equates to 0.302 t·km^{-2} on coral reefs.

Skipjack tuna

This group represents only Skipjack tuna (*Katsuwonus pelamis*). They were allotted their own functional group because they are heavily exploited in eastern Indonesia and constitute a major commercial resource. The species also exhibits faster growth and mortality rates than other major tuna stocks in the area, (e.g., yellowfin and bigeye tuna: *Thunnus albacares* and *T. obesus*), which are incorporated in the other tuna functional group.

Between the years 1998-2001, biomass of the western and central Pacific Ocean stock was thought to be at the highest levels in 30 years thanks to an upward shift in recruitment rates occurring during the mid-1980s (Langley *et al.*, 2003), and El Ninõ events in the 1990s may have benefited Skipjack tuna recruitment as well (SCTB, 2004). Skipjack biomass is now thought to lie above the level that produces MSY (B_{MSY}) (SCTB, 2004). Our RA model predicts that the values are close. We have allowed Ecopath to estimate Skipjack tuna biomass as 0.699 $t \cdot km^{-2}$, while B_{MSY} is predicted to be 0.765 $t \cdot km^{-2}$ by the equilibrium analysis. There is no biomass accumulation entered.

A range of values are reported in the literature for skipjack tuna mortality rates, a summary is provided by Wild and Hampton (1994). Those authors cite Bayliff (1977), who suggests an upper limit, 6.48 $year^{-1}$, while the inter-American Tropical Tuna Commission assumes a lower mortality for management, between 1.39 and 2.30 $year^{-1}$ (IATTC, 1989). We assumed an intermediate value for total mortality, 2 $year^{-1}$, which is applied as the P/B value for skipjack. This estimate is similar to one derived from Pauly's (1980) empirical M formula. When applied, the estimate of M, 0.99 $year^{-1}$, can be doubled to represent a fully exploited stock, where M=F. The resulting P/B is 1.99 $year^{-1}$.

Skipjack tuna received a high Q/B value of 32.57 $year^{-1}$ from Pauly (1989), and we do expect a high consumption rate for fishes with high-performance physiology like tunas and billfish due to elevated metabolism rates that facilitate their pelagic-hunter niche (Magnuson, 1969; Brill, 1996). However, Pauly's (1989) value is very high compared to our aggregate group for large pelagics (5.644 $year^{-1}$), indicating that skipjack are voracious predators. The stock evaluated by Pauly's (1989) in fact represents a Pacific stock at a lower temperature (24 ^{o}C) than Raja Ampat (28 ^{o}C), and so the consumption rate in RA may be higher still. However, we have chosen to use a lower value, 6.64 $year^{-1}$, so that production over consumption (P/Q) ratio approximate equals 0.3. This is a rule-of-thumb applicable to a fast growing pelagic species. As a highly migratory pelagic species, we have assumed a large amount of diet import in the models (85%) and we have applied a low EE (0.42). This represents the high rate of mortality caused by fisheries and predation elsewhere in the Pacific, external to the model.

The stock of western and central Pacific Ocean skipjack tuna is thought to be exploited at a modest level relative to its biological potential (Langley *et al.*, 2003). We have calculated a catch value of 0.347 $t \cdot km^{-2}$ based on DKP and Trade and Industry Office catch statistics - this represents an average of the years 2000-2005. The catch record is relatively well documented for skipjack tuna, and so we assume zero unreported catch. We also assume zero discards for this group. The equilibrium analysis provides the following fishery indicators: F_{2006} = 0.548 $year^{-1}$, F_{msy} = 0.479 $year^{-1}$, MSY = 0.366 $t \cdot km^{-2}$, predicted MSY for RA is about 16,400 tonnes. The stock is assumed for management purposes to be contiguous throughout the eastern and central Pacific (Wild and Hampton, 1994). Therefore, fishery catches elsewhere will affect the abundance of animals occurring in RA. This limits our ability to predict stock dynamics for this group (see Martell, 2004 for a discussion on modelling migratory species in EwE).

Other tuna

The 'other tuna' functional group includes 10 species of scombrids: wahoo (*Acanthocybium solandri*), bullet tuna (*Auxis rochei rochei*), frigate tuna (*A. thazard thazard*), Kawakawa (*Euthynnus affnis*), dogtooth tuna (*Gymnosarda unicolor*), albacore tuna (*Thunnus alalunga*), yellowfin tuna (*T. albacares*), bigeye tuna (*T. obesus*), Pacific bluefin tuna (*T. orientalis*) and longtail tuna (*T. tonggol*).

The current biomass of bigeye tuna is thought to lie above the MSY level (SCTB, 2004). The biomass of albacore in the South Pacific may be (as of 2004) at approximately 60% of unexploited biomass B_0, while the biomass of yellowfin in the western central Pacific Ocean may be 65-80% of B_0 (SCTB, 2004). Our biomass estimate of 0.604 $t{\cdot}km^{-2}$ was calculated by Ecopath by assuming a low EE of 0.4 for this migratory group. That biomass is approximately 88% of the B_0 predicted by the equilibrium analysis**. A biomass accumulation rate of -5% per year is included.

The production rate P/B (1.408 $year^{-1}$) is set according to Pauly's (1980) empirical formula for M, which is calculated at the species level and doubled to represent the contribution of F. P/B values were averaged for 8 species to provide an estimate for this group. The value compares well with M estimates for *T. albacares* and *T. obesus* obtained from (Hampton, 2000), which average out to 1.2 $year^{-1}$, once doubled to account for fishing mortality. The Q/B value for other tuna was estimated using species-specific parameters based on 9 RA species and applying the empirical equation of Pauly (1986). The original estimate 5.587 $year^{-1}$ was reduced to 4.693 $year^{-1}$, so that P/Q equals 0.3.

In RA, the fishery for tuna is primarily conducted by the pole and line fleet. Catch of other tuna is represented from DKP and Trade and Industry Office statistics. It was estimated to be very low from government statistics, 0.0263 $t{\cdot}km^{-2}$ - this represents an average of the years 2000-2005. We increased this amount by 80% to account for unreported catch and represent a fully exploited stock. We did not include any additional discards. This results in the following fishery indicators: F_{2006} = 0.746 $year^{-1}$, F_{msy} = 0.746 $year^{-1}$, MSY = 0.058 $t{\cdot}km^{-2}$. Predicted MSY for the whole of RA is therefore predicted to be about 2,610 tonnes.

Mackerel

The Mackerel group contains 9 species of scombrids identified in McKenna *et al.* (2002b) or reported as being present in the area by FishBase records. The species included are Double-lined mackerel (*Grammatorcynus bilineatus*), Short mackerel (*Rastrelliger brachysoma*), Island mackerel (*R. faughni*), Indian mackerel (*R. kanagurta*), Blue mackerel (*Scomber australasicus*), Narrow-barred Spanish mackerel (*Scomberomorus commerson*), Australian spotted mackerel (*S. munroi*), Queensland school mackerel (*S. queenslandicus*) and Broadbarred king mackerel (*S. semifasciatus*).

Biomass of mackerel, 0.086 $t{\cdot}km^{-2}$, is based on an estimate obtained from the relative abundance rankings of McKenna *et al.*, (2002b) for RA. The species-level abundance rankings were converted to absolute biomass by applying weighting factors. Weighting factors were calculated based on common species found in both the McKenna *et al.* (2002b) species list and the COREMAP (2005) biomass transects (see Section 2.5.8 - Biomass density estimates). No biomass accumulation rate is entered for this group.

The P/B rate for mackerels was set according to the empirical formula for M of Pauly (1980), based on 9 mackerel species and using species-specific growth parameters available from FishBase. The M morality rate was doubled to represent the contribution of F, so that P/B is set

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** The equilibrium analysis presented in Appendix B shows a lower B_0 for 'other tuna', 0.472 $t{\cdot}km^{-2}$, because it does not consider trophic interactions. These increase the potential surplus production.

at 2.913 year^{-1}. Species-level P/B values were averaged to provide an estimate for this group. Independent mortality estimates from sampling could only be found for one RA mackerel species, *Scomberomorus commerson*, at 0.59 year^{-1} (McIlwain, 2005). This is a low value, even when increased to account for fishing mortality, and it was not used for the group average. Buchary (1999) used a higher P/B rate for *Rastrelliger* spp., 4.248 year^{-1}. Q/B was set at 9.712 year^{-1} so that the gross efficiency (P/Q) ratio equals 0.3. The Q/B formula of Pauly (1986) suggested a slightly lower rate, 8.593 year^{-1}, based on 10 mackerel species. Buchary (1999) maintained a similar P/Q ratio (3.3) as in the present model.

Catch of mackerels was estimated based on DKP and Trade and Industry Office statistics (0.064 t·km^{-2}); this represent average RA catches between the years 2000-2005. We assume there is zero unreported catch in this group. Under these assumptions, the equilibrium analysis suggests that the group is now fully exploited: F_{2006} (0.746 year^{-1}) lies very close to F_{msy} (0.746 year^{-1}), while current catches are slightly above MSY (0.058 t·km^{-2}).

Billfish

The billfish functional group includes highly migratory sailfish and billfish species: Indo-Pacific sailfish (*Istiophorus platypterus*), black marlin (*Makaira indica*), Indo-Pacific blue marlin (*Makaira mazara*), shortbill spearfish (*Tetrapturus angustirostris*), striped marlin (*Tetrapturus audax*) and swordfish (*Xiphias gladius*).

The biomass of billfish was estimated by Ecopath as 0.825 t·km^{-2} based on an assumed EE of 0.2. This low EE value was used to represent a highly migratory species, where a large fraction of natural mortality (80%) occurs outside the modelled system. A significant diet import term (approx. 88% of diet) was also included to represent feeding that occurs outside of RA.

The P/B rate of billfish (0.956 year^{-1}) was set at the species level according to the empirical M formula of Pauly (1980), which was doubled to represent the contribution of F. This value represents the average of 4 billfish species. Q/B was set so that the P/Q ratio is equal to 0.3. This assumption results in a Q/B value of 3.187 year^{-1}, which is similar to the estimate derived from the consumption rate formula of Pauly (1986), 3.256 year^{-1} for 5 species of RA billfish.

There was no data available on billfish landings in the governmental fisheries statistics, and so we assume a small catch for billfish occurring in RA from trolling operations, including recreational fisheries. A catch of 0.05 t·km^{-2} in the RA model (~5% of standing biomass) corresponds to an F_{2006} of 0.06 year^{-1}, or about 40% of F_{msy} (0.148 year^{-1}) representing a lightly exploited stock. MSY is estimated by the equilibrium analysis to be approximately 0.068 t·km^{-2}, equivalent to almost 3,100 tonnes for RA. Billfish biomass is depleted in the present-day RA model to approximately 75% of the pristine level (B_o).

Coral trout

This functional group encompasses six species that are commonly referred to as coral trout: coral hind (*Cephalopholis miniata*), leopard coralgrouper (*Plectropomus leopardus*), blacksaddeled coralgrouper (*P. laevis*), spotted coralgrouper (*P. maculates*), highfin coralgrouper (*P. oligocanthus*) and squaretail coralgrouper (*P. areolatus*).

Coral trout biomass is based on reef transects conducted on Weigeo Island (COREMAP, 2005). It is calculated to be 0.040 t·km^{-2}, with about 93% of the biomass occurring in the adult group and the remainder in the juvenile group as determined by the multi-stanza routine using mortality parameters in Table A.3.3. A biomass accumulation rate of -0.07 year^{-1} was entered to adjust the surplus production potential so that current (2006) fishing mortality lies close to F_{msy}, representing a fully exploited stock.

The P/B rate of coral trout is set at 0.35 $year^{-1}$ for adults and 0.7 $year^{-1}$ for juveniles. The adult value is based on *P. leopardus* (ages 6-8) and *P. laevis*; it is an average of natural mortalities from sampling (Russ *et al.*, 1998), and it has been increased by 50% to account for fishing mortality. The juvenile production rate is based on a high value for total mortality (Z) found in the literature for P. maculatus (Ferrira and Russ, 1992), but it has been increased by 25% to account for additional predation mortality incurred by juvenile stanzas. The M predicted by Pauly's (1980) formula is 0.5 $year^{-1}$ for two RA coral trout species, which falls between the values used for our life history stanzas. Similarly, Gribble (2001) used 0.35 $year^{-1}$ for coral trout on the Great Barrier Reef, which lies between the adult and juvenile estimates. The parameters in use generate a realistic age-biomass distribution under assumed maturity parameters. Coral trout Q/B was estimated from Pauly's (1986) empirical formula as 6.1 $year^{-1}$ and is based on 6 species. This amount was ultimately decreased to 3.3 $year^{-1}$ for the adult group during balancing in order to more accurately reflect the consumption rates of physiologically comparable groups, such as large reef associated fish. The consumption rate for the juvenile stanza was estimated by the multi-stanza routine to be 8.393 $year^{-1}$ based on the adult rate and the given mortality schedule.

Catch of coral trout was estimated directly from DKP and Trade and Industry Office statistics at about 1.8 $kg \cdot km^{-2}$, which falls just below MSY indicating a fully exploited stock. If there are significant sources of unreported catch for coral trout, then this functional group may actually be overexploited. The catch of coral trout is based on the 'other' reef fish catch category listed in DKP and Trade and Industry Office statistics. That quantity was divided among reef-associated functional groups whose catch was not quantified explicitly by other catch statistic categories. The 'other' catch was divided between reef associated groups according to their relative number of species, assuming that the more specious groups contribute a greater fraction to the undetermined catch. In the preliminary models we assumed zero discarding. Equilibrium statistics are as follows: $F_{2006} = 0.045\ year^{-1}$, $F_{msy} = 0.092\ year^{-1}$, MSY = 1.9 $kg \cdot km^{-2}$, or about 85.5 tonnes total catch for RA. This is equivalent to 0.108 $t \cdot km^{-2}$ on coral reefs.

Large and small sharks

Large sharks include the grey reef shark (*Charcharhinus amblyrhynchos*), Pondicherry shark (*C. hemiodon*), blacktip reef shark (*C. melanopterus*), blue shark (*Prionace glauca*), whitetip reef shark (*Triaenodon obesus*) and tawny nurse shark (*Nebrius ferrugineus*). Small sharks include the graceful shark (*Carcharhinus amblyrhynchoides*), Australian sharpnose shark (*Rhizoprionodon taylori*), smallfin gulper shark (*Centrophorus moluccensis*), Indonesian speckled carpetshark (*Hemiscyllium freycineti*) and tasseled wobbegong (*Eucrossorhinus dasypogon*).

The biomass of large sharks is estimated to be approximately 0.115 $t \cdot km^{-2}$ in the RA model based on the subjective species-level abundance ratings provided by McKenna *et al.* (2002b); the biomass of small sharks is estimated to be 0.057 $t \cdot km^{-2}$. Biomass weighting factors were assigned to each qualitative abundance rating offered by McKenna *et al.* (2002b) (e.g., rare, "occasional", "common") based on quantitative values provided by COREMAP (2005) for certain species that were common to both lists. A biomass density is extrapolated for species missing from the COREMAP list according to the subjective biomass rating in McKenna *et al.* (2002b), and the biomass of the functional groups large and small sharks are calculated as the sum of the biomasses of constituent species. Group biomass is divided between the adult and juvenile stanzas for large sharks (56% and 44%, respectively) and small sharks (14% and 86%, respectively) according to the mortality schedule in Table A.3.3.

An EE of 0.5 was entered into adult large sharks to represent a migratory group that moves (and dies) outside the model boundaries. With biomass, production rate, consumption rate and EE entered as input parameters, Ecopath was able to estimate the biomass accumulation rate to be

9% year^{-1}. Small sharks were assumed to have more restricted ranges, and their EE is estimated by Ecopath to reflect a more sedentary nature (>0.95). Since the major depletion of large sharks probably occurred before 1980 in RA, the group is not of major trophodynamic consequence in the present-day model. Nevertheless, these top predators have the potential to fulfill a keystone functional role, and so it is important that their dynamics are accurately represented in the model. Forecasting scenarios will also require an accurate account in order to represent conservation interests. By design, the biomass of large sharks in the 2006 RA model represents approximately 10% of B_0, as determined using the equilibrium routine. This should provide a realistic scope for growth in restoration studies.

The P/B ratio of adult large sharks was estimated based on Pauly (1980). His empirical formula predicts an M equal to 0.64 year^{-1}, which we can increase by 50% to represent fishing mortality (0.967 year^{-1}). This value, based on 2 species, was used in the initial model, but it was subsequently increased to 1.1 year^{-1} during the process of balancing. Juvenile sharks were set slightly higher, 1.3 year^{-1}. Polovina (1984) used a lower value for his 'reef sharks' group in the French Frigate Shoals, 0.18 year^{-1} and Opitz (1993) used 0.24 year^{-1} for her 'large sharks/rays' category in the Caribbean. However, our higher P/B value is appropriate for a heavily exploited stock. Consumption rate for the adult stanza was set at 3.6 year^{-1} in order to initialize the gross efficiency P/Q ratio at 0.3. The juvenile Q/B was estimated based on the mortality schedule in Table A.3.3. The production and consumption rates of small sharks were set relatively higher than large sharks, at 1.2 year^{-1} and 4 year^{-1}, respectively for adult stanzas; juvenile small shark consumption rates were estimated by the multi-stanza routine.

Elasmobranchs are an important marine resource for many artisanal fishers in RA. In fact, Indonesia has among the highest landings of chondrichthyans in the world (Stevens *et al.*, 2000), yet this significant catch goes largely unregulated. Although the gross catch of sharks is typically small compared to other oceanic resources such as teleosts (FAO 2005), fishing can have a major impact on the species group considering the slow growth rates of large sharks, in particular, and the low fecundity of viviparous species. Trolling fisheries in RA pursue large sharks for their high value fins, and these animals are also likely to be taken as bycatch in pelagic fishing operations, although no records were found. Catch of large sharks is estimated from DKP and Trade and Industry Office statistics to be 0.028 t·km^{-2}, of which 90% is assumed to originate from the adult stanza. 78% of the catch is exported, according DKP statistics. This value represents an average of the years 2000-2005. There is also a minor bycatch of large sharks entered for the trolling fleet (0.001 t·km^{-2}). The catch statistics available from the government bureaus referred to 'shark fins'. We assumed that this catch was entirely attributable to the large sharks functional group, and we back-calculated the total amount of shark biomass required to provide that quantity of shark fins. Under the assumed conversion ratio, 1 tonne of fins equates to roughly 24.1 tonnes of sharks. This rough estimate is based on a remark made for Gulf of Mexico fisheries (P. Ortiz, National Oceanic and Atmospheric Administration, cited in Raloff, 2002).

Despite the positive biomass accumulation rate estimated by Ecopath in 2006, the large shark group stands as overexploited in the model, with F2006 (0.97 year^{-1}) well in excess of F_{msy} (0.48 year^{-1}). The MSY of large sharks is estimated to be only 0.01 t·km^{-2}, or 470 tonnes for the whole area of RA. It is less than half of the current estimated catch. Only a miniscule catch was estimated for small sharks from governmental fisheries statistics, although this value is highly uncertain. A revised catch figure was therefore entered for small sharks that would represent a lightly exploited stock, where F_{2006} is approximately equal to 0.25 F_{msy}. The catch of small sharks is set at 6.24 kg·km^{-2} in the preliminary RA model. We assume that small shark species constitute 50% of the domestic catch, while exported catch consists entirely of large sharks.

Whale shark

This group represents the planktivorous whale shark, *Rhincodon typus*. Little is known about the abundance of this animal in RA or the health of the stock. However, sightings recorded by an ecotourism company operating in the Andaman Sea out of Phuket, Thailand suggests that whale shark abundance may have dropped by as much as 96% between 1998 and 2001 (Theberge and Dearden, 2006), although there are a variety of possible explanations. Biomass was estimated by Ecopath to be 3.2 $kg \cdot km^{-2}$, providing an estimate of 143 tonnes of whale sharks in RA. This suggests that there could be very few of these animals in the study area, especially considering that their maximum size may be as large as 36 tonnes per animal (Ritter, 2000), although W_{max} is frequently cited as less than 20 tonnes per animal.

The P/B ratio for whale shark was entered in very approximately as 0.068 $year^{-1}$, based on the empirical relationship for M offered by Pauly (1980), and assuming zero fishing mortality. Q/B was set at 0.228 $year^{-1}$ to establish a P/Q ratio of 0.3. The value used for Q/B is preliminary. It could be low considering the empirical formula of Pauly (1986) provides a much higher Q/B estimate, 2.022 $year^{-1}$.

We have applied a very low EE of 0.025, but it is not clearly known the extent to which these animals migrate (Wilson *et al.*, 2005; Colman, 1997). Similarly, an 80% diet import term was applied to represent the potentially wide-ranging habits of these individuals. There is fishing for these animals throughout the world in countries such as Indonesia, India, Philippines, Pakistan, Iraq and other places (Theberge and Dearden, 2006; Colman, 1997 and references therein). Catches in Philippines are thought to have declined in recent years, although the cause is unsure (Colman, 1997). We have entered in a zero catch rate for whale shark and zero discards, pending better information.

Manta ray and Rays

The manta ray group includes the giant manta (*Manta birostris*). The ray group, which is divided into adult and juvenile stanzas, represents 7 species of families Dasyatididae, Mobulidae and Myliobatidae: the bluespotted stingray (*Dasyatis kuhlii*), Bluespotted ribbontail ray (*Taeniura lymma*), Chilean devil ray (*Mobula tarapacana*), spotted eagle ray (*Aetobatus narinari*), painted maskray (*Dasyatis leylandi*), blackspotted whipray (*Himantura toshi*) and pygmy devilray (*Mobula eregoodootenkee*).

The biomass of manta rays is estimated by Ecopath to be low, only 3.166 $kg \cdot km^{-2}$. This equates to about 142 tonnes in all of Raja Ampat. The biomass of rays (0.177 $t \cdot km^{-2}$) was estimated based on subjective species-level abundance rankings offered by McKenna *et al.* (2002b). Weighting factors were determined for each abundance ranking based on the estimated absolute biomass of certain species in common to both the McKenna *et al.* (2002b) species list and COREMAP (2005). COREMAP (2005) abundance counts were converted to biomass density using an average species weight obtained from an age-structured model (see Section 2.5.8 - Biomass density estimates).

The P/B for manta rays is set slightly lower than that of rays, at 0.6 $year^{-1}$. The P/B for rays is set at 0.96 $year^{-1}$ in order to establish a realistic age distribution as quantified by the multi-stanza routine. The multi-stanza routine utilizes species-specific growth and maturity parameters from FishBase. In the Java Sea, Buchary (1999) estimated a production rate for demersal rays of 1.3 $year^{-1}$, which compares sufficiently well with our P/B estimate. The Q/B rate for manta rays is set at 2 $year^{-1}$ to provide a gross efficiency (P/Q) ratio of 0.3. The Q/B rate for rays was estimated based on the empirical formula Pauly (1986) to be 3.817 $year^{-1}$ (based on 5 species), but this was later decreased to 2.416 $year^{-1}$ to reduce the P/Q ratio. For comparison, Buchary (1999) used a consumption rate for demersal rays of 8.2 $year^{-1}$, and Opitz (1993) used a value of

4.9 $year^{-1}$ for her 'large sharks/rays' group.

We assume zero catch of manta rays. Ray catch is set at 0.021 $t{\cdot}km^{-2}$ based on the 'other' demersal catch category listed in DKP statistics. That quantity was divided among demersal functional groups whose catch was not quantified in a more precise catch category; those are rays and large demersals. The 'other' catch was divided between rays and large demersal groups according to their relative number of species in each group, assuming that the more specious large demersal group contributed a greater fraction of the undetermined catch.

Butterflyfish

The butterflyfish functional group consists of 57 member species of family Chaetodontidae. Fourteen genera are represented, but almost half the species in this group belong to genus *Chaetodon*. This functional group was designed to capture the unique ability of butterflyfish to predate on sea anemones, although some species may also prey on coral polyps (anthozoids), invertebrates and plant material (Cox, 1994).

Biomass density was calculated for RA to be 0.325 $t{\cdot}km^{-2}$ based on 44 species counted in the reef resource inventory of COREMAP (2005). To convert the coral reef biomass density to an average value for all of RA, we applied a correction factor based on the marine area to reef area ratio of Indonesia presented in Spalding *et al.* (2001). Abundance counts are converted to biomass using an average individual weight obtained from an age-structured model (see Section 2.5.8 - Biomass density estimates). This biomass was divided between adults (79%) and juveniles (21%) by implementing the multi-stanza mortality schedule in Table A.3.3.

The P/B rate for butterflyfish is set at 1.0 $year^{-1}$ after a natural mortality estimate for *Centropyge bicolor* (Aldenhoven, 1986). We determined a higher alternate value, 2.14 $year^{-1}$, based on Pauly's (1980) M formula for two RA species. However, the higher value is not used because it leads to a left-skewed age-biomass distribution under species-specific growth and mortality rates available from FishBase. The production rate of juveniles was set at 1.6 $year^{-1}$. A relatively high rate was required to resolve issues with over-predation of juveniles in the diet matrix. The Q/B of adult butterflyfish was estimated to be 11.282 $year^{-1}$ based on FishBase information for 49 RA species of butterflyfish. However, this rate was ultimately reduced to 6.720 $year^{-1}$ to reduce the P/Q ratio and allow the Q/B estimate to lie closer to the value for physiologically similar groups, such as medium reef-associated fish.

There is no explicit mention of butterflyfish in governmental fishery statistics, and it is likely that fishery on this group is minor compared to their substantial biomass. These species are typically solitary, or occur in pairs, and do not tend to form large shoaling aggregations suitable for targeted fisheries. This group is underexploited in the model. Total catch for this group is estimated to be 0.017 $t{\cdot}km^{-2}$, of which 90% is directed at the adult stanza. The following fishery indicators are estimated by the equilibrium analysis: F_{2006} = 0.06 $year^{-1}$; F_{msy} = 0.553 $year^{-1}$; MSY = 0.079 $t{\cdot}km^{-2}$, or about 3550 tonnes for RA.

Cleaner wrasse

The cleaner wrasse functional group includes 3 labrids: the tubelip wrasse (*Labrichthys unilineatus*), the bicolor cleaner wrasse (*Labroides bicolor*) and the Bluestreak cleaner wrasse (*Labroides dimidiatus*). Cleaner wrasse was given its own functional group to represent the cleaning mutualism effect seen between members of these species and larger reef fish that solicit their services. The removal of ectoparasites, dead skin and other refuse is assumed to improve the health of reef fish. This is represented in the BHS EBM models through mediation effects; adult groupers and snappers benefit from high biomass density of cleaner wrasse (see Section 2.2.2 - Mediation factors).

The biomass of cleaner wrasse in the RA model, 0.009 t·km^{-2}, is based on COREMAP (2005) reef resource inventory transects. The value is adjusted for the relative reef area in RA using the reef area to marine area ratio for all of Indonesia (Spalding *et al.*, 2001). Abundance counts are converted to biomass using an average individual weight obtained from an age-structured model (see Section 2.5.8 - Biomass density estimates).

Production rate of cleaner wrasse (3.779 year^{-1}) is set after the small reef associated fish group, as there was insufficient data available for cleaner wrasse. The only independent sampling-based mortality figure located for this group refers to L. *dimidiatus* (Eckert, 1987). The adult M is estimated as 0.11 year^{-1} and the juvenile M is 0.5 year^{-1}. These values are not used because they are too low compared to the Q/B estimate for this group. The Q/B calculation used the empirical formula of Pauly (1986). The figure, 13.097 year^{-1}, is based on *L. unilineatus* and *L. dimidiatus*.

A minuscule catch for cleaner wrasse is incorporated, 0.819 kg·km^{-2}·year^{-1}. The figure is based on the 'other' reef fish catch category listed in DKP and Trade and Industry Office statistics. That quantity was divided among reef-associated functional groups whose catch was not quantified explicitly by other catch statistic categories. The 'other' catch was divided between reef associated groups according to their relative number of species in each group, assuming that the more specious groups contribute a greater fraction to the undetermined catch. This data-poor group would benefit from further investigation.

Large pelagic fish

The large pelagic fish group consists of mainly piscivorous fish. It is divided into adult and juvenile stanzas. It is diverse and includes 25 species in the following familes: Belonidae, Bregmacerotidae, Chirocentridae, Coryphaenidae, Elopidae, Exocoetidae, Gonostomatidae, Hemiramphidae, Leiognathidae, Molidae, Myctophidae, Nettastomatidae, Polynemidae, Pristigasteridae, Salmonidae, Scombridae, Sphyraenidae, Stomiidae and Tetragonuridae.

The biomass of large pelagic fish (0.086 t·km^{-2}) was estimated based on the subjective species-level abundance rankings offered by McKenna *et al.*, (2002b). Weighting factors were determined for each abundance ranking based on the estimated absolute biomass of certain species in common to both the McKenna *et al.* (2002b) species list and COREMAP (2005). COREMAP (2005) abundance counts were converted to biomass density using an average species weight obtained from an age-structured model (see Section 2.5.8 - Biomass density estimates). The biomass of this group was divided between the adult (63%) and juvenile (37%) stanzas according to mortality schedule in Table A.3.3.

The P/B rate of adult large pelagic fish is set at 0.8 year^{-1}, slightly lower than tuna groups or smaller pelagic fish groups. This rate was modified during balancing from the original value calculated with Pauly's (1980) empirical formula for M, 1.079 year^{-1}, which was increased by 50% to account for F. The higher P/B rate, which is based on 9 species out of 26, is instead retained for the juvenile group. Q/B is set at 2.667 year^{-1} to maintain a gross efficiency P/Q ratio of 0.3. The empirical Q/B formula of Pauly (1986) predicted 5.644 year^{-1}. For comparison, Buchary (1999) used the following values to represent large pelagic predators in the Java Sea: P/B = 1.2 year^{-1} and Q/B = 8.65 year^{-1}.

Catch of large pelagic fish are calculated based on the miscellaneous or generic catch categories listed in DKP statistics for domestic landings (e.g., other pelagics), and Trade and Industry Office statistics for exported landings (mixed, frozen and smoked fish). These miscellaneous categories were divided among 8 aggregate groups in the model (all size classes of pelagic, reef-associated and demersal groups). Total catch for large pelagics is estimated to be about 0.035 t·km^{-2}, or about 186 tonnes for RA. 90% of the catch was assumed to originate from the adult stanza, and

10% from the juvenile stanza. The equilibrium analysis suggests that this group is fully exploited; current fishing mortality lies very close to F_{msy}. The following fishery indicators are estimated: F_{2006} = 0.575 year^{-1}; F_{msy} = 0.575 year^{-1}; MSY = 0.023 t·km^{-2}, or about 1030 tonnes for RA.

Medium pelagic fish

The medium pelagic fish group contains adult and juvenile stanzas for yellowtail barracuda (*Sphyraena flavicauda*), herring scad (*Alepes vari*), leaping bonito (*Cybiosarda elegans*), Hawaiian lady fish (*Elops hawaiensis*), slender suckerfish (*Phtheirichthys lineatus*), long tom (*Strongylura krefftii*), spottail needlefish (*S. strongylura*), largescale archerfish (*Toxotes chatareus*) and silvermouth trevally (*Ulua aurochs*).

The biomass of medium pelagic fish (0.029 t·km^{-2}) is determined in the same way as large pelagic fish. It is based on the subjective species-level abundance rankings offered by McKenna *et al.*, (2002b), where an absolute biomass value is calculated based on representative species found in COREMAP (2005) species transects (see Section 2.5.8 - Biomass density estimates). The biomass of this group was divided between the adult (40%) and juvenile (60%) stanzas according to mortality schedule in Table A.3.3.

The P/B rate of adult medium pelagic fish is set at 1.0 year^{-1}, and the rate for juveniles is set at 1.5 year^{-1}. These values produce a reasonable age distribution in the multi-stanza routine for an exploited group under species-specific FishBase growth and mortality parameters, and they are in line with respect to physiologically similar groups. Q/B for the adult group was set at 5.0 year^{-1}; the estimate was revised downward during balancing from the initial estimate based on Pauly's (1986) empirical equation, 7.729 year^{-1}. The P/Q ratio is 2.

Catches for medium pelagic fish were estimated from DKP statistics for domestic landings based on the 'other' pelagic fish miscellaneous category, and from Trade and Industry Office statistics for exported landings based on a fraction of the miscellaneous catch categories (frozen, mixed and smoked). These miscellaneous categories were divided among 8 aggregate groups in the model (all size classes of pelagic, reef-associated and demersal groups). However, the catch of adult medium pelagic fish was ultimately reduced during balancing to 6.912 kg·km^{-2}, which is 25% of the initial estimate. Without this amendment, the fishing mortality of the group was predicted to be more than 10 times the predation mortality, which is unrealistic. The juvenile catch estimate remains unaltered. Therefore, the overall catch for this group is represented in the RA model as 9.984 kg·km^{-2} for both stanzas combined, with approximately 2/3 of that amount attributed to the adult group. The following fishery indicators are estimated: F_{2006} = 1.383 year^{-1}; F_{msy} = 1.276 year^{-1}; MSY = 0.023 t·km^{-2}, or about 1030 tonnes for RA.

Small pelagic fish

The small pelagic fish are divided into adult and juvenile stanzas. This group contains 75 species and 47 genera in the following families: Atherinidae, Bregmacerotidae, Carangidae, Centrolophidae, Champsodontidae, Clupeidae, Dentatherinidae, Exocoetidae, Gobiidae, Hemiramphidae, Lactariidae, Leiognathidae, Melanotaeniidae, Microstomatidae, Myctophidae, Nomeidae, Pristigasteridae, Pseudomugilidae, Scombridae, Scopelosauridae, Sternoptychidae, Stomiidae and Terapontidae.

The biomass of small pelagic fish (0.178 t·km^{-2}) is determined in the same way as large and medium pelagic fish. It is based on the subjective species-level abundance rankings offered by McKenna *et al.*, (2002b), where an absolute biomass value is calculated based on representative species found in COREMAP (2005) species transects (see Section 2.5.8 - Biomass density estimates). The biomass of this group was divided between the adult (40%) and juvenile (60%)

stanzas according to mortality schedule in Table A.3.3.

P/B for small pelagic fish was estimated to be 3.99 year^{-1} based on an empirical formula for M of Pauly (1980); the value was increased by 50% to account for additional fishing mortality. This is high compared to previously used values, and so we considered it an upper estimate of total mortality or production and it was applied to the juvenile stanza. Rates used for similar groups in coral reef models are 1.1 year^{-1} (small pelagics; Polovina, 1984) and 1.8 year^{-1} (small schooling fish; Opitz, 1993). The adult stanza P/B was instead set at 2.0 year^{-1}. Q/B was estimated using the empirical formula of Pauly (1986) as 18.462 year^{-1} based on 8 species, but this rate was reduced by about 30% during balancing to 13.267 year^{-1}.

Catches for small pelagic fish were estimated from DKP and Trade and Industry Office statistics and represents an average of the years 2000-2005. Miscellaneous catch categories (e.g., mixed fish, other pelagics) were divided among 8 aggregate groups in the model (all size classes of pelagic, reef-associated and demersal groups). Total catch for small pelagics is 0.038 t·km^{-2}, or about 1690 tonnes for RA. 90% of the catch was assumed to originate from the adult stanzas, and 10% from the juvenile stanzas. The following fishery indicators are estimated: F_{2006} = 0.824 year^{-1}; F_{msy} = 1.154 year^{-1}; MSY = 0.042 t·km^{-2}, or about 1900 tonnes for RA.

Large reef-associated fish

Large reef-associated fish are divided into adult and juvenile stanzas. This is the most speciose group in the RA model. It represents 213 species (54 families and 111 genera) not elsewhere included in functional groups. Since it is a large aggregate group, many life histories and feeding modes are implicitly represented.

Estimates vary greatly in the literature as to the biomass of large reef-associated fish on coral reefs. Reef transect results from Weigeo Island in COREMAP (2005) lead to an estimate of 11.640 t·km^{-2}; this value has been compiled at the species level and corrected for reef area to represent all of RA. We divided biomass between the adult (55%) and juvenile stanzas (45%) according to mortalities in Table A.3.3. Although we have entered this value into the preliminary RA model, it is worth noting that Weigeo may be less exploited than other areas in RA. This value may therefore represent an upper estimate of large reef fish biomass. It is high compared to the biomass value of large reef fish 3.5 t·km^{-2} for Caribbean reefs (Opitz, 1993; corrected for reef area ratio), 3.0 t·km^{-2} for NW Philippines reefs (based on a compilation of functional group data from Aliño *et al.*, 1993) or 0.5 t·km^{-2} for the Gulf of Thailand (estimated from Khongchai *et al.*, 2003). However, the COREMAP value is in line with the biomass density used by Polovina (1984) for a large area surrounding French Frigate Shoals, 23 t·km^{-2}; especially since his value could be reduced somewhat for accurate comparison with respect to species composition and relative reef area coverage. Project outputs are expected to provide a better estimate of large reef-associated fish biomass. A negative biomass accumulation rate of -0.15 year^{-1} was entered to reproduce the observed rate of decline seen in time series abundance estimates.

The P/B ratio of large reef-associated fish was set preliminarily as 0.4 year^{-1} for adults and 0.6 year^{-1} for juveniles. The M formula of Pauly (1980) suggested a high natural mortality rate for RA large reef associated species of 1.29 year^{-1}, to which we can likely add a sizable amount of fishing mortality. An alternate M estimate for this group, 1.31 year^{-1}, can be based on four member species of families Mullidae, Labridae and Siganidae (calculated from Macpherson *et al.*, 2000; Eckert, 1987; Pajuelo *et al.*, 1997; Ozbilgin *et al.*, 2004; Kaunda-Arara *et al.*, 2003). However, these high values perturbed the age structure; they lead to a left-skewed distribution and were not used. Q/B of large reef associated fish (4.0 year^{-1}) was reduced significantly during balancing from an initial estimate based on the formula of Pauly (1986) of over 8.9 year^{-1}. Further investigation is required to parameterize this influential functional group.

Large reef associated catch estimated from DKP statistics was about 0.069 t·km^{-2}. This amount was based on a compilation of catch statistic categories listed in governmental records including trevallies, breams, catfish and the 'other' unidentified reef fish category. The latter category was divided between this EwE functional group and other reef-associated groups not explicitly mentioned by catch statistics, in a proportion equal to the relative number of species in each group. The large reef associated group, having many species, garnered a large fraction (55%) of this undermined catch component. However, compared with the adult large reef-associated fish biomass estimate from COREMAP (2005) of 6.368 t·km^{-2}, the fishery did not appear to be a major source of mortality. The calculated catch value is low even compared to Venema (1997), whose catch estimate for 'coral fish' in an adjacent area can be converted to 0.509 t·km^{-2}.

However, it is likely that there is a large amount of unreported catch also occurring in this group. The statistics recorded by the DKP and the Trade and Industry Office refer to fish landed in Sorong. However, this group is targeted throughout the archipelago by commercial and artisanal fisheries. Catches may go unreported even when landed in port (M. Bailey, UBC Fisheries Centre, 2202 Main Mall, Vancouver, Canada, pers. comm.). Until we have a more formal estimate of unreported artisanal catch occurring in this group, we will make the precautionary assumption that 10% of the catch is recorded by government statistics. Total landings for this group are therefore 0.690 t·km^{-2}, which is applied to the adult stanza (80%) and juvenile stanza (20%). For the adult large reef-associated group this yields a current fishing mortality approximately equal to 1/3 of F_{msy}, representing a lightly exploited stock. F_{2006} is determined to be 0.081 year^{-1}, F_{msy} is 0.178 year^{-1} and MSY is 0.343 t·km^{-2}, or about 15,400 tonnes annually from RA.

Medium reef-associated fish

The medium reef-associated fish group includes 176 species, with 26 fish families represented and 79 genera. The majority of species belong to three families: wrasses (Labridae), damselfish (Pomacentridae) and cardinalfish (Apogonidae). The biomass of medium reef-associated fish is estimated based on COREMAP (2005) reef transect abundance counts to be about 5.2 t·km^{-2}. About 55% of biomass is concentrated in the adult stanza and the remainder is in the juvenile stanza according to the multi-stanza mortality schedule (Table A.3.3). The biomass estimate for the RA model, determined on transect sites near Weigeo Island, has been scaled to represent the relative marine to reef area ratio in Raja Ampat after Spalding *et al.* (2001).

The P/B ratio of medium reef-associated fish (adults: 0.8 year^{-1}; juveniles: 1.4 year^{-1}) is set arbitrarily to a reasonable value, as there is not enough species-level information to apply an empirical formula. Independent natural mortality estimates were located for three species in this group, *Selaroides leptolepis, Stethojulis strigiventer* and *Istigobius decoratus* (Torres *et al.*, 2004; Eckert, 1987; Kritzer, 2001). These values average out to 4.64 year^{-1}, but this M value is high compared to the other reef fish groups in the model, and it is probably not representative of medium reef-associated fish. The Q/B value was set at 5.0 year^{-1} for adult medium reef associated fish to maintain an intermediate value with respect to the small and large reef associated groups.

The catch of medium reef-associated fish, as estimated from DKP and the Trade and Industry Office statistics, was very low: only 0.027 t·km^{-2}. The estimate barely constitutes 2% of the standing stock biomass, and the resulting F is only 2% of M. We have assumed, as with the large reef-associated group, that there is a substantial amount of unreported catch. Catch of adult medium reef-associated fish was increased in the RA model to 0.3 t·km^{-2}, such that $F \approx 1/4$ M. This represents a lightly exploited stock. The assumption implies that the annual artisanal and unreported catch (and discards) could be as much as 10 times the reported landings. However, the methodology used to estimate the catch of this group, based on an assigned fraction of miscellaneous catch categories in governmental statistics, is very approximate. Therefore, the 'reported' catch figure is also highly uncertain. Juvenile catches were increased in the same proportion as the adults with respect to the initial fishery estimate. The following fishery indicators are estimated for this group: F_{2006} = 0.123 $year^{-1}$, F_{msy} = 0.4 $year^{-1}$ and MSY = 0.824 $t{\cdot}km^{-2}$, or about 37,000 tonnes for RA annually.

Small reef-associated fish

The small reef-associated fish group is divided into adult and juvenile stanzas. 206 fish species are included in 22 families and 92 genera. About 1/3 of the species in this group are gobies (Gobiidae); the other major familes are cardinalfish (Apogonidae), damselfish (Pomacentridae) and wrasses (Labridae).

The biomass of this group is estimated from COREMAP (2005) abundance transects as 0.394 $t{\cdot}km^{-2}$. We converted the abundance counts into biomass using an average weight for each species, calculated with an age-structured model (see Section 2.5.8 - Biomass density estimates). This value has been adjusted to represent average biomass density in RA using reef area to marine area ratio for all of Indonesia (Spalding *et al.*, 2001). The biomass value was split into adult (66%) and juvenile stanzas (34%) according to the multi-stanza mortality schedule (Table A.3.3). This functional group is energetically less important to the system than the medium or large aggregate reef fish groups due to the size-based criteria used in assigning fish species to groups.

P/B of adult small reef associated fish is based on data for 4 member species (1 cardinalfish and 3 damselfish). We applied the empirical relationship for M described by Pauly (1980) to estimate a production rate of 3.779 $year^{-1}$. We did not explicitly incorporate fishing mortality. For comparison, Aliño *et al.* (1993) used 14.02 $year^{-1}$ for gobies, 3.88 $year^{-1}$ for cardinal fish and 3.3 $year^{-1}$ for damselfish in modelling a reef flat in the Philippines. Independent sampling estimates a production rate of 5.95 - 6.37 $year^{-1}$1 for one species of blenny present in RA (*Salarias patzneri*, Wilson, 2004); rightfully, this small species should fall higher than the group average. Q/B for the adult stanza is set at 15.0 $year^{-1}$. It was reduced slightly from the estimate based on Pauly's (1986) formula, 18.3 $year^{-1}$ (based on 77 species out of 206) in order to keep the P/Q ratio (0.2) similar to other reef-associated groups.

As with large and medium reef associated fish, the catch figure derived from DKP and Trade and Industry Office statistics was low, 0.019 $t{\cdot}km^{-2}$. This number was not used, and a higher catch figure was added to Ecosim (0.165 $t{\cdot}km^{-2}$), so that $F \approx 1/4$ M. This represents a lightly exploited stock. Fishery values are as follows: F_{2006} = 0.579 $year^{-1}$, F_{msy} = 2.422 $year^{-1}$ and MSY = 0.371 $t{\cdot}km^{-2}$, or about 16,700 tonnes for RA annually.

Large and small demersal fish

The large demersal group includes the following species: Japanese rubyfish (*Erythrocles schlegelii*), whipfin silverbiddy (*Gerres filamentosus*), gobies (*Amblyeleotris arcupinna*, *Trimma griffthsi*, *T. halonevum*), freshwater moray (*Gymnothorax polyuranodon*), barredfin moray (*G. zonipectus*), spotted armoured gurnard (*Satyrichthys rieffeli*), Japanese flathead (*Inegocia japonica*) and Jarbua terapon (*Terapon jarbua*). The small demersal group includes: Ocellated waspfish (*Apistus carinatus*), cardinal fish (*Apogon fleurieu*, *A. ocellicaudus*), spotwing flying gurnard (*Dactyloptena macracantha*), blue speckled prawn goby (*Cryptocentrus octofasciatus*), wrasse (*Choerodon zosterophorus*), black-edged sweeper (*Pempheris mangula*), tuberculated flathead (*Sorsogona tuberculata*), freshwater demoiselle (*Neopomacentrus taeniurus*), insular shelf beauty (*Symphysanodon typus*) and threadfin blenny (*Enneapterygius philippinus*).

The total biomass for large demersal fish, 0.415 t·km^{-2}, is based on subjective species-level abundance rankings provided by McKenna *et al.*, 2004. The quantity is divided between adult (48%) and juvenile stanzas (52%) based on the mortality schedule in Table A.3.3. A weighing factor was assigned to each abundance ranking based on species common to both the McKenna *et al.* (2004) list and COREMAP (2005). The biomass for this group represents a sum of member species' values; it is corrected for area to represent a RA average, using marine to reef area ratios in Spalding *et al.* (2001). The biomass compares well to the estimate of Venema (1997), who quoted a biomass density in 1995 equivalent to 0.6 t·km^{-2}, and whose estimate included other specific taxa incorporated here into other functional groups. Biomass of small demersal fish (0.327 t·km^{-2}) is calculated in the same way as large demersal fish. It is similarly divided into adult (59%) and juvenile (41%) stanzas.

Pauly's (1980) equation was used initially to determine natural mortality for large demersals as 1.69 year^{-1}, based on a tigerfish and a silverbiddy. This value is high compared to the one used by Buchary (1999) for modelling large demersal predators (0.92 year^{-1}). It also provided an unrealistic age distribution in the multi-stanza routine and so was not used. A lower value is substituted for adult large demersals (0.6 year^{-1}). Buchary's (1999) value was assumed to represent an upper limit for this group, and it was applied to the juvenile stanza. Similarly, a value of 2 year^{-1} is set for small demersals, and Buchary's (1999) value for small demersal predators is applied to the juvenile stanza (2.56 year^{-1}). Large consumption rates were estimated using the Q/B relationship of Pauly (1986): for large demersals, 8.42 year^{-1} and for small demersals, 18.5 year^{-1}. These figures are uncertain and they are only based on 2 and 1 species, respectively. Buchary used lower values, 6.13 year^{-1} and 12.84 year^{-1} for large and small demersals, yet any of these produce unrealistic P/Q ratios. Lower consumption rates are therefore in place: for large demersals (3.1 year^{-1}) and for small demersals (8.6 year^{-1}), providing P/Q ratios $\approx$ 0.2.

We estimate that there is a catch of approximately 0.029 t·km^{-2} for large demersal fish. This is based on DKP statistics, and it represents an average of the years 2000-2004. The figure combines recorded catch for croakers, threadfins and miscellaneous groups such as 'other demersal fish'. The figure has also been increased by 50% to represent unreported artisanal catch and scaled in proportion to relative reef area (from marine area ratios in Spalding *et al.*, 2001) to provide an average RA estimate. The fishery catch offered by Venema (1997) for an adjacent area in Eastern Indonesia can be re-stated as 0.297 t·km^{-2}, when corrected for relative reef area in RA; it is an order of magnitude higher than the present estimate, and in fact higher than the standing biomass of the large demersal group. However, this catch value considers species which have been placed into other functional groups in the RA models. 90% of the large demersal catch is assumed to originate from the adult stanza; the remainder is considered juvenile catch. Small demersal catch is determined in the same way, as 0.032 t·km^{-2}. These catch values result in the following fishery indicators: for large demersals F_{2006} = 0.679 year^{-1}, F_{msy} = 0.561 year^{-1} and MSY = 0.040 t·km^{-2}, or about 670 tonnes for RA annually; for small demersals, F_{2006} = 0.210 year^{-1}, F_{msy} = 2.868 year^{-1} and MSY = 0.247 t·km^{-2}, or about 11,100 tonnes for RA. Large demersals are therefore represented as being overexploited, while small demersals are underexploited.

Large and small planktivore fish

The large planktivore fish group contains 52 species (19 families and 31 genera); well-represented are planktivorous species of fusiliers, trevally, jacks, scads and soldierfish. The small planktivore group contains 62 species (17 families and 39 genera); almost half of the species in this group are in family Pomacentridae (mainly damselfish and demoiselles), with some species of cardinalfish, blennies and gobies as well. These groups are divided into adult and juveniles stanzas. The planktivorous functional groups were created to represent an important trophic link on coral reefs, through which energy passes from planktonic secondary producers to the benthic reef fish community. Obligate and facultative planktivorous species are included in the planktivorous functional groups. For a species to be included into a planktivorous functional group a prominent mention of planktivory is required in diet remarks on the FishBase Species, Ecology, or FoodItems table (see Section 2.4.2 - Planktivorous fish).

Abundance data available from reef transects at Weigeo Island lead to a very high biomass density for large planktivorous for the RA model, 9.56 t·km^{-2}. Under the current mortality scheme (Table A.3.3) this would amount to more than 5 t·km^{-2} of adult fish in RA (about 290 t·km^{-2} on reefs). Although this group contains some abundant species, such as the red-bellied fusilier (*Caesio cuning*) (COREMAP, 2005) and the oxeye scad (*Selar boops*) (Obed Lense, TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, pers. Comm..), we considered this value to be too high for an RA average. The adult biomass was therefore set arbitrarily to 1.0 t·km^{-2}, and the juvenile stanza biomass was calculated by Ecopath as 0.89 t·km^{-2}. This may be a critical group in the trophic functioning of the RA ecosystem, and we hope that project outputs will allow us to improve this parameter.

The P/B ratio of adult and juvenile large planktivorous fish is determined based on the M relationship described by Pauly (1980). The value represents an average for 17 RA species. The calculated value, 2.0 year^{-1}, was applied to the juvenile stanza, while the adult stanza received a lower value, 1.5 year^{-1}. These figures provided a suitable age-biomass distribution. The small planktivore group uses a P/B rate of 2.0 year^{-1} for adult and juvenile stanzas. Pauly's (1980) M formula had been used to predict a P/B rate for small planktivorous fish of over 6.0 year^{-1} but when applied as a mortality rate, this high value produces a left-skewed age-biomass distribution. The empirical equation of Pauly (1986) predicted a Q/B consumption rate of over 20 year^{-1} for small planktivorous fish. This value was reduced substantially, so that P/Q equals 0.33. Q/B of the adult stanza was similarly set to produce a P/Q ratio of 0.3.

Catch was estimated for large planktivores at a very low quantity from DKP and Trade and Industry Office statistics, less than 0.019 t·km^{-2}. However, this estimate is based on highly aggregated statistics and may be missing a large amount of unreported catch. As this amount did not have any noticeable influence on the functional group in preliminary fishery simulations, the figure was discarded in favour of a larger value, 0.33 t·km^{-2}, so that $F \approx 0.4M$. This quantity elicits a more reasonable response from the large planktivore group under a realistic variety of fishing pressures. Small planktivore catch is set at 0.014 t·km^{-2}. For both large and small groups, 90% of the catch is assumed to originate from the adult stanza; the remainder from the juvenile stanza. The following fishery indicators are determined: for large planktivores F_{2006} = 0.3 year^{-1}, F_{msy} = 0.7 year^{-1} and MSY = 0.478 t·km^{-2}, or about 11,100 tonnes for RA; for small planktivores, F_{2006} = 0.031 year^{-1}, F_{msy} = 0.6 year^{-1} and MSY = 0.223 t·km^{-2}, or about 10,000 tonnes for RA. Large and small planktivores are therefore underexploited in the RA model.

Anchovy

The Anchovy group contains 17 Engraulids of genera Stolephorus, Thryssa, Setipinna and Thryssa; *Stolephorus* is the dominant genus by biomass in shallow habitats surrounding the Raja Ampat islands; especially important is *S. indicus* (Mark Erdmann. CI. Jl. Dr. Muwardi. 17 Renon Denpasar, Bali, Indonesia; Chris Rotinsulu. CI. Jl Arfak No. 45. Sorong, Papua, Indonesia 98413, pers. comm.). This species supports large artisanal fisheries throughout the RA archipelago. A major artisanal fishery is located on southern Weigeo Island in Kabui Bay and surrounding areas. Villagers export the anchovies for bait to northern Weigeo pelagic fisheries, or dry them for local consumption. The large anchovy population is thought to be supported by a productive upwelling area in central Dampier Strait (M. Erdmann. CI. Jl. Dr. Muwardi. 17 Renon Denpasar, Bali, Indonesia, pers. comm.).

Wolanski (2001) used an anchovy biomass of 3.122 t·km^{-2} for an inter-reef / lagoon Great Barrier

Reef model. As our study area contains a greater proportion of deep areas, the coastal anchovy species will have a lower average biomass density. We have elected to use a smaller arbitrary value, pending better information. Adult anchovy biomass is set at 1.5 t·km^{-2} and juvenile biomass is estimated by the multi-stanza routine, providing a total anchovy biomass of 3.737 t·km^{-2}. Fishers in Kabui Bay indicated that there has been a recent reduction in the available biomass of anchovies (M. Bailey, UBC Fisheries Centre. 2202 Main Mall, Vancouver, Canada, pers. comm.). A negative biomass accumulation rate of -0.2 year^{-1} was entered to represent this and set baseline surplus stock production so that F_{msy} is approximately 2-3 times greater than the current fishing mortality (Fig. B.2.1).

The P/B ratio entered for anchovy is 3.37 year^{-1}, based on M of *S. indicus* (Torres *et al.*, 2004). Pauly's (1980) equation predicts a similar value, M = 3.27 year^{-1}, averaged for eight RA anchovy species present in the model, while an average of 5 world engraulids from independent sampling studies yields M = 5 year^{-1} (Torres *et al.*, 2004). These values could be increased somewhat to represent fishing mortality. However, a greater mortality value than the one used results in an unrealistic left-skewed age-biomass distribution under the estimated maturity parameters. Moreover, other authors have used even lower production rate values for anchovy, such as Heymans *et al.*, 2004 (1.2 year^{-1} for Benguela upwelling) and Ainsworth *et al.*, 2001 (1.15 year^{-1} for Bay of Biscay). Q/B rate for anchovy (14.625 year^{-1}) is estimated from 9 RA engraulids using the regression relationship of Pauly (1986).

A rough estimation of anchovy catch based on reported catch rates from Waisai fishers by Bailey *et al.* (*this volume*) suggests an unreported catch rate of 0.401 t·km^{-2} for all Weigeo fisheries. Increasing that value by 20% to consider other area in RA, and adding the official fraction of reported catch (0.028 t·km^{-2}), leads us to an overall catch estimate of 0.509 t·km^{-2} for RA, which we apply entirely to the adult stanza. Here we have assumed that Weigeo fisheries constitute the large majority of RA anchovy catch, as is the consensus among field-based researchers. This provides a similar estimate to an independent catch calculation based on data in Venema (1997). They reported a catch rate in 1993 of 70 thousand tonnes of small pelagics from Area III.3 (Ceram, Maluku and Tomini), or 1.829 t·km^{-2}. Assuming that anchovies comprise 30% of this catch we may expect 0.549 t·km^{-2}, which is close to our current estimate. The following fishery indicators are estimated for anchovy: F_{2006} = 0.391 year^{-1}, F_{msy} = 1.218 year^{-1} and MSY = 0.887 t·km^{-2}, or almost 40,000 tonnes for RA.

Deep-water fish

Deep-water fish is a large aggregate group representing 58 species that occur at depths greater than 200 m, on the shelf slope or deeper. Bathypelagic and bathydemersal species were included in this group based on their habitats listed in the FishBase Species table 'Habitat' field, and on the depth range reported in the 'DepthRangeDeep' field. This group summarizes data for 26 fish families, but almost half the species in this group belong to families Myctophidae (lanternfishes) and Stomiidae (dragonfishes).

No species of deep-water fish were identified in the available surveys for RA. However, the rough estimate for adult stanza biomass, 0.6 t·km-2, provides an appropriate EE value (~0.9). With juvenile biomass estimated by the multi-stanza routine, overall biomass for deep-water fish is set at 1.394 year^{-1}.

The production rate used is 1.13 year^{-1}, and it is based on *Myctophum asperum* (Palomares and Pauly, 1998). This value is significantly lower than the natural mortality estimate made using Pauly's (1980) M formula, 3.94 year^{-1} based on six RA deepwater species. The higher value is not used because it results in a left-skewed age-biomass distribution under the assumed maturity parameters. An alternate estimate for myctophids is 0.91 year^{-1}, which is based on 5 world species (Palomares and Pauly, 1998). Q/B (3.667 year^{-1}) is set relative to the production rate, so that the gross efficiency P/Q ratio equals 0.3.

The catch estimate for deep-water fish is based on the entry for hairtails in DKP statistics, as there are 4 species of family Trichiuridae in the models and they all occur in this group. The figure represents an average of the years 2000-2004. We assume zero unreported catch and zero discards. The catch estimate (9.2 kg·km^{-2}) is divided between adult (90%) and juvenile (10%) stanzas. Ecosim estimates the following fishery indices: F_{2006} = 0.034 year^{-1}, F_{msy} = 0.450 year^{-1} and MSY = 0.115 t·km^{-2}, or about 5100 tonnes for RA.

Macro-algal browsing

Herbivorous fish in the RA models are divided into three functional groups according to how severely they impact the substrate. Most damaging are the eroding grazers, followed by scraping grazers and then macro-algal browsing fish. Macro-algal browsing fish represent an important functional link in coral reef ecosystems. Together with sea urchins, they regulate the biomass of algae, and may help coral recruits to settle by keeping the substrate exposed (Mous and Muljadi, 2005). The group represents three herbivorous species: *Piaractus brachypomus*, *Nematalosa erebi* and *Valamugil buchanani*.

Local abundance data is expected in late 2006 for some herbivorous species on reefs from Kofiau Island transects, but it was not available for this report. No species in this group were identified by the available RA surveys, and so a preliminary biomass value of 0.25 t·km^{-2} was entered. It is a relatively low value for this selective group of 3 species. With juvenile biomass estimated by the multi-stanza routine, total biomass of macro-algal browsing fish is estimated to be 0.75 t·km^{-2}.

P/B was set at 1.339 year^{-1} using the M formula of Pauly (1980) based on *V. buchanani* and *P. brachypomus*. Juvenile P/B is set at 1.4 year^{-1}. Q/B was estimated for all species as 13.76 year^{-1} using the empirical formula of Pauly (1986).

A small catch was entered in for macro algal browsing fish of about 8 kg·km^{-2}. This is a small fraction of the large reef associated group catch estimated from the DKP and Trade and Industry Office statistics. The amount is proportional to the relative number of species occurring in each group. This group is underexploited in the model. The fishery indicators for this group are: F_{2006} = 3E-3 year^{-1}, F_{msy} = 0.25 year^{-1} and MSY = 0.033 t·km^{-2}, or about 1500 tonnes for RA.

Eroding grazers

This group consists of green humphead parrotfish (*Bolbometopon muricatum*) and the steep head parrotfish (*S. microhinos*). The biomass estimate for eroding grazers is derived from COREMAP (2005) reef transects on Weigeo Island, 0.783 t·km^{-2}. The value has been scaled down based on the relative reef area in RA using ratios in Spalding *et al.* (2001). That amount is divided between the adult (67%) and juvenile stanzas (33%) according to the mortality schedule in Table A.3.3. The abundance data refers to *Bolbometropon spp.* but we assume the majority of biomass is accounted for by the member species of this group.

The production rate of eroding grazers is based on *B. muricatum*. The value, 0.435 year^{-1} represents M from Pauly's (1980) equation, but it has been increased by 50% to account for fishing mortality. Juvenile P/B is set at 1.0 year^{-1}. We estimated the Q/B of *B. muricatum* as 4.319 year^{-1} using the formula of Pauly (1986), but subsequently we accepted a lower value of 1.45 year^{-1} so that P/Q equals 0.3.

A small amount of catch was entered in the base model representing a fraction of the estimated large reef associated fish catch. The proportion is set based on the relative number of species in each group. The fishery indicators for this group are: F_{2006} = 3E-3 $year^{-1}$, F_{msy} = 0.25 $year^{-1}$ and MSY = 0.056 t·km^{-2}, or about 2500 tonnes for RA.

Scraping grazers

Scraping grazers include 82 species of parrotfish (family Scaridae), surgeonfish and unicornfish (Acanthuridae) and filefile (Monacanthidae). Scraping grazers were given their own functional group in the RA models to represent the important role that these animals play on coral reefs (Bellwood *et al.*, 2004). The biomass estimate for eroding grazers is derived from COREMAP (2005) reef transects on Weigeo Island, 2.004 t·km^{-2}. The value has been scaled down based on the relative reef area in RA. It is divided between adult (17%) and juvenile stanzas (83%) according to the mortality schedule (Table A.3.3).

The P/B ratio is based on Pauly's (1980) M relationship, and averages 18 fish in the scraping grazers group. The value, 2.339 $year^{-1}$ has been increased by 50% to account for additional fishing mortality. Juvenile P/B is set at 3.0 $year^{-1}$. The Q/B value is was estimated from the equation of Pauly (1986) as 12.74 $year^{-1}$ based on 50 species.

There is a small amount of catch entered for scraping grazers, 0.025 t·km^{-2}. This represents a fraction of the large reef associated catch proportional to the relative number of species in each group. Scraping grazers are underexploited in the model. The fishery indicators for this group are: F_{2006} = 0.094 $year^{-1}$, F_{msy} = 0.7 $year^{-1}$ and MSY = 0.092 t·km^{-2}, or about 4100 tonnes for RA.

Detritivore fish

Seven detritivorous fish species were categorized into this group. To qualify, a prominent mention of detritivory is required for the predator species in the FishBase 'Diet' table, or in the 'Species' table comment field. Although many species consume detritus incidentally, or as a minor diet component, only species that rely on detritus as a main food source were included in these functional groups. Detritivory is based on the FishBase 'Species' table 'comment' field and 'Ecology' table 'Herbivory2' field.

The detritivorous fish group contributes relatively little to the overall reef fish biomass in the RA model, as it has been noted that invertebrates, not detritivorous reef fish, are primarily responsible for energy cycling in the ecosystem (A. Muljadi. TNC-CTC. Jl Gunung Merapi No. 38, Kampung Baru, Sorong, Papua, Indonesia 98413, pers. comm.). Reef transects confirm a low biomass of these species, 0.016 t·km^{-2} (COREMAP, 2005). This value has been scaled to represent the average of RA.

The P/B rate of detritivorous fish is set at 2.339 $year^{-1}$; it is set equal to the value used for scraping grazers. No addition mortality information could be found for these species. A Q/B value was estimated using Pauly's (1986) empirical equation, 11.86 $year^{-1}$, but this was reduced to 8.33 $year^{-1}$ so that P/Q would lie closer to 0.3.

A small catch is entered for this group in the base model as a fraction of the large reef associated group catch. The proportion represents the relative number of species in each group. The group is lightly exploited in the model; F is about 6% of M.

Azooxanthellate corals

Azooxanthellate corals are consumers. We have allowed Ecopath to estimate their biomass in the system based on the assumption that EE ≈ 0.95. Biomass is estimated to be 0.6 t·km^{-2}. A production rate of 1.44 $year^{-1}$ was used because it is two-thirds of the value used for reef-building corals, and a Q/B rate of 3.6 $year^{-1}$ provides a P/Q ratio of 0.4.

Hermatypic scleractinian corals

These are the reef-building scleractinian corals. Hermatypic scleractinian corals are modelled as facultative consumers because they predate on zooplankton, yet also have endosymbiotic zooxanthellae, autotrophic dinoflagellates that provide photosynthetic products to the coral.

There have been a wide range of parameters applied to coral functional groups in previous EwE studies (Table 2.6). We use a biomass value calculated from Crossland *et al.* (1991), who suggested a global coral reef biomass density in the range of 10-100 gC·m^{-2}. Their mean reported value was used, 30 gC·m^{-2}. This amount was converted to wet weight using a carbon to carbohydrate conversion factor, which we assumed to equal animal dry weight, and a dry to wet weight conversion factor from Atkinson *et al.* (1984). This calculation gives a biomass estimate of about 50 t·km^{-2} on reefs. Corrected for the relative reef area in RA using the marine to reef area ratio for Indonesia reported by Spalding *et al.* (2001) gives an overall biomass value for the study area of 0.875 t·km^{-2}. We hope to replace this approximate value with a better estimate from RA coral cover estimates.

The production rate of reef building corals was calculated from Crossland *et al.* (1991). They estimated a daily turnover rate of reef biomass on the order of 0.003 day^{-1}. This equates to 1.095 year^{-1}. The Q/B was set at 3.6 year^{-1}, giving a high P/Q ratio of 0.6. This is appropriate for a facultative consumer.

Table 2.6 - Biomass and production rates used previously in EwE to represent reef-building corals.

Area	**Biomass (t·km^{-2})**	**P/B (·year^{-1})**	**Original group name**	**Source**
Central Java	17.48	0.1	"Living bottom structure"	Nurhakim, 2003
Mexican Caribbean	1-30	0.7-1.8	"Sessile animal feeders"	Arias-González, 1998
Java Sea	20	0.1	"Living bottom structure"	Buchary, 1999
Caribbean	1000	0.8	"Sessile animals"	Opitz, 1993
Bolinao, Philippines	200	0.1	"Sessile invertebrate consumers"	Aliño *et al.*, 1993
Hong Kong	0.399	1.09	"Corals"	Buchary, 1999
Tiahura, Moorea Island, French Polynesia	19.74	1.92	"Corals"	Arias-González, 1997
New Caledonia	1.47	1.47	"Corals/zooxanthellae"	Bozec *et al.*, 2004
French Frigate Shoals	289	3	"Heterotrophic benthos"	Polovina, 1984
Great Barrier Reef		0.04	_____	Sorokin, 1981
World averages		1.095	_____	Crossland *et al.*, 1991

The loss rate of hard corals from destructive fishing methods and other stressors is not well known, but one estimate from Bolinao, Philippines supposes that 0.4% of the live coral cover is lost each year (McManus *et al.*, 1997); and cyanide fishing is also known to have caused damage to reefs in Raja Ampat. The damage arises from the toxin's direct contact on coral polyps, and also from the action of divers breaking coral away to retrieve the stunned fish. The loss of coral can cause major changes in the reef ecosystem, and it has been associated with a decline in fish biodiversity (Wilson *et al.* 2006).

A range of possible values for coral loss were identified for Indonesia: a conservative 0.05-0.06% per year estimate to 0.5-0.7% per year (Mous *et al.*, 2000); the authors note that this is a small possible rate of loss compared to coral re-growth rates. We therefore enter a biomass accumulation rate into this group of -0.5% per year for the 2006 RA model, which has a minimal impact on dynamics.

Non reef-building scleractinian corals and soft corals

Like the hermatypic sceractinian corals, the non-reef building ahermatypic scleractinian corals and the soft corals are both facultative consumers containing symbiotic zooxanthellae. Until we can find or produce more accurate information for RA, we have allowed Ecopath to estimate the biomass of these groups based on the assumption that EE ≈ 0.95. For both groups, this produces a biomass value very close to 0.6 year^{-1}. The production rate of non-reef building scleractinian corals is set arbitrarily at 1.4 year^{-1}, slightly lower than azooxanthellate corals.

Penaeid shrimps and Shrimps and prawns

Biomass of penaeid shrimp and shrimps and prawns is set as 2.0 t·km^{-2} respectively pending better information. The P/B value used for penaeid shrimps in the RA model is 3.824 year^{-1}. This value was calculated as the average of the P/B values calculated for 4 species. The P/B for *Penaeus duorarum* (an Atlantic species), and *Metapenaeus monoceros* was calculated using Brey's (1995) equation. The maximum age and maximum weight for *Penaeus duorarum* is 1.17 year and 38.05 g (Bielsa et al, 1983). Maximum age for *Metapenaeus monoceros* was estimated by Srivatsa (1953) as 1.59 year. The maximum weight is calculated based on length-based relationship of Abdurahiman *et al.* (2004). P/B values of 5.245 year^{-1} and 3.83 year^{-1} were used for the average based on *Trachypenaeus fulvus* and *Parapenaeus longipes* (Pauly *et al.*, 1984). For comparison, Buchary (1999) used a P/B ratio for penaeid shrimps of 5 year^{-1} , which agrees, but Pauly *et al.* (1993) calculated a higher ratio for shrimps, equivalent to 18.2 year^{-1}.

The Q/B for penaeid shrimps is taken as the average value for *Penaeus longistylus* and *Penaeus esculentus* from an Ecopath model of Great Barrier Reef (Gribble, 2003), 37.9 year^{-1}. Buchary (1999) had used a Q/B ratio of 28.95 year^{-1} for her adult penaeid shrimp group. The value for other prawns from Gribble (2003) was used as the Q/B for shrimps and prawns in the RA model, 20 year^{-1}. The Q/B estimate of Schwamborn and Criales (2000) for juvenile pink shrimp (*Farfantepenaeus duorarum*) (an Atlantic species), might also be applicable to this group at 48.976 year^{-1}. The value is likely too high for our use as it refers to juvenile animals. Pauly *et al.* (1993) suggested a Q/B ratio for shrimps of 28.94 year^{-1}, which is more in line with our estimate.

Squid and Octopus

The P/B value used for squid in the RA model is 4.348 year^{-1}. This value was calculated as the average of the P/B value calculated for 7 species using Brey's (1995) equation. Maximum age and weights for *Photololigo chinensis*, *Photololigo edulis*, *Sepioteuthis australis* and *Sepioteuthis lessoniana* is obtained from (BRS, 1999). Maximum ages for *Loligo duvauceli* and *Loligo chinensis* is from Jackson (2004) and maximum weights were obtained from Kongprom *et al.* (2003). Maximum age for *Sepia officinalis* is from Zielinski and Portner (2000) and maximum weight is from FAO (2006). The production rate used by Buchary (1999) for cephalopods in the Java Sea is slightly lower at 3.1 year^{-1}; the rate used by Optiz (1993) for a Caribbean reef was also 3.1 year^{-1}. Our value is intermediate though compared to the P/B rate for squid calculated by Pauly *et al.* (1993) for a Philippines reef, which equates to 10.66 year^{-1}. The P/B ratio used for octopus in the RA model is 2.327 year^{-1}. This value was calculated using Brey's (1995) equation based on the maximum age of *Octopus cyanea* (Cascorbi, 2004) and maximum weight obtained from FAO (2006). Pauly *et al.* (1993) used a higher value for octopus, 4.49 year^{-1}.

The Q/B rate used by Buchary (1999) for cephalopods was 20.318 year^{-1}; the Q/B rate used by Opitz was 11.7 year^{-1}. The Q/B value used in the RA model is intermediate, at 14.792 year^{-1}. This value was calculated as a weighted average according to the biomasses of three species: *Sepioteuthis lessoniana*, *Sepia officinalis* and *Sepiola affinis*. Q/B is based on food intake studies of these species by Wells (1996). Q/B for octopus was also calculated from the same source to be 13.24 year^{-1}; this value was the average for 5 species: *Eledone moschata*, *E. cirrhosa*, *Octopus cyanea*, *O. dofleini*, *O. maya* and *O. vulgaris*. An alternative estimate of Q/B is 10.95 year^{-1} based on *Sepioteuthis lessoniana* from food intake studies (Rodhouse and Nigmatullin, 1996). This value was not used in the calculation of the group Q/B estimate. Pauly *et al.* (1993) used the following Q/B values for the Bolinao Reef Ecosystem in the Philippines: squids, 16.64 year^{-1}, octopus 7.3 year^{-1}.

Sea cucumbers

Sea cucumber biomass was estimated for the RA model based on reef transect results provided in COREMAP (2005). The average number of individuals on the Weigeo Island reef top was 2.3 individuals per 40 m^2. We converted this density to weight by assuming an individual animal weight of 965 g, as calculated from Desumont (2003) based on 20 sea cucumber species occurring in Papua New Guinea. Total biomass density for sea cucumbers in RA then is 0.971 t·km^{-2}, when corrected for reef area using ratios in Spalding *et al.*, (2001). This amount equates to 55.5 t·km^{-2} biomass density on coral reefs. For comparison, the biomass of sea cucumbers was identified by Aliño *et al.* (1993) as 35.77 t·km^{-2} on coral reefs. However, Trobe-Bateman *et al.*, (2004) provided a much higher estimate for sea cucumber biomass in Papua New Guinea. Using the same assumptions regarding average individual weight, their biomass density on reefs computes to 221.95 t·km^{-2}, which is about four times higher than the RA model estimates currently in place.

The P/B rate used for sea cucumbers, 0.74 year^{-1}, represents an average value for *Actinopyga echinites* and *Holothuria scabra* (Shelley, 1985). Aliño *et al.* (1993) suggested a higher value for sea cucumbers, 4.45 year^{-1}, and Pauly *et al.* (1993) suggested 2.66 year^{-1}.

The Q/B value used in the RA model for sea cucumbers is 8.248 year^{-1}. The value is an average of the individual consumption to biomass ratios calculated for 20 species using an empirical model by Cammen (1980). The average weight of sea cucumber species was obtained from species identification cards issued by Papua New Guinea National Fisheries Authority. The average weight was converted to dry weight using a factor 0.11 (Brey, 2006). Pauly *et al.* (1993) used a lower Q/B value, 3.58 year^{-1}.

Lobsters

Lobster biomass was estimated for the RA model to be 0.219 t·km^{-2} based on reef transect results provided in COREMAP (2005). The average number of individuals in reef top transects is 0.5 individuals. Reef top transect area is 40 m^2. This gives an average density of 0.0125 individuals·m^{-2}. This density was converted to weight using the average individual weight of 1 kg. Biomass density on reefs was corrected for reef area based on Spalding *et al.* (2001).

The P/B value used for squid in the RA model is 0.446 year^{-1}. This value was calculated using Brey's (1995) equation as the average P/B value for 4 species. Maximum age and weights for *Panulirus ornatus*, *Thenus* spp., *Jasus verreauxi* and *Panulirus cygnus* were obtained from (BRS, 1999). The Q/B value of 15.207 year^{-1} was calculated from a consumption estimate of 0.1151 gC·m^{-2}·y^{-1} and a biomass estimate 0.076 gC·m^{-2} obtained from Florida Bay (Jorgensen *et al.*, 1991).

Large and small crabs

In the Java Sea, Buchary (1999) estimated the biomass of crustaceans to be 0.86 t·km^{-2}. This value is equally distributed among the three crustacean groups (lobsters, large crabs and small crabs) to obtain the biomass estimate of 0.286 t·km^{-2} for each. The P/B for large crabs is calculated to be 1.24 year^{-1}. The value is the average of P/B values for 3 species (*Portunus pelagicus*, *Ranina ranina* and *Scylla serrata*) determined using Brey's (1995) equation. The maximum weight and age for the species are from BRS (1999). The P/B for small crabs was calculated as 2.610 year^{-1}. The value is the average of P/B values for 8 species (*Uca rapax*, *U. maracoani*, *U. cumulanta*, *U. vocator*, *Eurytium limosum*, *Emerita analoga*, *Pachygrapsus gracilis* and *Ucides cordatus*) from Brey (2006).

The Q/B values of 14.55 year^{-1} and 20.21 year^{-1} are calculated for large and small crabs respectively from consumption and biomass estimates in Jorgensen *et al.* (1991); data is from Florida Bay:

The annual catch made on large and small crabs represents a very rough approximation (2.76 kg·km^{-2} each). It was determined by splitting evenly the quantity of 'other' catch reported in DKP and Trade and Industry Office between several groups which were not explicitly recorded in other catch categories. The statistics represent catch in the years 2000-2005. We are awaiting improved estimates for catch.

Crown of thorns starfish

This functional group contains only the crown-of-thorns starfish (*Acanthaster planci*), which is a highly influential (keystone) predator species on coral reefs (Pearson, 1981; Moran, 1986). Biomass for crown of thorns starfish is taken from COREMAP (2005). They estimated 0.5 individuals on average per 40 m^2 of reef top. Assuming that each animal weighs 1 kg provides a biomass estimate on reefs of 12.5 t·km^{-2}. Scaling this by the marine area to reef area ratio of Spalding *et al.*, (2001) provides an estimate for RA of 0.218 t·km^{-2}.

Evidence of coral damage from crown-of-thorns starfish in Raja Ampat was weak according to an earlier survey. McKenna *et al.* (2002a) observed coral damage in only 6.7% of the sites surveyed in RA.

The P/B value used in the RA model is 0.463 year^{-1}. This value was calculated using Brey's (1995) equation. The maximum age used was 8 years (Zann, *et al.*, 1990) and maximum weight was calculated using the diameter to weight equation in Birkeland and Lucas (1990). The maximum size was 60 cm from Moran (1990).

The Q/B value is based on consumption by juveniles and adults (Jangoux, 1982); the value is weighted according to the relative percentages of juveniles (23.5%) and adults (76.5%) in the population (Engelhardt *et al.*, 2000) and the average body weight of juveniles and adults (Bass and Miller, 2006).

Giant triton

The giant triton biomass was assumed to be 1% of the bivalve biomass estimated for the RA model and was fixed at 0.05 t·km^{-2}. The P/B value calculated for epifaunal detrivorous invertebrates was also used for giant triton in the RA model. This value is equal to 1.224 year^{-1}. A P/Q ratio of 0.3 was assumed as this is a slow growing species; the Q/B ratio was thus calculated as 4.08 year-1. It has been suggested that removal of predators such as the giant triton (*Charonia tritonis*) may play a role in the periodic crown-of-thorn outbreaks that threaten coral reefs, although the evidence is not conclusive (Sweatman, 1995).

Herbivorous echinoids

Herbivorous urchins probably have a more influential affect on algal cover in the coral reef environment than do herbivorous fishes such as parrot fishes (Scaridae) and surgeon fishes (Acanthuridae) (Levinton, 1982). The biomass for herbivorous echinoids is based on COREMAP (2005) estimate of 3.3 sea urchins per reef-top transects for sites near Weigeo Island. Assuming an average weight of 0.5 kg per animal, and correcting for reef area in RA based on the marine area to reef area ratio for all of Indonesia (Spalding *et al.*, 2001), provides a herbivorous echinoids biomass estimate for RA model of 0.722 t·km^{-2}. The biomass on coral reefs alone is then approximately 41.25 t·km^{-2}, which compares favorably with the value used by Aliño *et al.*, (1993). They assumed a sea urchin biomass on Philippine reefs of 35.77 t·km^{-2} based on unpublished data cited therein. However, for a Caribbean reef, Opitz (1993) assumed a very high biomass value for echinoderms of 600 t·km^{-2}.

The P/B for the RA model is 0.541 year^{-1}. A histogram of the average test diameter of 20 sea urchin species was plotted and 5 cm was found to be the most frequent value for test diameter. The test diameter was converted to weight using the relationship $W= 0.247 \cdot D^{-2.66}$ (Russo, 1977). The maximum age estimate is 8 years for the species *Brissopsis lyrifera* (Hollertz, 2002) is used in Brey's (1995) equation to obtain the P/B value. Our production rate is lower than the one used by Pauly *et al.* (1993) for sea urchins, which is equivalent to 2.34 year^{-1}.

The Q/B value for the model (9.423 year^{-1}) was calculated as the average for 2 species (*Tripneustes gratilla* and *Salmacis sphaeroides*) based on feeding ecology of tropical sea urchins (Klumpp et al, 1993). A consumption rate cited in Pauly *et al.* (1993) is 3.58 year^{-1}.

A small catch for sea urchins was entered into the RA model, 2.76E-3 t·km^{-2}. It is based on the 'other invertebrate' category identified in DKP fisheries statistics. That unidentified amount was divided between 5 invertebrate groups that did not have more precise catch information available. The statistics represent average catch in the years 2000-2005.

Bivalves

Bivalve biomass is estimated for the RA model based on reef transect results for giant clam provided in COREMAP (2005). The average number of individuals in reef top transects is 2.1 individuals. Reef top transect area is 40 m^{2}. This gives an average density of 0.053 individuals·m^{-2}. This density was converted to weight using the average individual weight of 2 kg to obtain a total biomass estimate of 1.8377 t·km^{-2}. Assuming that giant clam contributed to a fifth of the biomass of bivalves, bivalve biomass was estimated to be 9.189 t·km^{-2}. Biomass density on reefs has been corrected for the relative reef area in RA based on Spalding *et al.* (2001).

The P/B for bivalves in the model is 2.514 year^{-1}. The value is calculated as the average of 31 warm water species from Brey (2006). The Q/B value of 5.618 year^{-1} is calculated for bivalves from consumption and biomass estimates from the same source.

A catch is calculated for RA as 5.89E-3 t·km^{-2}. It is based on entries in DKP fisheries statistics for pearl oyster, unidentified mollusks, clam and abalone. It is an average of the years 2000-2004.

Sessile filter feeders

The biomass of the group, 4.58 t·km^{-2}, is based on estimates of sponge biomass from fore-reef, lagoon and back-reef environments on Davies Reef (Wilkinson and Evans, 1989). The P/B value of 1.48 year^{-1} for sessile filter feeders was borrowed from a Mexican coral reef model (Alverez-Hernandez, 2003). The Q/B value, 5.258 year^{-1}, was calculated from consumption estimates of epireefal sponges from Kötter (2002). A small catch was entered for sessile filter feeders, 0.001 t·km-2.

Epifaunal detritivorous invertebrates

The biomass of the epifaunal detritivorous invertebrate group is based on starfish biomass calculated from COREMAP (2005) reef transect densities. That document suggests 3.2 individuals per 40 m^2 of reef area. Assuming an average weight of 1 kg per animal, and multiplying the total estimate by five to account for unsampled taxa in this functional group, a biomass estimate is determined for RA as 7.0 t·km^{-2} (this density has been corrected for reef area in RA based on ratios in Spalding *et al.*, 2001). This amount was split between epifaunal detritivorous and carnivorous invertebrate groups in the ratio of 1 to 5. Biomass of epifaunal detritivorous invertebrates is therefore estimated for RA to be 1.4 t·km^{-2}. The total biomass of epifaunal invertebrates calculated here (7.001 t·km-2) equates 400 t·km^{-2} on reefs. This agrees well with the reef biomass density used by Optiz (1993) for miscellaneous mollusks/worms on a Caribbean reef system, 430 t·km^{-2}.

The P/B was calculated as the average of the P/B of grazing, suspension feeding, deposit feeding and scavenger gastropods (13 year^{-1}) and echinoderm species (16 year^{-1}) from (Brey, 2006). Detritivores ingest about 0.01 to 0.4 times their body weight daily (Lopez and Levington, 1987). For the calculation of Q/B, the average was arbitrarily chosen, 0.05, for all the detritivorous invertebrates. This gave a Q/B equal to 18.25 year^{-1}. The consumption rate cited in Alverez-Hernandez (2003) is 15 year^{-1}.

A small catch for epifaunal detritivorous invertebrates (3.08E-3 t·km^{-2}) is entered into the RA model. It is based on the 'other invertebrate' category identified in DKP fisheries statistics. That unidentified amount was divided between 5 invertebrate groups that did not have more precise catch information available. The catch used in the RA model also includes figures listed for mancadu, a gastropod. The statistics represent average catch in the years 2000-2005.

Epifaunal carnivorous invertebrates

As mentioned in the group description above, total epifaunal biomass was estimated to be 7.0 t·km^{-2} based on starfish abundance counts from COREMAP (2005). The starfish biomass estimates were inflated by five times to represent other taxa, and this amount was split between epifaunal detritivorous and carnivorous invertebrate groups in the ratio of 1 to 5 (see above entry for more information). Biomass of epifaunal carnivorous invertebrates is therefore estimated to be 5.833 t·km^{-2}, although that amount was subsequently reduced in balancing the model to 5.6 t·km^{-2}.

The P/B ratio for the predatory echinoderm *Asterias forbesi* (2.64 year^{-1}) was used (Robertson, 1979). The Q/B value of 10.52 year^{-1} was calculated for predatory gastropods and echinoderms from consumption and biomass estimates in Jorgensen *et al.* (1991) from Florida Bay.

A small catch for epifaunal carnivorous invertebrates (3.6E-3 t·km^{-2}) is entered into the RA model. It is based on the 'other invertebrate' category identified in DKP fisheries statistics. That unidentified amount was divided between 5 invertebrate groups that did not have more precise catch information available. Catch for this group also includes the figures listed for snails. The statistics represent average catch in the years 2000-2005.

Infaunal invertebrates

The infaunal biomass was estimated for a coral reef lagoon to be 3.181 gC·m^{-2}. This value was converted to wet weight using the factor 0.116 (Brey, 2006) to obtain the biomass estimate 27.422 t·km^{-2} for the RA model. The P/B ratio for large and small macrophagus polychaetes, microphagous polychaetes, crustaceans, bivalves, gastropods, and other infauna (Riddle *et al.*, 1990) was weighted by relative biomass and averaged to obtain a P/B equal to 4.014 year^{-1}. The Q/B was estimated to be 19.267 year^{-1} from consumption estimates of infauna from shallow and deep zones (Riddle *et al.*, 1990).

Jellyfish and hydroids

The biomass estimate from Buchary (1999) for the Java sea model 0.1 t·km^{-2} was used for the model. An alternate estimate equal to 0.222 t·km^{-2} was found for Florida Bay (Uye and Shimauchi, 2005). The P/B ratio 10.230 year^{-1} (Venier, 1997) was used for the RA model. The Q/B value (25.463 year^{-1}) is based on consumption estimates of Aurelia aurita in the inland sea of Japan (Uye and Shimauchi, 2005). For comparison, Buchary (1999) used a lower P/B ratio for jellyfish from the Java Sea of 5.011 year^{-1} but her Q/B value was very similar, 25.050 year^{-1}.

Carnivorous zooplankton

Aliño *et al.*, (1993) used a zooplankton biomass estimate for a Philippines reef system of 2.87 t·km^{-2}, while Buchary (1999) used 0.310 t·km^{-2}. The value used in this model, 1.0 t·km^{-2} is intermediate. The P/B value 63.875 year^{-1} was based on Borgne (1982) daily P/B estimate in the range 15 to 20% daily for carnivorous zooplankton species. The mid value of the range was used to calculate the P/B value.

The Q/B value used by Aliño *et al.*, (1993) was 133.33 year^{-1}, although they allowed Ecopath to estimate this figure. The Q/B value used by Buchary (1999) was similar at 135.05 year^{-1}. Although the consumption rate used in the RA model for carnivorous zooplankton (196.28 year^{-1}) was finally estimated by Ecopath assuming an EE of 0.95, estimates of Q/B were located for chaetognaths, mysids, planktonic amphipods and ichtyoplankton. Q/B for chaetognaths is calculated as 53.851 year^{-1} (Saito and Kiorobe, 2001), mysids consumption is 26.456 year^{-1} based on a laboratory experiment (Chipps and Bennett, 2002), planktonic amphipod consumption is 23.884 year^{-1} based on ingestion rate experiments (Ikeda and Shiga, 1999) and ichthyoplankton consumption is 178.487 year^{-1} based on an empirical relationship (Houde and Schekter, 1980). Another similar estimate was obtained for *Sagitta elegans* Q/B equal to 65.675 year^{-1} was calculated based on consumption estimate by Terazaki (1996); this assumes a mean size of 7.5 to 10 mm and weight of 41 μgC per individual (Saito and Kiorobe, 2001).

Large and Small herbivorous zooplankton

The RA model uses the biomass estimate from Buchary (1999) for the Java sea of 0.56 t·km^{-2} for large herbivorous zooplankton and 2.43 t·km^{-2} for small herbivorous zooplankton. An alternate estimate was made as 6.645 t·km^{-2} for all the zooplankton groups. This represents the average of zooplankton biomass for the latitude (0.5N to 2.5N) and longitude (129.5E to 130.5E) (O'Brien, 2005). This estimate agrees with the one used in the RA model when the figure is divided among the EwE zooplankton groups.

The P/B value for large herbivorous zooplankton 29.2 year^{-1} is based on Borgne's (1982) daily P/B estimate in the range 6 to 10% of body weight daily for herbivorous zooplankton species. The mid value of the range was used to calculate the P/B value. The P/B value used for the model is 32.0 year^{-1}; it was increased slightly to lay closer to the carnivorous zooplankton rate, as the carnivorous group would consist of larger species. An alternate estimate was made as 101.284 year^{-1} as the average P/B for *Daphnia galeata* and *Bosmina longirostris* (McCauley *et al.*, 1996), although these high rates are likely inappropriate as a group average. The value for herbivorous zooplankton used by Christensen (1996) is 27 year^{-1}, close to our estimate.

The P/B value for small herbivorous zooplankton 91.25 year^{-1} is based on Borgne's (1982) P/B estimate in the range 22 to 28% daily for small herbivorous zooplankton species. The mid value of the range was used to calculate the P/B value. Another estimate was calculated based on the average P/B for small herbivorous plankton from 4 sites (Princess Charlotte Bay, CairnseInnisfail, North West Cape shelf and NWC shelf break) in Great Barrier Reef. That value is 54.743 year^{-1} (McKinnon *et al.*, 2005). A conversion ratio of 0.29 is used to convert zooplankton weight in mgC to wet weight (Hansen *et al.*, 2004).

The Q/B for large zooplankton is calculated based on ingestion rates estimated by McCauley *et al.*, (1996). The adult weight of *Daphnia galeata* and *Bosmina longirostris* is determined using a size-weight table for *Daphnia* (Gorokhova and Kyle, 2002); it was assumed that *Bosmina* has the same relation of body size to body weight. The Q/B for small herbivorous zooplankton is calculated based on consumption by copepods estimated by Borgne *et al.* (1989) to be 265.813 year^{-1}. Another estimate calculated using an empirical relation for ingestion rate for copepods (Huntley, 1988) was too high 2232.537 year^{-1} and was abandoned.

Phytoplankton

A biomass estimate of 26.1 t·km^{-2} was calculated from the average of phytoplankton standing biomass during upwelling (3.7 gC·m^{-2}) and downwelling (2.1 gC·m^{-2}) from the Banda Sea (Tomascik *et al.*, 1997). The P/B value of 109.118 year^{-1} was calculated by dividing the average PP estimate 2848 g·m^{-2}·year^{-1} (GoMor SAI, Italy 2006) for the cells used in the RA model by the biomass estimate. Production rates used for phytoplankton in other reef Ecopath models follow: Caribbean: 160 year^{-1} (Arias-Gonzalez, 1998), 70 year^{-1} (Opitz, 1993); Java Sea: 135 year^{-1} (Buchary, 1999). Ours is therefore an intermediate value.

Macro-algae

The biomass estimate for macro-algae is 39.389 t·km^{-2} based on algal biomass on Caribbean coral reefs (Odum and Odum, 1995). The biomass estimate was obtained as 2250.4762 t·km^{-2}. This was scaled according to coral reef area (using ratios in Spalding *et al.*, 2001) to obtain the value 39.389 year^{-1}.

The P/B rate for macro-algae was set in the RA model as 10.225 year^{-1}; it is based on benthic algal production in coral reefs reported by Russ and McCook (1999). The same value is cited in Wolanski (2001) for 'benthic autotroph' production rates. By comparison, the P/B rate used for benthic autotrophs in Caribbean reef systems by Opitz (1993) and by Arias-Gonzalez (1998) was 13.25 year^{-1}. The value used by Buchary (1999) for the Java Sea was 11.885 year^{-1} for the group 'benthic producers'; and the value used by Aliño *et al.*, (1993) in the Philippines for 'seaweeds' was 15.34 year^{-1}. These estimates all agree closely.

Sea grass

The biomass was calculated based on the biomass estimates of 9 sea grass species (*Enhalus acoroides*, *Cymodocea rotundata*, *Cymodocea serrulata*, *Halophia ovalis*, *Halodule pinifolia*, *Halodule uninervis*, *Syringodium isoetifolium*, *Thalassia hemprichii* and *Thalassodendron ciliatum*) from Flores Sea (Tomascik *et al.*, 1997). The biomass was calculated to be 3180.952 t·km^{-2}, this value was scaled according to the potential sea grass area in the model to obtain the value 20.157 t·km^{-2}. This amount is similar to the value used by Aliño *et al.*, (1993), who based their value on Fortes (1990) and estimated 702 g·ww·m^{-2}, which converts to about 14 t·km^{-2} when corrected for the area of coral reefs in RA. Other estimates of sea grass biomass when scaled to seagrass area are 3.680 t·km^{-2} (DeIongh *et al.*, 1995) and 6.97 t·km^{-2} (Erftemeijer. 1994). P/B is calculated to be 13.758 year^{-1} based on leaf biomass and production of *Thallassia hemprichii* (Erftemeijer, 1994).

Mangroves

The average dry weight litter production was estimated to be 7.7 t·ha^{-1}·year^{-1} (Tomascik *et al.*, 1997). The litter biomass can be calculated by dividing the production estimate by mangrove P/B. Alternatively, the primary production from mangroves was given by Tomascik *et al.* (1997) as 25.936 kgC·ha^{-1}·day^{-1}. Biomass was calculated using this production estimate, however the values obtained in both cases were very high (>30,097 t·km^{-2}) so were not used for the model. This amount refers to production in mangrove areas and will be lower when averaged over RA, but we elected to use Ecopath's estimate. The EE of the mangroves was fixed at 0.02 to account for terrestrial mortality and Ecopath was allowed to calculate the biomass as 19.136 t·km^{-2}.

The P/B was calculated from the leaf litter production over total mangrove biomass (includes the roots, trunk, branches and leaves) for the 2 species *Rhizophora mucronata* and *Ceriops tagal*. The average P/B is calculated to be 0.066 year^{-1} based on biomass and production estimates from Slim *et al.* (1996). Alternatively, P/B could be calculated based on net primary production of *Rhizophora apiculata* as 0.170 year^{-1} (Christensen, 1978).

Mangroves thrive in close proximity to the shoreline reefs in Mayalibit Passage in Waigeo, there is an excellent mix of mangroves and sheltered reefs in Wayag Islands (Tomascik *et al.*, 1997). However, Indonesia's mangrove forests face a variety of threats. They are harvested for timber and they are also being removed for land reclamation and to make habitat for fish ponds (Priyono and Sumiono, 1997). Loss of mangroves hurts the shrimp fishery (Martosubroto and Naamin, 1977) and may impact the survival of juvenile fish that congregate to forage and avoid predation (Laegdsgaard and Johnson, 2001). These behaviours are incorporated in the EwE models through use of mediation functions (Section 2.5.2 - Mediation factors). Faunce and Serafy (2006) provide a comprehensive review of field studies that consider mangroves as fish habitat.

Fishery discards and detritus

The standing biomass of fishery discards is set at 20 t·km^{-2}. Detritus biomass is set at 100 t·km^{-2}.

The 1990 Raja Ampat model

Group biomasses

A 1990 RA Ecopath model is designed based on the 2006 RA model. Biomasses for the 1990 model are shown in Table A.4.1, along with the rationale used to parameterize biomass and catch of each functional group. Groups for which no relative biomass estimates are available are assumed to have a similar biomass in 1990 as in 2006; this mainly applies to non-commercial and non-fish groups (i.e., listed as "No change" in Table A.4.1). The biomasses of some commercial groups are set in the 1990 model according to the relative abundance change suggested by catch per unit effort (CPUE) series ("CPUE" in Table A.4.1). The CPUE series did not suggest significant biomass declines for groupers or snappers, despite the fact that they have been heavily fished since 1990. We assume that the decline in these species has been masked by the CPUE series due to their reproductive biology. Because they congregate in spawning aggregations, and because fishers target those aggregations, the biomass density available to fisheries may remain constant over a wide range of population sizes. For a discussion on the dangers of using CPUE data as a proxy for abundance see Beverton and Holt (1957), Gulland (1974) or Hilborn and Walters (1992). Grouper and snapper biomass was therefore assumed to have decreased by 50% since 1990 ("Custom" in Table A.4.1). In general, the CPUE data suggested a higher abundance of commercial fish predators in 1990 relative to 2006. This was evident in balancing the 1990 model because many of the invertebrate prey groups appeared overexploited by fish predators. We therefore allowed Ecopath to estimate the biomass of several basal invertebrate and planktonic groups, by assuming an EE of 0.99 ("Ecopath" in Table A.4.1).

For multi-stanza groups, the total biomass of all age classes combined is assumed to have increased or decreased since 1990 in direct proportion to CPUE, or according to the custom rules used. Group biomass is divided into age stanzas according to the mortality schedule, which is inherited from the 2006 model for all functional groups except groupers, snappers, coral trout, Napoleon wrasse and large reef associated fish. Recent fisheries have developed for these groups that might have shifted their population age structures, and so we assume that the 2006 ecosystem contains a greater proportion of immature individuals relative to 1990. The total mortality of adult stanzas is reduced in the 1990 model by 20% for these groups. Large sharks are also heavily exploited in RA, but we assume that they have a similar age distribution today as they did in 1990, since it is likely that most of the depletion of this group occurred prior to 1990.

Fisheries

Fishery catches for 1990 were set for commercial groups directly from the trends suggested by the recorded landings in DKP and/or Trade and Industry Office statistics (see Section 2.5.10 - Interpreting catch statistics) (i.e., listed as "Time series" in Table A.4.1). For some groups, the time series data does not extend as far back as 1990, and so the values used to initialize the 1990 Ecopath model typically record the earliest catch figure available. Where the time series landings record is uncertain, we have made critical assumptions regarding the annual quantities of group catch over the last 16 years. A relatively new and major fishery has developed for Napoleon wrasse, for example. As the time series data was inadequate, we assumed that the catch in 1990 was equivalent to 10% of the current amount (listed as "10%" in Table A.4.1). Other heavily exploited species also had inadequate time series catch information. Most often, we made the assumption that the catch in 1990 was equal to 50% of the current landings; this is listed as "50%" in Table A.4.1. Non-commercial groups are generally assigned "no catch" in Table 1990 model parameters.

Fitting to time series

The 1990 RA model is driven forward 16 years using an independent series of fishing effort. Refinements were made to the model structure to improve the data fit with respect to the observed catch and CPUE time series. Coarse corrections were made to basic parameters to correct the model's dynamic behaviour (see functional group descriptions). The proper adjustment of P/B ratios for multi-stanza groups is especially critical to Ecosim's performance. The diet matrix and the vulnerability matrix were modified, as well as Ecosim's feeding parameters. 1990 vulnerabilities are presented in Table A.3.6; feeding parameters are in Table A.5.1.

Trophic flow parameters

The vulnerability matrix for the 1990 RA model was parameterized manually and by using the automated vulnerability search routine available in Ecosim (Christensen and Walters, 2004a). The search routine uses an iterative procedure to first identify predator-prey interactions critical to model functioning. With a least-squares criterion, it optimizes those key vulnerabilities in order to recreate observed time series of catch, biomass or other input data. The optimization was performed first on a large number of interactions. Then, additional searches were used throughout the balancing process on a fewer number of groups that are highly influential in the system. The most influential predator groups in the 1990 model tend to be mackerel, large and medium reef associated fish, skipjack and other tuna.

Biomass accumulation rates were used widely to manipulate the initial mortality to production ratios of functional groups, and achieve realistic biomass change as suggested by CPUE data. Generally, commercial groups are made to follow their observed pattern of biomass change through the impacts of fisheries; we coerced other groups to follow time series data by redistributing predation mortality throughout the diet matrix and reshaping the predation mortality trends using vulnerability adjustments. The assumption that we have made is therefore that the decline seen in commercial groups is attributable primarily to fishing, while changes to non-commercial groups are due to trophodynamics.

In many cases with commercial groups, the catch recorded in governmental statistics is not sufficient to cause the decrease in group biomass suggested by CPUE data. The time series catch estimates used for fitting were therefore increased over the original DKP and Trade and Industry Office statistics to acknowledge the impact of unreported catches. For each year between 1990 and 2006, the reported catch was increased by a fixed percentage. The relative proportion is based on the estimates of unreported catch used in the 2006 and 1990 models (see Section 2.5.11 - Functional group descriptions). The catch has therefore been scaled so that the time series forms a continuous trend passing through the start and end point model values. The CPUE trend, which serves as a proxy for biomass, is entered into Ecosim as a relative trend. The suspected decline in grouper and snapper biomass over the last 16 years is not reflected in the CPUE trends for biological reasons discussed earlier. These groups were therefore omitted from the vulnerability search criterion; the automated routine did not attempt to fit these groups to data.

Primary production anomaly

We introduce a primary production anomaly trend using Ecosim's data fitting technique. Ecosim generated a climate anomaly trend for the years 1990-2006 that would minimize the residuals between observed and predicted catch and CPUE. The P/B anomaly is applied only to the most variable group, phytoplankton, and it is designed to reduce the sum of squares with regard to all ecosystem components. Five spline points are introduced to smooth the production trend.

We rescaled and reentered the production modifier so that the predicted annual phytoplankton biomass variability from simulations matched the observed variability, as determined by SeaWifs primary production data (Sea Around Us Project, 2006). The annual coefficient of variation (CV) is estimated to be 4.7% from the satellite data. That is an average for all the cells listed in the database for RA, and it represents the average variability of each 5 year period between 1990-2005. We used the average 5-year variability so that random environmental fluctuations would be the main cause of interannual biomass change, and not directional biomass reductions caused by fisheries. The CV is based on data from the years 1998-2002. The amplitude of the primary production forcing pattern was reduced by 42% to generate the required CV.

By adjusting the primary production anomaly trend in this way, discrepancy between predicted and observed catch and relative biomass for the ecosystem is made slightly worse (sum of squares is increased by 1.7%). However, Ainsworth (2006) demonstrated that this method can lead to realistic population variability at higher trophic levels. Accurately representing the variability of production trends throughout the system can greatly improve the output of more advanced analyses in Ecosim. For example, a Monte Carlo technique can be used in an ecosystem-based population viability analysis to estimate the extinction risk for commercial species associated with various fishing policies (Ainsworth, 2006; Pitcher *et al.*, 2005). This technique is applied for RA in Section 3.4 - Challenges to Ecosim.

Equilibrium analysis

The equilibrium analysis routine in Ecosim helps us examine functional group dynamics under varying degrees of fishing pressure. This routine is an invaluable diagnostic tool and it can be used to answer fundamental questions regarding the production potential of stocks and their resilience to fishing. The routine sketches the surplus yield curve and the biomass equilibrium curve[††] (Equilibrium routine: Christensen *et al.* 2004a). Increasing fishing mortality stepwise from zero to several times the baseline model value, the automated routine calculates the equilibrium biomass of a subject functional group under a long-term fishing scheme (1000 years).

At the left-most extent, the biomass equilibrium curves tell us what biomass level the group assumes under zero fishing mortality (i.e., pristine biomass or B_0). The catch equilibrium curves are essentially single-species surplus production curves; the maximum height of the curve shows maximum sustainable yield (MSY) of the stock and the fishing mortality at which that occurs, the F_{msy}. It is useful to compare the current fishing mortality, for example in 2006 (F_{2006}), with the F_{msy}. In a properly parameterized model, the baseline fishing mortality of underexploited groups should be less than F_{msy} and greater than F_{msy} for overexploited stocks. How a functional group behaves under dynamic simulation will be greatly influenced by the initial relative level of exploitation represented in the basic Ecopath model. The predictions made by this routine can be compared to estimates derived from single-species tools, and presented to fisheries experts in Indonesia for the purposes of validation.

The equilibrium routine offers several settings, including one that holds the biomass of other functional groups in the model at their (static) baseline conditions. By selecting this option, Ecosim is reduced to a single-species model, and higher order trophic interactions are removed from consideration. Alternatively, the user can permit the usual predator-prey dynamics to occur that Ecosim is designed to simulate. In this use, the equilibrium analysis will consider the multi-species context and provide, in principle, a more accurate representation of ecosystem response to fishing that is suitable for EBM. By excluding these interactions, the analysis serves as a validation tool, by which we can compare Ecosim's predictions with 'classical' single-species analysis models.

Where possible, the equilibrium analysis is performed for subject groups while holding the biomass constant for other functional groups to facilitate comparison with single-species models. However, where multi-stanza groups were employed, it was sometimes necessary to perform the equilibrium analysis manually in Ecosim to circumvent a current limitation in the equilibrium analysis routine.

The equilibrium analysis routine increments fishing mortality only for the subject functional group being tested (V. Christensen. UBC Fisheries Centre, 2202 Main Mall, Vancouver Canada,

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[††] Hilborn and Walters (1992) discuss the theory and applications of equilibrium stock assessment models.

pers. comm.). If the test is run on an adult stanza, then the routine holds fisheries constant for the juvenile and/or sub-adult stanzas. If there is normally a high fishing rate on the juvenile or sub-adult stanzas, then the equilibrium analysis can be misleading. It will suggest a high estimate of sustainable adult fishing mortality because the adult pool is being fed by constant recruitment from the immature stanzas. In reality, an increasing amount of catch on adults will usually be accompanied by increased catch on immature groups, either intentionally or incidentally. This increase is currently missed by the equilibrium routine. This has always been a potential source of error, where split-pools were used to describe age stanzas, but the problem was amplified with the addition of the multi-stanza routine. Now, large amounts of fishing effort may typically be modelled on sub-adult groups, yet the equilibrium analysis routine will continue to assume knife edge entry to the fishery effectively, and increment fishing effort only on the adult stanza. To provide a more realistic view of surplus stock production for these groups, it is necessary to perform the equilibrium analysis manually, increasing fishing mortality on juvenile and sub-adult groups as well as the adults. This was done here on key groups, and these runs are indicated by asterisks in Fig. B.2.1. Trophic interactions must necessarily be included in these runs.

Challenges to Ecosim

The 2006 RA Ecosim model is subjected to various challenges to test its behaviour and stability. By applying extreme fishing scenarios we can see how the model performs when fishery and functional group parameters vary far from their initialization values. Species interactions, which may appear nominal under baseline conditions, can compound in unexpected ways to cause oscillations or chaotic model behaviour. If a region of instability exists in the fleet-effort responses of the model, normal fishing forecasts that apply conservative or realistic fishing strategies may or may not be affected. However, if a combination of fishing efforts exists that can drive the model to instability, the policy search routine will typically become useless as it then only locates unstable solutions that offer impossibly large benefits.

We use three fishing strategies to challenge the model: no fishing, baseline fishing and increasing fishing. For the ‘no fishing’ scenario, the fishing mortality of each gear type is reduced to zero for all simulation years and target groups (including directed and bycatch mortality). Under this fishing test, we expect depleted commercial functional groups to rebound, and the prey of these groups should see a corresponding decrease. The baseline fishing scenario is provided for comparison; it represents the current (2006) fishing mortalities applied into the future. The ‘increasing fishing’ scenario assumes an annual increase in fishing mortalities of 3.2% across all gear types. This rate corresponds to the recent increase in the human population in eastern Indonesia (BPS, 2006). We expect to see the biomass of exploited functional groups decline and a corresponding increase in the biomass of their prey. All Ecosim simulations are for 16 years, from 2006-2022.

As an additional test of the model’s performance, we have used 50 Monte Carlo simulations to vary Ecopath’s biomass parameters for commercial groups. For this sensitivity analysis, groups are allowed to vary +/- 20% from their Ecopath biomass values, the Monte Carlo draws from a uniform distribution. The following commercial groups are varied: adult and sub-adult groupers, adult and sub-adult snappers, adult and sub-adult Napoleon wrasse, skipjack tuna, other tuna, mackerel, billfish, and the adult stanzas of coral trout, large sharks, large, medium and small pelagic, large, medium and small reef-associated, large and small demersals, large and small planktivores, and anchovy. The Monte Carlo routine allows us to test the sensitivity of initial biomass parameters, establish a range of error for predictions, and determine the depletion risk for functional groups in a population viability analysis.

Ecospace parameterization

An Ecospace model was developed for RA and is presented here. Ecospace maps are also presented for high resolution models of Kofiau Island and Dampier Strait, as well as habitat classifications (Table 2.7) and fishery locations (Table 2.8). All of the Ecospace work is preliminary thus far; dynamics have not been analyzed and we present these here only for expert evaluation. High-resolution models for Kofiau Island, Dampier Strait and SE Misool Island will be integrated into Ecospace in 2007, following the development and refinement of reef-based Ecopath models, where biomass, catch and other parameters are adjusted to represent the smaller study areas using site-specific data.

The RA Ecospace model utilizes GIS information assembled by the BHS EBM project, as well as oceanographic and biological data from the literature to represent the study area in a 2 dimensional grid matrix of spatial habitat cells. Standard Ecopath and Ecosim parameters are inherited from the 2006 RA model described in this report.

Table 2.7 - Habitats occupied by functional groups in three 2006 Ecospace models. RA, Kofiau Island and Dampier Strait.

	Raja Ampat							Kofiau									Dampier St.								
	All	10m	20m	200m	Deep (> 200m)	Reef	Area occupied	All	20m	200m	Deep (> 200m)	Reef	Enclosed lagoon	Estuary	Mangrovev	Area occupied	All	20m	200m	Mesopelagic (200-1000m)	Bathypelagic (> 1000m)	Reef	Enclosed lagoon	Mangroves	Area occupied
Mysticetae	□	□	□	■	■	□	0.90	□	□	■	■	□	□	□	□	0.93	□	□	■	■	■	□	□	□	0.92
Pisc. odontocetae	□	□	■	■	■	□	0.96	□	□	■	■	□	□	□	□	0.93	□	□	■	■	■	□	□	□	0.92
Deep. odontocetae	□	□	□	■	■	□	0.90	□	□	□	■	□	□	□	□	0.84	□	□	□	□	■	□	□	□	0.22
Dugongs	□	■	■	□	□	□	0.08	□	■	■	□	■	■	■	■	0.16	□	■	■	□	□	■	■	■	0.44
Birds	■	□	□	□	□	□	1.00	■	□	□	□	□	□	□	□	1.00	■	□	□	□	□	□	□	□	1.00
Reef assoc. turtles	■	□	□	□	□	□	1.00	■	□	□	□	□	□	□	□	1.00	■	□	□	□	□	□	□	□	1.00
Green turtles	■	□	□	□	□	□	1.00	■	□	□	□	□	□	□	□	1.00	■	□	□	□	□	□	□	□	1.00
Oceanic turtles	■	□	□	□	□	□	1.00	■	□	□	□	□	□	□	□	1.00	■	□	□	□	□	□	□	□	1.00
Crocodiles	□	■	□	□	□	□	0.02	□	■	□	□	□	□	□	□	0.02	□	■	□	□	□	□	□	□	0.05
Ad. groupers	□	■	□	□	□	■	0.04	□	■	□	□	■	□	□	□	0.06	□	■	□	□	□	■	□	□	0.07
Sub. groupers	□	■	□	□	□	■	0.04	□	■	□	□	■	□	□	□	0.06	□	■	□	□	□	■	□	□	0.07
Juv. groupers	□	□	□	□	□	■	0.01	□	□	□	□	■	□	□	□	0.04	□	□	□	□	□	■	□	□	0.02
Ad. snappers	□	■	□	□	□	■	0.04	□	■	□	□	■	□	□	□	0.06	□	■	□	□	□	■	□	□	0.07
Sub. snappers	□	■	□	□	□	■	0.04	□	■	□	□	■	□	□	□	0.06	□	■	□	□	□	■	□	□	0.07
Juv. snappers	□	□	□	□	□	■	0.01	□	□	□	□	■	□	□	□	0.04	□	□	□	□	□	■	□	□	0.02
Ad. Napoleon wrasse	□	■	□	□	□	■	0.04	□	■	□	□	■	□	□	□	0.06	□	■	□	□	□	■	□	□	0.07
Sub. Napoleon wrasse	□	■	□	□	□	■	0.04	□	■	□	□	■	□	□	□	0.06	□	■	□	□	□	■	□	□	0.07
Juv. Napoleon wrasse	□	□	□	□	□	■	0.01	□	□	□	□	■	□	□	□	0.04	□	□	□	□	□	■	□	□	0.02
Skipjack tuna	□	■	■	■	■	□	0.99	□	■	■	■	■	□	□	□	0.99	□	■	■	■	■	■	□	□	0.99
Other tuna	□	■	■	■	■	□	0.99	□	■	■	■	■	□	□	□	0.99	□	■	■	■	■	■	□	□	0.99
Mackerel	□	■	■	■	■	□	0.99	□	■	■	■	■	□	□	□	0.99	□	■	■	■	■	■	□	□	0.99
Billfish	□	□	□	■	■	□	0.90	□	□	■	■	□	□	□	□	0.93	□	□	■	■	■	□	□	□	0.92
Ad. coral trout	□	■	□	□	□	■	0.04	□	■	□	□	■	□	□	□	0.06	□	■	□	□	□	■	□	□	0.07
Juv. coral trout	□	□	□	□	□	■	0.01	□	□	□	□	■	□	□	□	0.04	□	□	□	□	□	■	□	□	0.02
Ad. large sharks	□	□	□	■	■	□	0.90	□	□	■	■	■	□	■	□	0.97	□	□	■	■	■	■	□	□	0.58
Juv. large sharks	□	□	□	■	■	□	0.90	□	□	■	■	■	□	□	□	0.97	□	□	■	■	■	■	□	□	0.58
Ad. small sharks	□	□	□	■	■	□	0.90	□	■	■	■	■	□	■	□	0.99	□	■	■	■	■	■	□	□	0.99
Juv. small sharks	□	□	□	■	■	□	0.90	□	■	■	■	■	□	□	□	0.99	□	■	■	■	■	■	□	□	0.99
Whale shark	□	□	□	■	■	□	0.90	□	□	■	■	■	□	□	□	0.97	□	□	■	■	■	■	□	□	0.58
Manta ray	□	■	■	■	■	■	1.00	□	■	■	■	■	■	■	□	0.99	□	■	■	■	■	■	■	□	0.99
Adult rays	□	■	■	■	■	■	1.00	□	■	■	■	■	■	□	□	0.99	□	■	■	■	■	■	■	□	0.99
Juv. rays	□	■	■	■	■	■	1.00	□	■	■	■	■	■	□	□	0.99	□	■	■	■	■	■	■	□	0.99
Ad. butterflyfish	□	■	□	□	□	■	0.04	□	■	□	□	■	□	□	□	0.06	□	■	□	□	□	■	□	□	0.07
Juv. butterflyfish	□	□	□	□	□	■	0.01	□	■	□	□	■	■	■	■	0.07	□	■	□	□	□	■	■	■	0.08
Cleaner wrasse	□	□	□	□	□	■	0.01	□	■	□	□	■	■	□	□	0.06	□	■	□	□	□	■	■	□	0.07
Ad. large pelagic	■	□	□	□	□	□	1.00	□	■	■	■	□	□	■	□	0.95	□	■	■	■	■	□	■	□	0.97
Juv. large pelagic	■	□	□	□	□	□	1.00	□	■	■	■	□	□	■	■	0.96	□	■	■	■	■	□	■	■	0.98
Ad. medium pelagic	■	□	□	□	□	□	1.00	□	■	■	■	□	□	■	□	0.95	□	■	■	■	■	□	■	□	0.97
Juv. medium pelagic	■	□	□	□	□	□	1.00	□	■	■	■	□	□	■	■	0.96	□	■	■	■	■	□	■	■	0.98
Ad. small pelagic	■	□	□	□	□	□	1.00	□	■	■	■	□	□	■	□	0.95	□	■	■	■	■	□	■	□	0.97
Juv. small pelagic	■	□	□	□	□	□	1.00	□	■	■	■	□	□	■	■	0.96	□	■	■	■	■	□	■	■	0.98
Ad. large reef assoc.	□	■	□	□	□	■	0.04	□	□	■	■	■	■	■	□	0.97	□	□	■	■	■	■	■	□	0.94
Juv. large reef assoc.	□	□	□	□	□	■	0.01	□	■	■	□	■	■	■	■	0.16	□	■	■	□	□	■	■	■	0.44
Ad. medium reef assoc.	□	■	□	□	□	■	0.04	□	■	■	■	■	■	■	□	0.99	□	■	■	■	□	■	■	□	0.77
Juv. medium reef assoc.	□	□	□	□	□	■	0.01	□	■	■	□	■	■	■	■	0.16	□	■	■	□	□	■	■	■	0.44
Ad. small reef assoc.	□	■	□	□	□	■	0.04	□	■	■	■	■	■	■	□	0.99	□	■	■	■	□	■	■	□	0.77
	□	■	□	□	□	■		□	■	■	■	■	■	■	□		□	■	■	■	□	■	■	□	
Juv. small reef assoc.	□	□	□	□	□	■	0.01	□	■	■	□	■	■	■	■	0.16	□	■	■	□	□	■	■	■	0.44
Ad. large demersal	□	■	■	■	□	□	0.39	□	□	■	■	□	■	■	□	0.93	□	□	■	■	■	□	■	□	0.92
Juv. large demersal	□	■	■	■	□	□	0.39	□	■	■	□	□	■	■	■	0.13	□	■	■	□	□	□	■	■	0.42
Ad. small demersal	□	■	■	■	□	□	0.39	□	■	■	■	□	■	■	□	0.95	□	■	■	■	■	□	■	□	0.97
Juv. small demersal	□	■	■	■	□	□	0.39	□	■	■	□	□	■	■	■	0.13	□	■	■	□	□	□	■	■	0.42
Ad. large planktivore	□	■	□	□	□	■	0.04	□	□	■	■	■	■	■	□	0.97	□	□	■	■	□	■	■	□	0.72
Juv. large planktivore	□	□	□	□	□	■	0.01	□	■	■	□	■	■	■	■	0.16	□	■	■	□	□	■	■	■	0.44
Ad. small planktivore	□	■	□	□	□	■	0.04	□	■	■	■	■	■	■	□	0.99	□	■	■	■	□	■	■	□	0.77
Juv. small planktivore	□	□	□	□	□	■	0.01	□	■	■	□	■	■	■	■	0.16	□	■	■	□	□	■	■	■	0.44
Ad. anchovy	□	■	■	■	□	■	0.41	■	□	□	□	□	□	□	□	1.00	□	□	□	■	■	□	□	□	0.56
Juv. anchovy	□	■	■	■	□	■	0.41	■	□	□	□	□	□	□	□	1.00	□	□	□	■	■	□	□	□	0.56
Ad. deepwater fish	□	□	□	□	■	□	0.59	□	□	□	■	□	□	□	□	0.84	□	□	□	■	■	□	□	□	0.56
Juv. deepwater fish	□	□	□	■	■	□	0.90	□	■	■	■	□	□	□	□	0.95	□	■	■	■	■	□	□	□	0.97
Ad. macro algal browsing	□	■	□	□	□	■	0.04	□	■	■	■	■	■	■	□	0.99	□	■	■	■	■	■	■	□	0.99
Juv. macro algal browsing	□	□	□	□	□	■	0.01	□	■	■	□	■	■	■	■	0.16	□	■	■	□	□	■	■	■	0.44

Table 2.7 - (cont.)

Raja Ampat

	All	10m	20m	200m	Deep (> 200m)	Reef	Area occupied
Ad. eroding grazers		■				■	0.04
Juv. eroding grazers						■	0.01
Ad. scraping grazers		■				■	0.04
Juv. scraping grazers						■	0.01
Detritivore fish		■	■			■	0.10
Azooxanthellate corals		■	■			■	0.10
Hermatypic corals						■	0.01
Non reef building corals		■	■			■	0.10
Soft corals		■	■			■	0.10
Calcareous algae		■	■			■	0.10
Anemonies		■	■	■	■		0.99
Penaeid shrimps			■	■	■		0.96
Shrimps and prawns			■	■	■		0.96
Squid				■	■		0.90
Octopus	■						1.00
Sea cucumbers	■						1.00
Lobsters	■						1.00
Large crabs	■						1.00
Small crabs	■						1.00
Crown of thorns		■				■	0.04
Giant triton		■	■			■	0.10
Herbivorous echinoids	■						1.00
Bivalves		■	■	■		■	0.41
Sessile filter feeders		■	■	■			0.39
Epifaunal det. inverts.	■						1.00
Epifaunal carn. inverts	■						1.00
Infaunal inverts.		■	■	■	■		0.99
Jellyfish and hydroids	■						1.00
Carn. zooplankton	■						1.00
Large herb. zooplankton	■						1.00
Small herb. zooplankton	■						1.00
Phytoplankton	■						1.00
Macro algae		■	■	■		■	0.41
Sea grass		■	■				0.08
Mangroves		■					0.02
Fishery discards	■						1.00
Detritus	■						1.00

Kofiau

	All	20m	200m	Deep (> 200m)	Reef	Enclosed lagoon	Estuary	Mangrovev	Area occupied
Ad. eroding grazers		■	■	■	■	■	■		0.99
Juv. eroding grazers		■	■		■	■	■	■	0.16
Ad. scraping grazers		■	■	■	■	■	■		0.99
Juv. scraping grazers		■	■		■	■	■	■	0.16
Detritivore fish		■	■	■	■	■	■		0.99
Azooxanthellate corals		■	■		■	■			0.15
Hermatypic corals					■				0.04
Non reef building corals		■	■		■	■			0.15
Soft corals		■	■		■	■			0.15
Calcareous algae		■	■		■	■			0.15
Anemonies		■	■	■	■	■			0.99
Penaeid shrimps		■	■	■	■	■	■		0.99
Shrimps and prawns		■	■	■	■	■	■		0.99
Squid			■	■					0.93
Octopus		■	■	■	■	■			0.99
Sea cucumbers	■								1.00
Lobsters	■								1.00
Large crabs	■								1.00
Small crabs	■								1.00
Crown of thorns		■			■				0.06
Giant triton		■			■				0.06
Herbivorous echinoids	■								1.00
Bivalves		■	■	■	■	■	■		0.99
Sessile filter feeders		■	■	■	■	■	■		0.99
Epifaunal det. inverts.	■								1.00
Epifaunal carn. inverts	■								1.00
Infaunal inverts.		■	■	■		■	■	■	0.96
Jellyfish and hydroids		■	■	■	■	■	■		0.99
Carn. zooplankton	■								1.00
Large herb. zooplankton	■								1.00
Small herb. zooplankton	■								1.00
Phytoplankton	■								1.00
Macro algae		■	■		■	■			0.99
Sea grass							■	■	0.01
Mangroves								■	0.01
Fishery discards	■								1.00
Detritus	■								1.00

Dampier St.

	All	20m	200m	Mesopelagic (200-1000m)	Bathypelagic (> 1000m)	Reef	Enclosed lagoon	Mangroves	Area occupied
Ad. eroding grazers		■	■	■		■	■		0.77
Juv. eroding grazers		■	■			■	■	■	0.44
Ad. scraping grazers		■	■	■		■	■		0.77
Juv. scraping grazers		■	■			■	■	■	0.44
Detritivore fish		■	■	■		■	■		0.77
Azooxanthellate corals		■	■			■	■		0.43
Hermatypic corals						■			0.02
Non reef building corals		■	■			■	■		0.43
Soft corals		■	■			■	■		0.43
Calcareous algae		■	■			■	■		0.43
Anemonies		■	■	■	■	■	■		0.99
Penaeid shrimps		■	■	■	■	■	■		0.99
Shrimps and prawns		■	■	■	■	■	■		0.99
Squid			■	■	■				0.92
Octopus		■	■	■		■	■		0.77
Sea cucumbers	■								1.00
Lobsters	■								1.00
Large crabs	■								1.00
Small crabs	■								1.00
Crown of thorns		■	■			■			0.43
Giant triton		■	■			■			0.43
Herbivorous echinoids	■								1.00
Bivalves		■	■	■	■	■	■		0.99
Sessile filter feeders		■	■	■	■	■	■		0.99
Epifaunal det. inverts.	■								1.00
Epifaunal carn. inverts	■								1.00
Infaunal inverts.		■	■	■	■		■	■	0.98
Jellyfish and hydroids		■	■	■	■	■	■		0.99
Carn. zooplankton	■								1.00
Large herb. zooplankton	■								1.00
Small herb. zooplankton	■								1.00
Phytoplankton	■								1.00
Macro algae		■	■	■		■	■		0.77
Sea grass								■	0.01
Mangroves								■	0.01
Fishery discards	■								1.00
Detritus	■								1.00

Table 2.8 - Designated fishing activity in Ecospace habitat types.

Raja Ampat

	All	10m	20m	200m	Deep (> 200m)	Reef
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	■					
Set line			■	■	■	
Lift net	■					
Foreign fleet				■	■	
Shrimp trawl				■	■	

Kofiau

	All	20m	200m	Deep (> 200m)	Reef	Enclosed lagoon	Estuary	Mangrovev
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	■							
Set line			■	■	■		■	
Lift net	■							
Foreign fleet	-	-	-	-	-	-	-	-
Shrimp trawl	-	-	-	-	-	-	-	-

Dampier St.

	All	20m	200m	Mesopelagic (200-1000m)	Bathypelagic (> 1000m)	Reef	Enclosed lagoon	Mangroves
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	■							
Set line			■	■	■	■		
Lift net	■							
Foreign fleet	-	-	-	-	-	-	-	-
Shrimp trawl	-	-	-	-	-	-	-	-

Raja Ampat 2006 Ecospace model

The RA Ecospace map is 100 x 120 cells and describes an area about 256 km east to west, and 321 km north to south; each cell represents an area 2.56 x 2.57 km, or approximately 6.57 km2 at mid-latitudes. The north-westernmost coordinate lies at 1290 12' E, 00 12'N, and the south-easternmost coordinate lies at 1300 30' E, 20 42'S. Five aquatic habitat types are used in the RA Ecospace model. The habitats are based partly on bathymetry, with 10, 20 and 200 m contours represented as light green, orange and dark green cell colours in Fig. 2.6. A deep-water habitat type describes cells greater than 200 m in depth (blue), and a reef habitat type shows the locations of submerged reefs (red). Bathymetric information was obtained from Indonesian nautical charts collected by the BHS-EBM project in GIS files (contact: M. Barmawi, TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia).

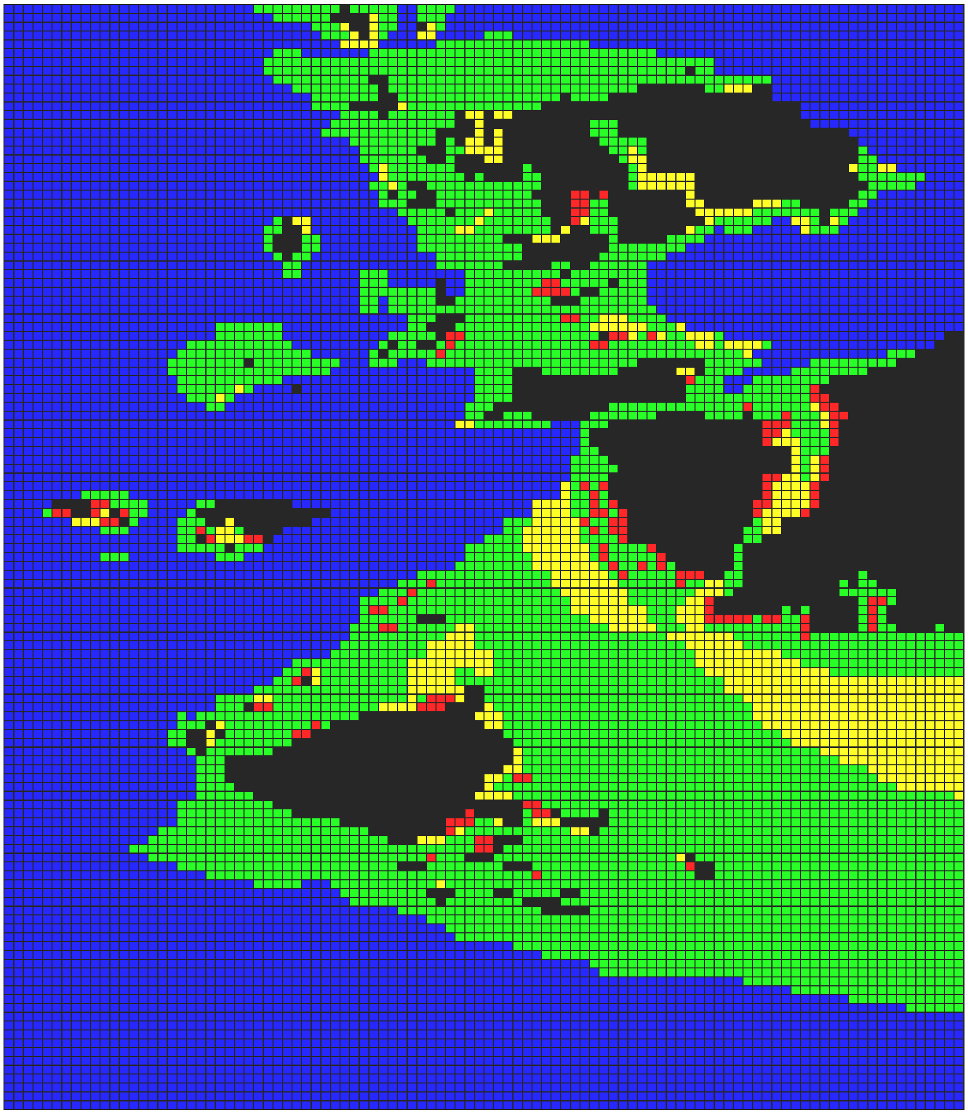

Figure 2.6 - Ecospace habitat map of RA. Land cells are black, and five habitat types summarize major oceanographic zones (light green: 10 m isobath; orange: 20 m isobath; dark green: 200m isobath; blue: deep water (>200 m); red: reef areas). Map dimensions are 125 x 100 cells. Cell dimensions are approximately 2.56 x 2.57 km.

Primary production spatial forcing pattern

A primary production spatial forcing pattern is entered for the RA model using data from the Sea Around Us Project ecology database (Sea Around Us Project, 2006); the information is retrieved automatically by an Ecospace sub-routine (contact: V. Christensen, UBC Fisheries Centre. 2202 Main Mall, Vancouver, Canada). The primary production has been estimated using a model by Platt and Satyendranath (1999) that integrates PP by depth based on chlorophyll pigment concentrations and photosynthetically active radiation (Lai, 2004; Hoepffner *et al.*, 1999). Ocean colour is provided by the SeaWiFS database at a spatial resolution of approximately 6 minutes, or 11 km (http://oceancolor.gsfc.nasa.gov/SeaWiFS/).

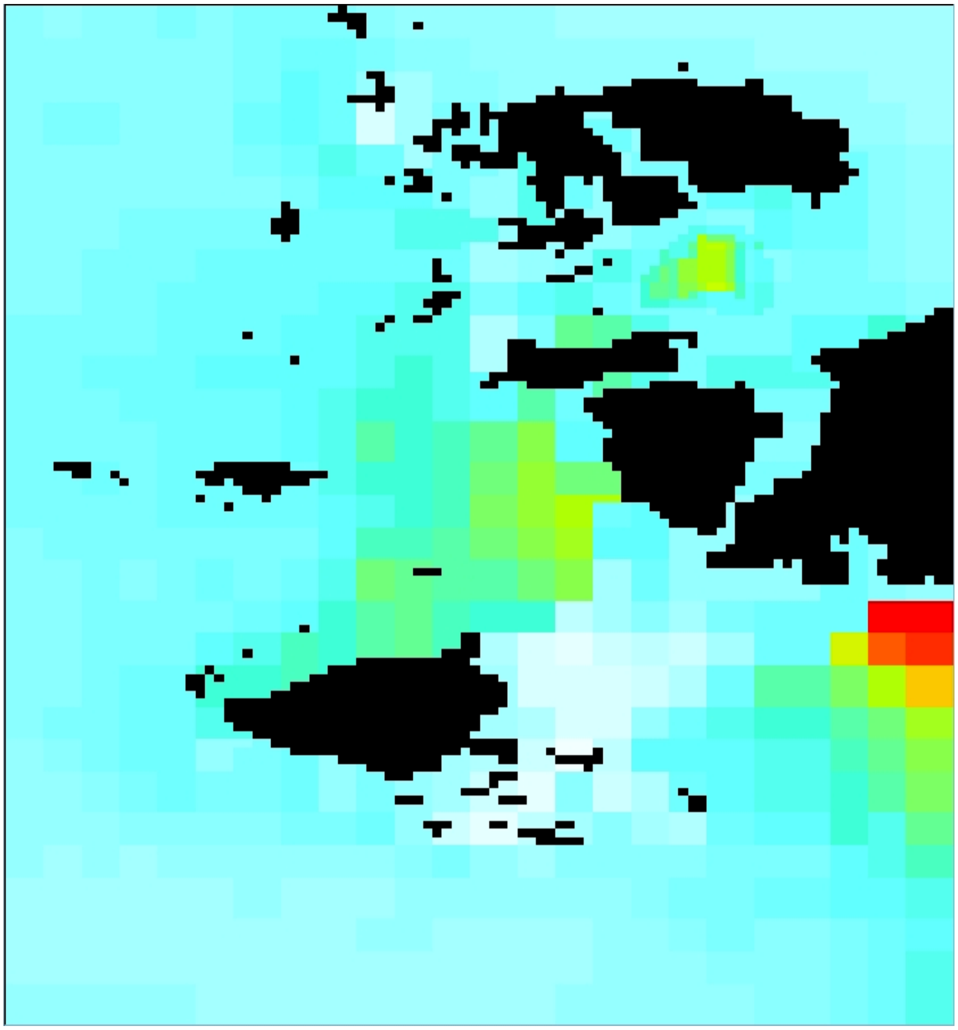

Figure 2.7 - Spatial primary production (P/B) for Raja Ampat. High production (red) corresponds to production values >1000 gC·m^{-2}·year^{-1}; green areas represent medium production ~400-600 gC·m^{-2}·year^{-1}; blue areas are low production ~200-400 gC·m^{-2}·year^{-1}; white areas are oligotrophic <200 gC·m^{-2}·year^{-1}. Resolution: 6 minutes. Modified from: Sea Around Us Project database (Sea Around Us Project, 2006).

There is an average primary production of about 315.4 gC·m^{-2}·year^{-1} in the study area. The chlorophyll data showed an area of high productivity (>1000 gC·m^{-2}·year^{-1}) in the northern extent of the Arafura Sea, in the southeast region of the study area. However, there is a large amount of river input to the sea along the mainland coast of Papua, and remote sensing techniques based on ocean colour may become confused as the concentration of optically absorbing particles increases. Suspended material, dissolved organic matter, and bottom reflectance can influence the data. Although terrigenous nutrient loading will legitimately increase primary production in that area, we caution that the colour signal north of the Arafura Sea may also be biased by the suspension of sediments which affects ocean reflectance. Similarly, the area of high production indicated to the west of Salawati Island may be biased by turbidity due to suspended sediments from waves, and upwelling produced in the Sagewin Strait to the NE (M. Erdmann. CI. Jl. Dr. Muwardi. 17 Renon Denpasar, Bali, Indonesia, pers. comm.). We have applied the primary production data directly as obtained from the Sea Around Us Project database, but we offer these caveats. Further work can test the sensitivity of the Ecospace analyses to our assumptions concerning the distribution of primary production.

There were no elevated levels of primary production reported by Sea Around Us Project (2006) data for the central portion of Dampier Strait, despite the presence of a strong and productive region of upwelling that supports a large anchovy fishery (Mark Erdmann. CI. Jl. Dr. Muwardi. 17 Renon Denpasar, Bali, Indonesia, pers. comm.). To capture this production in the Ecospace model, a region of high productivity was entered in manually. The most productive region of central Dampier Strait was set arbitrarily at 250% of the reported production rate; the area of high production tapers off to 30% above the reported rate to the east and west of the central upwelling zone. On average, cells in this zone are in the 90th percentile of production rates among map cells. The maximum production rate in this zone is 723 $gC \cdot m^{-2} \cdot year^{-1}$, and the region contributes 1.5% to the total RA primary production. This modification to the Sea Around Us Project (2006) data is visible in Fig. 2.7 as a yellow-green area in central Dampier Strait. Note that this modification does not change the overall primary productivity of the Ecopath model. Ecospace scales the relative cell production rates so that their average equals the phytoplankton P/B defined in the basic parameter set (Table A.3.2).

Kofiau Island model

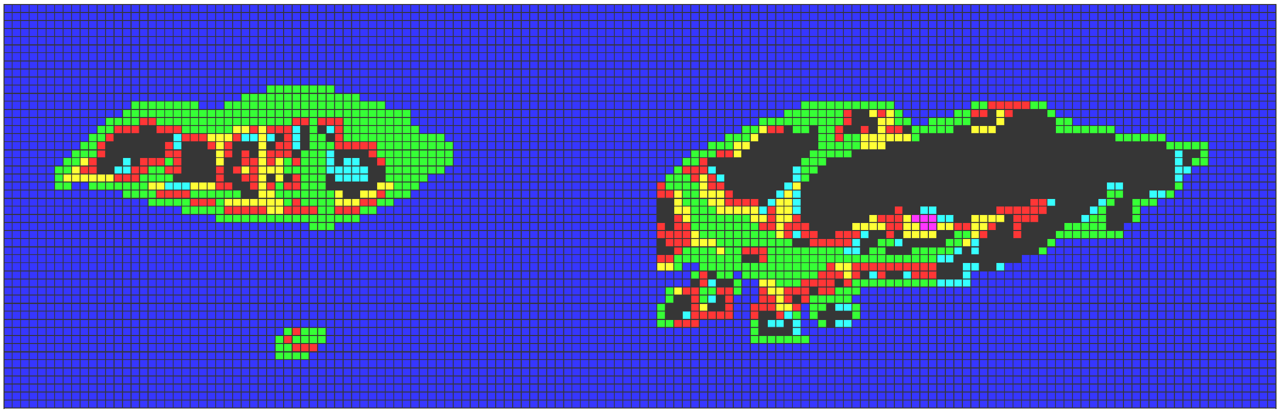

Figure 2.8 - Ecospace habitat map of Kofiau Island. Land cells are black, and seven habitat types are used to describe the marine area (orange: 20m isobath; dark green: 200m isobath; blue: deep water (> 200m); red: reef areas; light blue: enclosed lagoon; purple: estuary; teal: mangroves). Map dimensions are 50 x 150 cells. Cell dimensions are approximately 0.56 x 0.58 km, or about 0.32 km^2.

The Kofiau Island model is represented by 150 cells east to west, and 50 cells north to south (Fig. 2.8). The modelled area is approximately 27.8 km by 87.6 km; each cell covers an area 555 m by 580 m, incorporating about 0.32 km^2 of sea area per cell. The north-westernmost coordinate lies at 1290 14’ 20” E, 10 5’S, and the south-easternmost coordinate lies at 1300 1’ 20”E, 10 20’S. Seven habitat types are used for the Kofiau Island Ecospace model. Three are based on bathymetric data from GIS collections: 20 m isobath (orange habitat), 200 m isobath (green habitat) and deep water (>200 m) (dark blue habitat). Reef areas (red), mangrove areas (teal) and estuaries (light blue) were identified by the marine use survey; these are all incorporated as dedicated habitat types.

Figure 2.9 - An enclosed lagoon on Taudore Island. Location is west of Kofiau Island, photographed during aerial surveys. Photo credit: Erdi Lazuardi.

The model relies on GIS data collected by the BHS EBM project (M. Barmawi, TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia. Unpublished data), and on habitat information reported in COREMAP (2005). We include ecologically significant areas identified by expert knowledge and by community interviews in the BHS EBM resource use assessment study. The habitats consider an enclosed lagoon area (Fig. 2.9) in the Boo Island group west of Kofiau Island. This area will function as an enclosed lagoon in Ecospace by having little biomass exchange with outside areas due to land cell proximity. By assigning a dedicated habitat type we can further quarantine this area from the rest of the system, removing or limiting the trophic influence of oceanic and high sea species, like billfish, large sharks or whales. A seamount area (Dona Carmalita) (Fig. 2.10) was identified by the marine use survey; it is included in Ecospace as a collection of reef and shallow water habitats.

A simple advection pattern surrounding the Kofiau Island group has been entered based on results from the SPAG vial release program. 286 out of 1000 vials have been recovered. They were found in disperse places, but all east of the release point. The majority of vials (255) were recovered south and east of Kofiau, near Wejim Is. (north of Misool). (C. Rotinsulu. CI. Jl Arfak No. 45. Sorong, Papua, Indonesia 98413, pers. comm.). We therefore applied a southeast advection current. Ocean currents must be monitored in RA throughout the year, however, so that we can account for seasonal variations. Vials were also found to the east on Salawati and Batanta Islands, and to the north on Weigeo Island indicating complex current systems. When the Ecospace models are more advanced, we will try to adjust the dispersal rates of juvenile groups to allow settlement throughout RA.

There are also tidal flows north to south throughout the year passing between the Kofiau Island group and the Boo Island group in a deep central area. Tidal mixing may sustain a population of small pelagics providing a significant feeding area for sea birds (A. Muljadi, TNC-CTC. Jl Gunung Merapi No. 38, Kampung

Figure 2.10 - Dona Carmalita seamount. Location is south of the Boo Island group (west of Kofiau Island) photographed during aerial surveys. Photo credit: Andreas Muljadi.

Baru, Sorong, Papua, Indonesia 98413, pers. comm.). We will model that interaction when Ecospace is more fully developed.

Dampier Strait model

The Dampier Strait model uses 105 cells east to west, and 60 cells north to south (Fig. 2.11). The area covered by the model is approximately 139 km by 80 km. Each cell is 1.33 km by 1.33 km, or about 1.76 km^2. Seven habitat types were used to represent Dampier Strait. Two habitat types are based on bathymetry from assembled GIS data: 20 m isobath (orange habitat), 200 m isobath (green habitat) (M. Barmawi, TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia, unpublished data). Although we did not have accurate depth contour information for areas greater than 200 m, we have assumed that the interior of Dampier Strait consists of a deeper area between 500-1000 m (dark blue). Mangrove areas (teal) and reef areas (red) are based on recent BHS EBM project outputs (Firman and Azhar, 2006). The enclosed Mayalibit bay (light blue) receives its own habitat type to distinguish the sheltered, shallow bay from the deeper oceanic areas of Dampier Strait. A narrow channel connects Mayalibit Bay to Dampier Strait (Fig. 2.12).

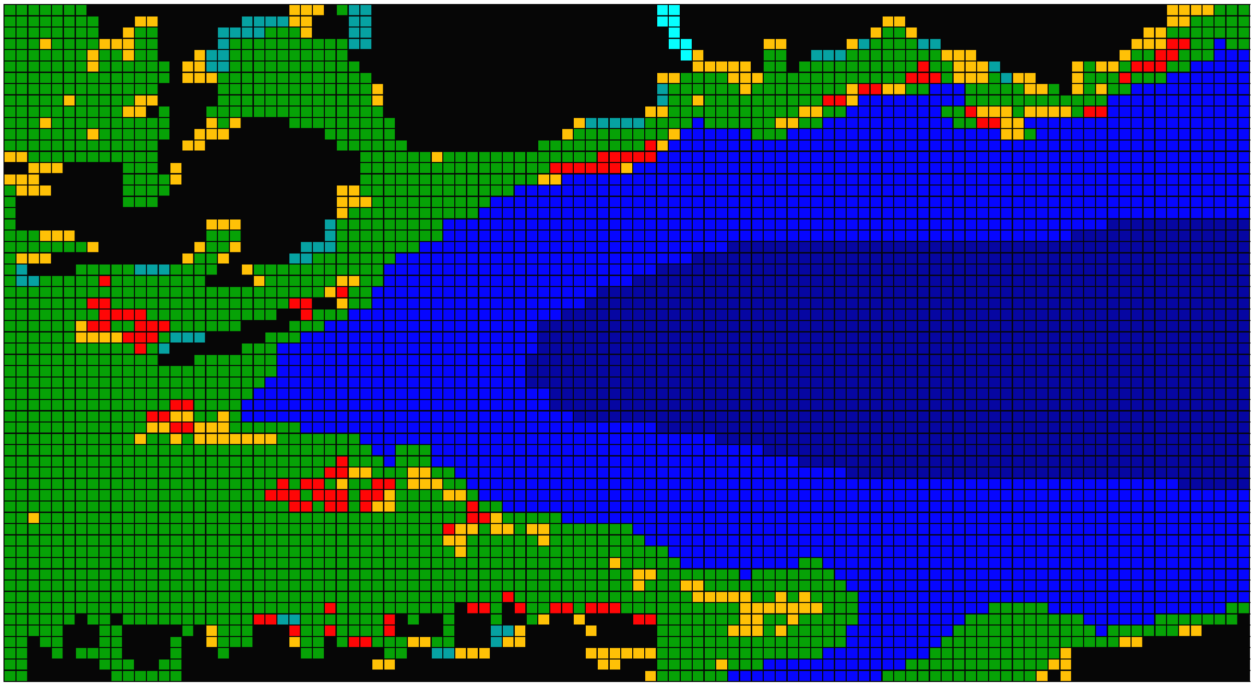

Figure 2.11 - Ecospace habitat map of Dampier Strait. Weigeo Island borders on the north, Batana Island is in the south. Land cells are black, and seven habitat types are used to describe the marine area (orange: 20 m isobath; dark green: 200 m isobath; blue: deep water (>200 m); red: reef areas; light blue: enclosed lagoon; purple: estuary; teal: mangroves). Map dimensions are 50 x 150 cells. Cell dimensions are approximately 0.56 x 0.58 km, or about 0.32 km^2.

Fishing policy optimizations

The policy search routine in Ecosim (Christensen and Walters, 2004b) iteratively varies the fleet effort and reruns harvest simulations until it finds the optimal combination of fishing mortalities that maximizes harvest benefits. The routine can be used to identify fishing patterns that increase economic, social and ecological benefits from the ecosystem by use of a multi-criterion objective function. We use this routine here to explore the sustainable production potential of the RA ecosystem, and quantify the ecological impacts of various optimal fishing policies. We use randomly selected F per gear type for initialization, and employ the Fletcher-Powell conjugate gradient optimization method (Fletcher and Powell, 1963). For each gear type in the model, a single optimal fishing mortality is calculated and applied to each year in the simulation to find the best equilibrium-level solution in a 16 year forecast, from 2006-2022.

Figure 2.12 - Myalibit Bay entrance. A narrow channel connects Dampier Strait to the shallow enclosed area of Myalibit bay. Photo credit: Andreas Muljadi.

The objective function used here considers two criteria, the economic value produced from the ecosystem, and the ecological health of the system measured using a proxy for functional group longevity (B/P). This is the default ecological objective in the policy search routine and it is inspired by Odum’s (1969) description of mature ecosystems. Economic benefits are assessed according to their net present value (NPV). NPV is a term used in cost-benefit analysis to summarize the expected future flow of benefits into a single value, which can be compared across investment alternatives. Intergenerational discounting (Sumaila, 2001; 2004; Sumaila and Walters, 2005) is used by default in Ecosim, where the standard discount rate (δ) is 4% and the rate for future generations (δ_{fg}) is 10%. This is a precautionary economic criterion because it assures that resources will be preserved for future generations (Sumaila, 2001).

A range of optimal policies are generated that incrementally vary the relative weightings of the economic and ecological criteria. The weightings are represented by W_{ECON} and W_{ECOL} in eq. 2.15; OBJ is the objective function to be maximized by the search.

$$OBJ = W_{ECON} \cdot \Sigma\, NPV_{ij} + W_{ECOL} \cdot \Sigma\, B/P_{it} \qquad (2.15)$$

The summed terms evaluate socio-economic and ecological benefits of the harvest plan across functional group (*i*), gear type (*j*) and simulation time step (*t*).

This application of the policy search routine will allow us to sketch the trade-off frontier between profit and ecosystem health, and calculate the marginal costs and benefits of conservation.

RESULTS

Time series fitting

Fits to biomass and catch data for functional groups are presented in Figs. B.2.2 and B.2.3, respectively. Regarding biomass predictions, there is acceptable agreement with data for most functional groups. Groupers and snappers show a poor fit, but CPUE data is a poor proxy for the biomass of these groups due to their aggregation behaviour. Because they congregate in spawning aggregations, and because fishers target those aggregations, the biomass density available to fisheries may remain constant over a wide range of population sizes. The populations of groupers and snappers have likely declined throughout RA, and Ecosim predicts this case under the effort assumptions in place (Section 2.5.10 - Effort time series).

One other discrepancy in the time series fitting from 1990 to 2006 is that there is little or no decrease seen in the biomass of large, medium and small reef associated fish, despite a reported decline in the CPUE during that period. These groups will be the subject of further tuning after we have processed abundance data from fisher interviews (see discussion), and improved our understanding of the relative biomass change in the RA ecosystem.

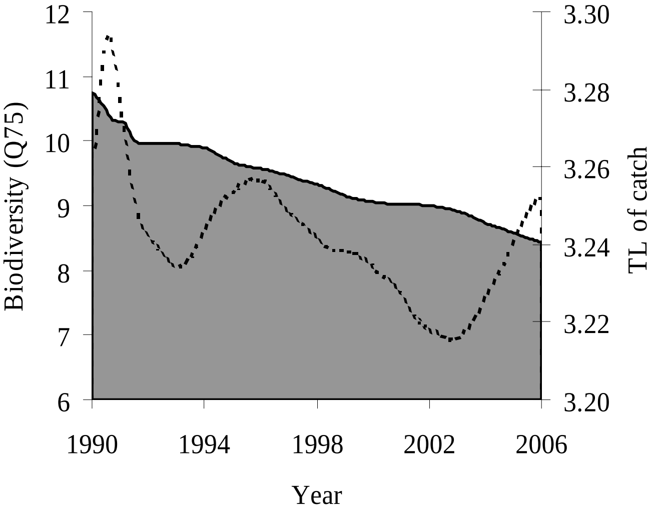

Figure 3.1 - Raja Ampat ecosystem indicators (1990-2006). Biodiversity trajectory predicted for 1990-2006 (shaded area). Biodiversity is measured using Q75, a variant of Kempton's Q index. Trophic level of catch (broken line) may have decreased, indicating 'fishing down the food web'.

For many commercial functional groups, the catch required to cause the biomass decline suggested by CPUE is substantially larger than the catch estimated from government records (Fig. B.2.3); the difference may serve as a first estimate of unreported catch for the study area.

Biodiversity is predicted to have declined from 1990-2006 according to Fig. 3.1. The biodiversity statistic in use, Q75, is a variant on Kempton's Q Index (Kempton and Taylor, 1976) that has been designed for use with ecosystem box models‡‡.

The average trophic level of the catch in RA is reported in Fig. 3.1. The analysis suggests that the average trophic level may have seen a slight downward trend for most of the last 16 years. However, the pattern has been variable, and the total overall decline from 1990 to 2006 remains small, from 0 to 0.07 TL. For comparison, Essington *et al.* (2006) suggested that a mean decline in the trophic level of catch of 0.15 constitutes evidence of ecologically significant 'fishing down the food web' (Pauly *et al.*, 1998). In the model, the trophic level of the catch remains somewhat constant because of an expanding fishery on high trophic level predator fish groups throughout the length of the simulation, and decreased catches of anchovy because of a population decline (Fig. B.2.3).

Predicted climate anomaly

The optimal primary production anomaly trend determined by Ecosim (broken line; Fig. 3.2) suggests a higher than average rate of production for early years in the simulation, 1990-1995, as high as 12% above the mean value. The trend shows a lower relative rate of production in recent years, 2002-2006, approximately 15% below average. Applying the P/B forcing pattern to phytoplankton reduces ecosystem residuals by 5%. When we scale the primary production

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‡‡ Kempton's Q index represents the inter-quartile slope of the cumulative species log-abundance curve; it evaluates both species evenness and species richness. Larger values indicate a more biodiverse system. For a discussion on the use of Kempton's Q Index in ecosystem models, see Ainsworth and Pitcher (2006); for implementation of the Q75 index in EwE see Christensen *et al.* (2004).

anomaly trend to reproduce the observed phytoplankton variability, ecosystem residuals are reduced only 3.7% versus the baseline simulation. Future work may confirm whether the predicted biomass variability of higher trophic level groups has been improved, although data is limiting.

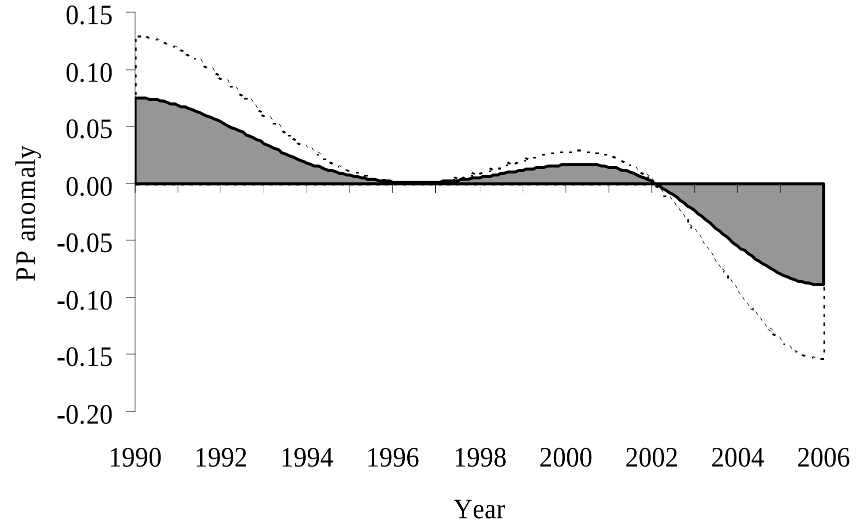

Figure 3.2 - Primary production anomaly. Anomaly is predicted to reduce discrepancy between observed and predicted catch and relative biomass; 5 spline points are used. Broken line indicates optimal forcing pattern predicted by Ecosim; shaded area shows pattern rescaled to match observed phytoplankton variability.

The estimated anomaly shows a weak (non-significant) negative correlation with the Southern Oscillation Index (SOI) (Spearmans rank correlation $\rho = -0.05$; $\rho_{0.05(2),16} = 0.503$) (AGBM, 2006) and a stronger but also non-significant negative correlation with sea surface temperature (SST) ($\rho = -0.31$) (IRI, 2006). The west coast of Papua has the highest primary production variability in Indonesia (Susanto *et al.*, 2006). Therefore, the outputs of the primary production analysis could potentially affect our choice of sustainable fishing policies in RA.

Fig. 3.3 shows the coefficient of variation for functional group biomass in RA. The dynamics from 1990-2006 are conservative without the primary production forcing pattern in place. Using the optimal forcing pattern determined by Ecosim results in the greatest reduction in residuals versus observed data, and also causes a high degree of ecosystem volatility. By rescaling the primary production trend to match phytoplankton observations, the variability of functional groups is reduced in the model.

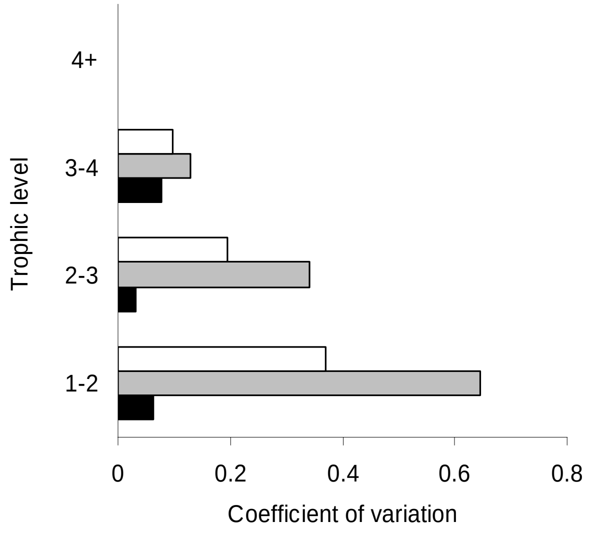

Figure 3.3 - Coefficient of variation (CV) of RA functional group biomass (1990-2006). CV is sorted by trophic level. Black bars indicate no primary production (PP) forcing, grey bars show optimal PP forcing pattern, white bars show rescaled pattern that improves phytoplankton variability.

Equilibrium analysis

Table B.2.1 presents the equilibrium analysis results. Key fishery indicators for commercial functional groups are summarized in Table 3.1. Where catch on juveniles is significant, the equilibrium analysis was performed manually.

Table 3.1 - Fishery indicators for major commercial groups in the 2006 RA model. Values are determined by the equilibrium analysis. Asterix indicates that the equilibrium values were determined manually and fishing mortality was incremented for all life history stanzas (see text).

#	Group	MSY	F_{msy}	F_{2006}	F_{2006}/F_{msy}	2006 catch
		($t \cdot km^{-2}$)	($year^{-1}$)	($year^{-1}$)		($t \cdot km^{-2}$)
10	Ad. groupers	0.027	0.207	0.094	0.454	0.017
13	Ad. snappers	0.008	0.210	0.155	0.735	0.014
16	Ad. Napoleon wrasse*	0.002	0.228	0.085	0.372	0.001
17	Sub. Napoleon wrasse*	0.003	0.244	0.048	0.197	0.001
19	Skipjack tuna	0.366	0.479	0.548	1.144	0.348
20	Other tuna	0.058	0.251	0.097	0.385	0.047
21	Mackerel	0.058	0.746	0.746	1.000	0.064
22	Billfish	0.068	0.147	0.061	0.417	0.050
23	Ad. coral trout	0.002	0.092	0.045	0.484	0.002
25	Ad. large sharks	0.010	0.476	0.971	2.041	0.025
33	Ad. butterflyfish	0.079	0.553	0.060	0.109	0.016
36	Ad. large pelagic	0.023	0.575	0.575	1.000	0.031
38	Ad. medium pelagic	0.008	1.276	1.383	1.084	0.014
40	Ad. small pelagic	0.042	1.154	0.825	0.714	0.034
42	Ad. large reef assoc.	0.343	0.178	0.081	0.455	0.577
44	Ad. medium reef assoc.*	0.824	0.400	0.123	0.307	0.438
46	Ad. small reef assoc.	0.371	2.422	0.142	0.059	0.019
48	Ad. large demersal	0.040	0.561	0.679	1.210	0.024
50	Ad. small demersal	0.247	2.868	0.211	0.074	0.028
52	Ad. large planktivore*	0.478	0.700	0.300	0.429	0.339
53	Juv. large planktivore*	0.452	0.700	0.034	0.048	0.034
54	Ad. small planktivore*	0.130	0.600	0.031	0.052	0.013
55	Juv. small planktivore*	0.223	0.600	0.002	0.004	0.001
56	Ad. anchovy	0.887	1.218	0.391	0.321	0.509
58	Ad. deepwater fish*	0.115	0.450	0.034	0.075	0.022
59	Juv. deepwater fish*	0.158	0.300	0.016	0.055	0.014
60	Ad. macro algal browsing*	0.033	0.250	0.003	0.013	0.001
61	Juv. macro algal browsing*	0.034	0.300	0.000	0.001	0.000
62	Ad. eroding grazers*	0.056	0.250	0.003	0.013	0.000
63	Juv. eroding grazers*	0.036	0.250	0.000	0.001	0.000
64	Ad. scraping grazers*	0.092	0.700	0.094	0.134	0.022
65	Juv. scraping grazers*	0.495	0.800	0.002	0.002	0.002

Challenges to Ecosim

Fig. 3.4 shows synoptic results of the challenges to Ecosim. It summarizes the biomass change in reef associated fish functional groups (including specific and aggregated reef groups), pelagic fish, predator fish (TL > 3), forage fish (TL 2-3), invertebrates and mammals. The 'no fishing' scenario (0F) completes the simulation with the highest standing biomass for exploited species groups such as reef fish, pelagic fish and high trophic level fish. The 'increasing fishing' scenario (F+) ends with depressed biomasses for these exploited groups. Forage fish, with trophic levels between 2 and 3 are the prey for piscivores, and their biomasses do see an appropriate decrease once predators recover. Likewise, the invertebrate biomasses are highest in the 'increased fishing' scenario, when predators have been removed from the system, and lowest in the 'no fishing' scenario, when predators are allowed to recover.

Fig. B.2.4 shows biomass predictions for functional groups under the three fishing scenario challenges. The error bars show the variation in biomass trajectories predicted by the Monte Carlo analysis, when Ecopath biomass parameters are allowed to vary for key groups by +/- 20%. The error bars represent 1 standard deviation around the mean; the mean is indicated by an open circle. All groups see an appropriate decline in biomass relative to baseline levels for the 'increased fishing' scenario; all groups see an increase relative to baseline biomass for the 'no fishing' scenario. Only the absolute biomass values of coral trout and large reef-associated fish appear unsatisfactory; they should recover under relieved fishing pressure. As the model is improved with field data, biomass dynamics will be revisited for these groups.

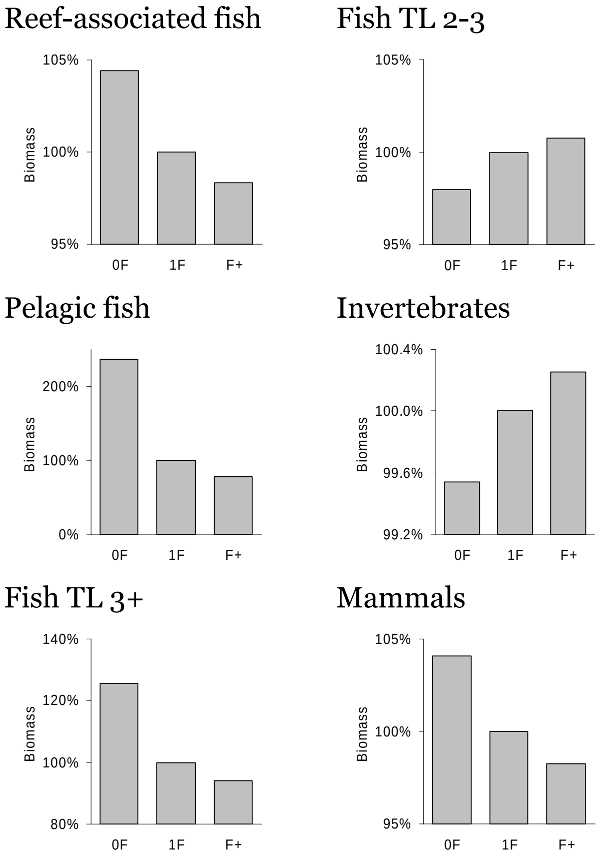

Figure 3.4. Group biomass change following extreme fishing policies (2006-2022). No fishing (0F), baseline fishing (1F) and increasing fishing (F+). Mean biomass values are shown that result from a Monte Carlo that varies input biomass for commercial fish. Simulations are from 2006-2022; biomass is relative to baseline endstate.

Table 3.2 shows the depletion risk of functional groups associated with the three fishing scenarios. The 'no fishing' scenario has the fewest number of depletions, and the least severe depletions. Under baseline fishing conditions, where current 2006 fishing mortalities are carried on until 2022, adult snappers drop below 30% of their current biomass value in 6% of trials. Also threatened are coral trout and large sharks, which each decline to 40% of their current biomass under baseline conditions in 6% of simulations.

Under increasing fishing mortality, the depletions are more severe. Snappers are prone to collapse to 15% of their current biomass value in 80% of trials, while mackerel, coral trout, sharks and large pelagics all a serious depletion risk. Large reef associated fish perform poorly in most simulations; this group requires further tuning.

Fishing policy optimizations

Fig. 3.5 shows the relationship between the expected NPV from the optimal harvest policy, and ecosystem maturity B/P. 156 optimal policies have been computed based on a random F vector starting. More valuable harvest plans tend to result in a lower ecosystem maturity score due to a depletion of slow-growing animals such as large predators. The current ecosystem state is reported in Fig. 3.5 for comparison. The current RA fisheries appear sub-optimal; neither economic nor ecological benefits are being realized to their full potential.

Table 3.2 - Group depletion risk (in %) following extreme fishing scenarios. No fishing (0F), baseline fishing (1F) and increasing fishing (F+). Depletion risk shows the percentage of times that each functional group declined to a given level of biomass during Monte Carlo simulations (n = 50). Biomass depletion is stated relative to baseline model biomass. Adult (ad.); sub-adult (sub.); juvenile (juv.).

	Group	**End-state biomass (2022) vs. baseline model (2006)**				
		15%	**20%**	**30%**	**40%**	**50%**
0 F	Ad. coral trout					16
	Juv. coral trout					12
	Juv. large sharks					44
1 F	Ad. snappers			6	100	100
	Sub. snappers				20	62
	Juv. snappers				28	64
	Ad. coral trout				6	50
	Juv. coral trout					38
	Ad. large sharks				6	18
F+	Ad. snappers	80	100	100	100	100
	Sub. snappers		8	64	92	98
	Juv. snappers		12	72	94	96
	Mackerel			2	54	94
	Ad. coral trout				10	76
	Juv. coral trout					46
	Ad. large sharks				8	32
	Ad. large pelagic				52	100
	Juv. large pelagic				8	56

A convex relationship appears between the two criteria, suggesting that a win-win harvest policy may exist that will generate the greatest economic return while preserving the ecosystem. However, results could change with model improvements, and no such win-win policy exists with respect to total catch and biodiversity. Fig. 3.6 re-expresses the benefits of the optimal scenarios in these terms, and indicates a linear relationship. The correct fishing policy to employ remains a matter of social priority.

Results suggest that under an optimal fishing policy, the RA ecosystem could sustainably deliver more catch that it currently does. The high degree of biodiversity estimated for the 2006 RA ecosystem

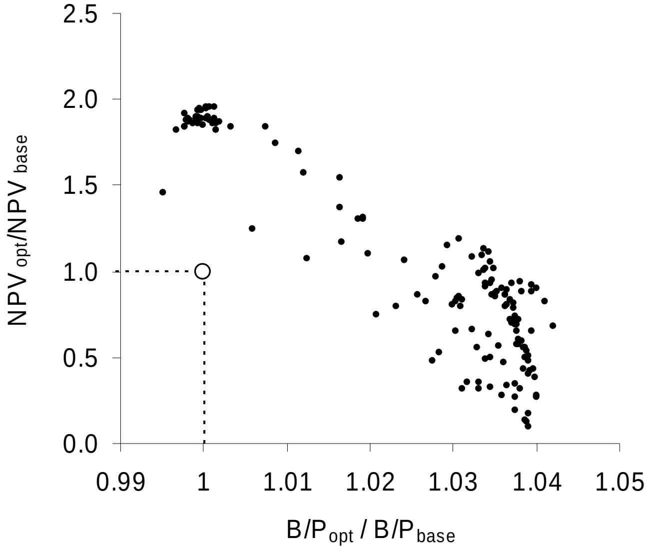

Figure 3.5 - Tradeoff between NPV and B/P. Points are determined through policy optimizations. Open circle show current RA fishery (sub-optimal), black points show the trade-off frontier (optimal).

can be expected to decrease if any of the optimal policies presented here are applied. In order to preserve biodiversity explicitly, the policy search routine needs to be updated to include Q75 as an objective function. This is on the horizon.

Fig. 3.7 re-expresses the inherent trade off in RA between catch and biodiversity. From left to right, the optimal fishing plans put a heavier relative weighting on economic returns and a lower weighting on ecological benefits. Any optimal fishing plan that considers these two objectives will fall somewhere on this scale.

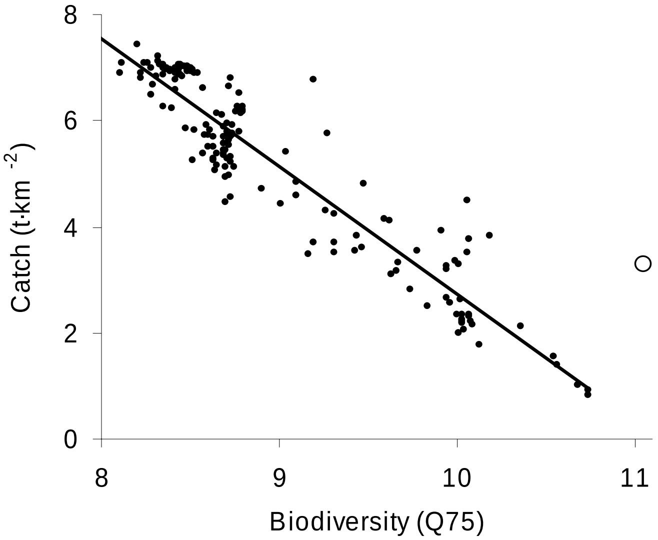

Figure 3.6 - Tradeoff between catch and biodiversity. Points determined through policy optimizations. Open circle show current RA fishery, black points show the trade-off frontier. Linear best fit shown.

Fig. 3.8 analyzes the fishing strategies resulting from the policy search routine. It uses a principle components analysis to summarize the similarities between the optimal F vectors developed by the policy search. The F vector represents the optimal equilibrium-level fishing mortalities applicable to each of the 17 gear types in the RA model. Each point represents a unique combination of optimal fishing mortalities. The relative position of any two points in the X-Y plane indicates the similarity of the fishing solutions; the Z value is indicated by grayscale, where lighter values indicate greater equilibrium harvest benefits (catch on left; biodiversity on right).

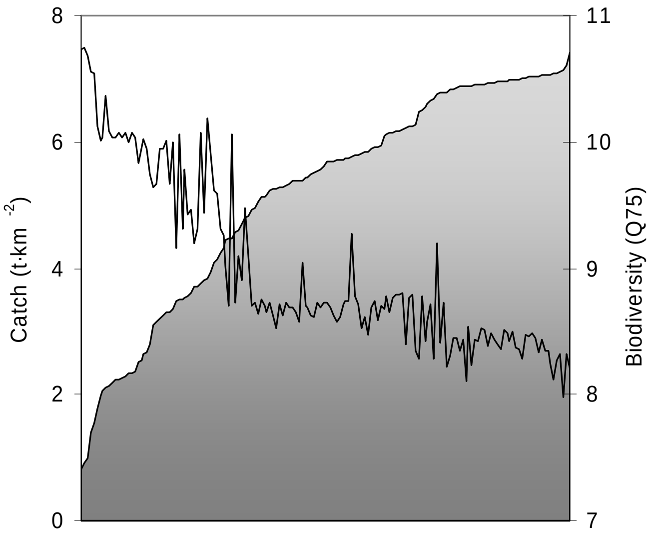

Figure 3.7 - Equilibrium catch and biodiversity levels for optimal fishing plans. The X-axis shows 156 policy optimizations conducted from random F starting points. From left to right, the relative contribution of the economic criterion increases versus the ecological criterion. The best catch (grey area) and biodiversity (line) achieved by the policy search is shown.

A pattern emerges among the fleet-effort solutions; they can be grouped into three broad categories. On the right side of the graphs, solutions cluster that tend to generate high catch at the expensive of biodiversity. These solutions were found by applying a high weighting on the economic harvest criterion. They tend to concentrate and increase fishing effort in the spear and harpoon gear type (Fig. 3.9). The cluster in the center of the plots (vertex) tends to preserve biodiversity but generates less catch; optimal fishing effort is low overall, only a slight increase in spear and harpoon effort is permissible. The cluster on the left has located a compromise solution, using shore gillnet as the principle fishing apparatus. All solutions tend to increase fishing effort of shrimp trawl. Note that habitat impacts of fishing gear are not considered in the model.

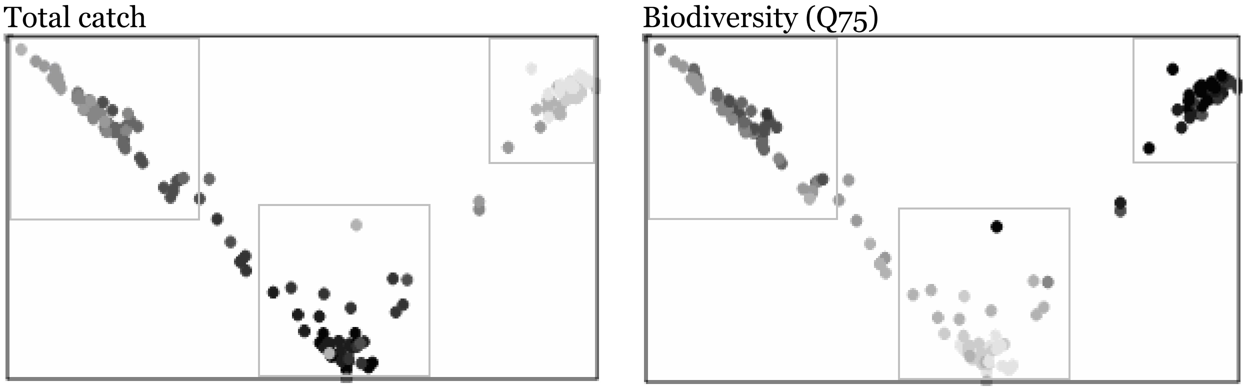

Figure 3.8 - Principal components analysis showing policy search response surface. These plots show the similarity between optimal fleet-effort vectors (i.e., one F per gear type, n = 17) determined by the policy search routine. Points located close to each other use similar fishing strategies; points distant from each other use dissimilar strategies. The resulting equilibrium-level catch and biodiversity from the optimal plans are shown in grayscale, where lighter colours indicate higher catch (left) and higher biodiversity (right). Darker colours show low values. The fishing strategies employed by the policy search routine can be roughly categorized into 3 clusters (rectangles). The right-most cluster achieves high catch at the expense of biodiversity, the centre cluster (vertex) preserves biodiversity but generates less catch, and the left-most cluster represents a compromise solution.

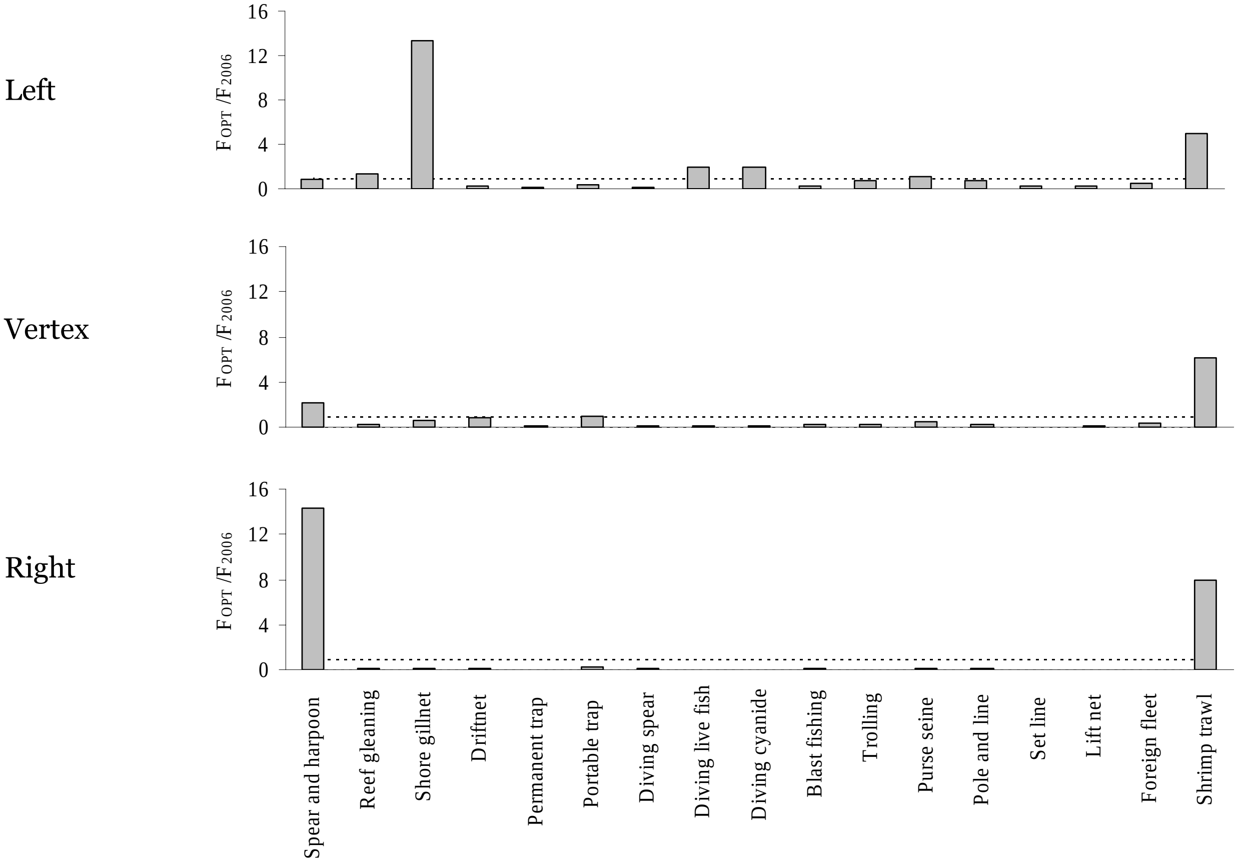

Figure 3.9 - Characterization of optimal fleet-effort patterns. Three clusters of solutions are identified from PCA (left, vertex, right), the bars show the average F for each cluster as a fraction of baseline (2006) F. Broken line indicates the baseline fishing mortality per gear type. All fishing strategies tend to increase shrimp trawl.

DISCUSSION

Fitting the model

In this report, we have used our best guess vulnerability matrix for the 2006 model because it produced reasonable group behaviour under the equilibrium analysis and under challenges to the model outlined in this report. Ideally, we would like to extend the fitted vulnerabilities of the 1990 model to the 2006 model after being corrected for differences in the predation mortalities between those two time periods. This approach assumes stationarity in the density-dependant foraging tactics of species; however the vulnerability values must still be scaled properly to be relevant to the present day model.

If predation mortality was higher in the past, then the vulnerability parameter, which represents the maximum increase in predation mortality as compared to model baseline, should be proportionately reduced for a given prey (C. Walters, University of British Columbia. 2202 Main Mall, Vancouver, Canada, pers. comm.). For each trophic interaction, the product of the vulnerability and predation mortality rate is conserved between time periods. It was demonstrated that this method is more reliable for parameterizing adjacent time periods than alternative assumptions, such as global vulnerabilities or scaling by trophic level (Ainsworth, 2006). When better time series information becomes available, we will repeat the fitting procedure presented here. We should then have enough confidence in the fitted vulnerability parameters to warrant replacing them in the 2006 matrix.

The CPUE proxy for relative biomass is generally flawed. Although fitting to these series does set the model's behaviour to within satisfactory limits for a first draft of the model, better time series information will soon be available as we continue to process fisher interview information that was recently compiled by TNC field staff (contact: C. Rotinsulu. CI. Jl Arfak No. 45. Sorong, Papua, Indonesia 98413) (also see Ainsworth *et al.*, 2006).

Fishing policy optimizations

The policy search routine in Ecosim is used here for a very basic analysis, a comparison of the trade-offs between economic harvest benefits (measured using NPV) and ecological harvest benefits (based on ecosystem maturity). A clear relationship emerges among the optimal fleet-effort vectors developed by the policy search routine. Policies designed to maximize the economic value of the fishery tend to increase spear and harpoon effort (right cluster in Fig. 3.8), while policies designed to maintain the ecology tend to reduce overall effort on most fleets from the baseline situation (vertex cluster in Fig. 3.8). There exists a third, moderate, policy option where the shore gillnet fleet is the principle fishing method employed (left cluster in Fig. 3.8). This solution achieves an effective compromise between economics and ecology.

There exists a continuum of optimal fishing solutions connecting the left cluster with the vertex, and the right cluster with the vertex. Interestingly, the left and right clusters appear mutually exclusive. That is, no optimizations utilized both spear/harpoon and shore gillnet simultaneously, perhaps indicating that these gear types conflict with each other trophodynamically. Indeed, the mixed trophic impacts analysis (network analysis) confirms that they do compete with each other, although it does not necessarily follow that the use of these two gear types must be mutually exclusive. We will have to explore this preliminary finding and comment in later reports.

Almost all solutions, regardless of the harvest criterion in place, increased the shrimp trawl fishery over baseline exploitation levels. Only in 3 out of 156 optimizations did the shrimp trawl fishery appear reduced from the baseline levels. Penaeid shrimp, being largely underexploited in the model, can evidently support higher sustainable harvests in RA. However, the majority of the Penaeid shrimp fishery in BHS occurs to the southeast of our study region in the Arafura Sea (DF, 2001); the optimal fishing rates should not be implicitly extended to that area without further analysis.

Fisher interview forms

In a series of community interviews conducted by TNC in various RA villages, we presented a species list to local fishers, who were asked to comment on the relative abundance change of these animals during their lifetimes. The English version of those interview forms is provided in Appendix C.1 of Ainsworth *et al.* (2006). For each decade from 1970 to present, the fishers indicated whether the populations of these commercial species were increasing or decreasing. We intend to use a fuzzy logic approach to convert the qualitative statements into relative biomass abundance trends.

As we come to understand more fully the changes in the ecosystem over the last 30 or more years, we will be able to generate models of earlier time periods. Having several models that represent various snapshots in time will help us improve biomass dynamics; trends can be maneuvered to coincide with these point estimates. We will be able to evaluate major ecosystem changes over the scale of decades, and we will be able to hone the trophic flow parameters, improving forecasts into the future. At the time of this report, the interview results had just become available; data processing continues.

Stomach content analysis

To improve the diet matrix, and to validate the diet allocation algorithm used in this paper, we are now in the process of collecting and analyzing stomach content data from RA as a component of the BHS EBM project (field work contact: C. Rotinsulu. CI. Jl Arfak No. 45. Sorong, Papua, Indonesia 98413). Specimens of commercial reef associated and pelagic fish groups are being purchased from fishers and market. Stomach dissections are being performed by UNIPA student researchers in the laboratory. 134 stomachs have so far been analyzed from 11 reef fish families. We expect to complete the laboratory work in January; the information will be analyzed and processed into Ecopath functional groups for comparison against the fitted diet matrix. In addition to the stomach content data, information on the predator is being collected, such as body length and gape size. This will help improve the diet allocation algorithm. The protocol for the stomach content analysis study is presented in Ainsworth *et al.* (2006).

CONCLUSIONS

The EwE models presented in this report will continue to be modified and improved over the coming months. Functional group dynamics will be revisited once the UBC spatial modelling group has completed its analysis of the biomass trend information recently obtained from LEK interviews. The Synthesis Post-Doctoral Fellow, Cameron Ainsworth, and Post-Graduate researcher, Divya Varkey, presented the models to local marine experts during the second field visit to Indonesia from January 17 to March 5, 2007. The main purpose of this trip was to validate the model structure and functioning through expert opinion. We were especially interested in feedback concerning the Ecospace models of Kofiau Island, SE Misool and Dampier Strait from TNC, CI and WWF scientists, and from field site coordinators. We collected BHS EBM project information that has recently become available. Results from that meeting will be published in a later article.

Biomass information resulting from transect studies will form the basis of the fine-scale models. Results from the CI socioeconomic study will be used to strengthen the price and cost fields of Ecosim and Ecospace, and allow more detailed economic evaluation using the policy search routine and Ecospace. By applying the findings of the MPA zoning exploration work currently being conducted with MARXAN (contact: P. Mous, TNC-CTC. Jl Pengembak 2, Sanur, Bali, Indonesia), we will be able to model the proposed closure areas and evaluate the tropho-dynamic and socioeconomic consequences of site protection. The deadline for project information contributing to the Kofiau Island model has been set for the end of January 2007. The deadline for project information contributing to the Dampier Strait and SW Misool models has been set for the end of March 2007.

A later meeting is planned between UBC researchers and TNC, CI and WWF staff, which will take place during a third field visit, July 16-18, 2007. The purpose of that meeting will be to present the outcomes of the spatial modelling study, accept any final recommendations or changes to the models, and arrange a publication schedule for co-authored contributions to be completed by the end of the UBC spatial modelling component, in December 2007. We also hope to discuss the goals and outputs of the spatial modelling component to ensure that this study assists the development of EBM policies and aids the Regency, Provincial and Federal marine policy makers in Indonesia.

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APPENDIX A - EWE PARAMETERIZATION

Appendix A1 - Species level data

Table A1.1 - Fish species represented in the RA EwE models.

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
Groupers	6441	Serranidae	*Aethaloperca rogaa*	Redmouth grouper	46
	4922	Serranidae	*Anyperodon leucogrammicus*	Slender grouper	
	6396	Serranidae	*Cephalopholis argus*	Peacock hind	
	6444	Serranidae	*Cephalopholis boenack*	Chocolate hind	
	6445	Serranidae	*Cephalopholis cyanostigma*	Bluespotted hind	
	6448	Serranidae	*Cephalopholis leopardus*	Leopard hind	
	6449	Serranidae	*Cephalopholis microprion*	Freckled hind	
	6453	Serranidae	*Cephalopholis sexmaculata*	Sixblotch hind	
	6454	Serranidae	*Cephalopholis sonnerati*	Tomato hind	
	6455	Serranidae	*Cephalopholis spiloparaea*	Strawberry hind	
	6456	Serranidae	*Cephalopholis urodeta*	Darkfin hind	
	6457	Serranidae	*Cromileptes altivelis*	Humpback grouper	
	6603	Serranidae	*Diploprion bifasciatum*	Barred soapfish	
	5367	Serranidae	*Epinephelus areolatus*	Areolate grouper	
	7331	Serranidae	*Epinephelus bilobatus*	Twinspot grouper	
	6440	Serranidae	*Epinephelus caruleopunctatus*	Whitespotted grouper	
	6465	Serranidae	*Epinephelus coioides*	Orange-spotted grouper	
	6466	Serranidae	*Epinephelus corallicola*	Coral grouper	
	5348	Serranidae	*Epinephelus fasciatus*	Blacktip grouper	
	4460	Serranidae	*Epinephelus fuscoguttatus*	Brown-marbled grouper	
	6468	Serranidae	*Epinephelus lanceolatus*	Giant grouper	
	6661	Serranidae	*Epinephelus macrospilos*	Snubnose grouper	
	5350	Serranidae	*Epinephelus maculatus*	Highfin grouper	
	4923	Serranidae	*Epinephelus merra*	Honeycomb grouper	
	6472	Serranidae	*Epinephelus ongus*	White-streaked grouper	
	6473	Serranidae	*Epinephelus polyphekadion*	Camouflage grouper	
	5837	Serranidae	*Epinephelus spilotoceps*	Foursaddle grouper	
	5525	Serranidae	*Epinephelus tukula*	Potato grouper	
	6477	Serranidae	*Gracila albimarginata*	Masked grouper	
	4925	Serranidae	*Grammistes sexlineatus*	Sixline soapfish	
	7315	Serranidae	*Grammistops ocellatus*	Ocellate soapfish	
	7318	Serranidae	*Liopropoma susumi*	Meteor perch	
	7453	Serranidae	*Luzonichthys waitei*	Waite's splitfin	
	12727	Serranidae	*Pogonoperca punctata*		
	7454	Serranidae	*Pseudanthias dispar*	Peach fairy basslet	
	10632	Serranidae	*Pseudanthias fasciatus*	One-stripe anthias	
	6567	Serranidae	*Pseudanthias huchtii*	Red-cheeked fairy basslet	
	8124	Serranidae	*Pseudanthias hypselosoma*	Stocky anthias	
	7458	Serranidae	*Pseudanthias luzonensis*	Yellowlined anthias	
	6569	Serranidae	*Pseudanthias pleurotaenia*	Square-spot fairy basslet	
	6571	Serranidae	*Pseudanthias randalli*	Randall's fairy basslet	
	6568	Serranidae	*Pseudanthias squamipinnis*	Sea goldie	
	6502	Serranidae	*Pseudanthias tuka*	Yellowstriped fairy basslet	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	7320	Serranidae	*Pseudogramma polyacanthum*	Honeycomb podge	
	6478	Serranidae	*Variola albimarginata*	White-edged lyretail	
	5354	Serranidae	*Variola louti*	Yellow-edged lyretail	
Snappers	1385	Lutjanidae	*Etelis coruscans*	Flame snapper	32
	1394	Lutjanidae	*Lipocheilus carnolabrum*	Tang's snapper	
	1407	Lutjanidae	*Lutjanus argentimaculatus*	Mangrove red snapper	
	1410	Lutjanidae	*Lutjanus biguttatus*	Two-spot banded snapper	
	1417	Lutjanidae	*Lutjanus bohar*	Two-spot red snapper	
	1418	Lutjanidae	*Lutjanus boutton*	Moluccan snapper	
	1424	Lutjanidae	*Lutjanus carponotatus*	Spanish flag snapper	
	1428	Lutjanidae	*Lutjanus decussatus*	Checkered snapper	
	793	Lutjanidae	*Lutjanus ehrenburgi*	Blackspot snapper	
	261	Lutjanidae	*Lutjanus fulviflamma*	Dory snapper	
	262	Lutjanidae	*Lutjanus fulvus*	Blacktail snapper	
	265	Lutjanidae	*Lutjanus gibbus*	Humpback red snapper	
	264	Lutjanidae	*Lutjanus johnii*	John's snapper	
	156	Lutjanidae	*Lutjanus kasmira*	Common bluestripe snapper	
	157	Lutjanidae	*Lutjanus lemniscatus*	Yellowstreaked snapper	
	159	Lutjanidae	*Lutjanus lutjanus*	Bigeye snapper	
	166	Lutjanidae	*Lutjanus monostigma*	Onespot snapper	
	172	Lutjanidae	*Lutjanus quinquelineatus*	Five-lined snapper	
	173	Lutjanidae	*Lutjanus rivulatus*	Blubberlip snapper	
	176	Lutjanidae	*Lutjanus russelli*	Russell's snapper	
	179	Lutjanidae	*Lutjanus semicinctus*	Black-banded snapper	
	184	Lutjanidae	*Lutjanus vitta*	Brownstripe red snapper	
	186	Lutjanidae	*Macolor macularis*	Midnight snapper	
	187	Lutjanidae	*Macolor niger*	Black and white snapper	
	192	Lutjanidae	*Paracaesio sordidus*	Dirty ordure snapper	
	8430	Lutjanidae	*Pinjalo lewisi randall,*	Slender pinjalo	
	200	Lutjanidae	*Pristipomoides auricilla*	Goldflag jobfish	
	201	Lutjanidae	*Pristipomoides filamentosus*	Crimson jobfish	
	209	Lutjanidae	*Pristipomoides sieboldii*	Lavender jobfish	
	211	Lutjanidae	*Pristipomoides zonatus*	Oblique-banded snapper	
	214	Lutjanidae	*Symphorichthys spilurus*	Sailfin snapper	
	215	Lutjanidae	*Symphorus nematophorus*	Chinamanfish	
Napoleon wrasse	5604	Labridae	*Cheilinus undulatus*	Napoleon / Humphead wrasse	1
Skipjack tuna	107	Scombridae	*Katsuwonus pelamis*	Skipjack tuna	1
Other tuna	89	Scombridae	*Acanthocybium solandri*	Wahoo	10
	93	Scombridae	*Auxis rochei rochei*	Bullet tuna	
	94	Scombridae	*Auxis thazard thazard*	Frigate tuna	
	96	Scombridae	*Euthynnus affinis*	Kawakawa	
	106	Scombridae	*Gymnosarda unicolor*	Dogtooth tuna	
	142	Scombridae	*Thunnus alalunga*	Albacore	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	143	Scombridae	*Thunnus albacares*	Yellowfin tuna	
	146	Scombridae	*Thunnus obesus*	Bigeye tuna	
	14290	Scombridae	*Thunnus orientalis*	Pacific bluefin tuna	
	148	Scombridae	*Thunnus tonggol*	Longtail tuna	
Mackerel	104	Scombridae	*Grammatorcynus bilineatus*	Double-lined mackerel	9
	109	Scombridae	*Rastrelliger brachysoma*	Short mackerel	
	110	Scombridae	*Rastrelliger faughni*	Island mackerel	
	111	Scombridae	*Rastrelliger kanagurta*	Indian mackerel	
	116	Scombridae	*Scomber australasicus*	Blue mackerel	
	121	Scombridae	*Scomberomorus commerson*	Narrow-barred Spanish mackerel	
	129	Scombridae	*Scomberomorus munroi*	Australian spotted mackerel	
	133	Scombridae	*Scomberomorus queenslandicus*	Queensland school mackerel	
	135	Scombridae	*Scomberomorus semifasciatus*	Broadbarred king mackerel	
Billfish	77	Istiophoridae	*Istiophorus platypterus*	Indo-Pacific sailfish	6
	217	Istiophoridae	*Makaira indica*	Black marlin	
	218	Istiophoridae	*Makaira mazara*	Indo-Pacific blue marlin	
	3915	Istiophoridae	*Tetrapturus angustirostris*	Shortbill spearfish	
	223	Istiophoridae	*Tetrapturus audax*	Striped marlin	
	226	Xiphiidae	*Xiphias gladius*	Swordfish	
Coral trout	6450	Serranidae	*Cephalopholis miniata*	Coral hind	6
	6082	Serranidae	*Plectropomus areolatus*	Squaretail coralgrouper	
	7372	Serranidae	*Plectropomus laevis*	Blacksaddled coralgrouper	
	4826	Serranidae	*Plectropomus leopardus*	Leopard coralgrouper	
	4886	Serranidae	*Plectropomus maculatus*	Spotted coralgrouper	
	7319	Serranidae	*Plectropomus oligocanthus*	Highfin coralgrouper	
Large sharks	861	Carcharhinidae	*Carcharhinus amblyrhynchos*	Grey reef shark	6
	871	Carcharhinidae	*Carcharhinus hemiodon*	Pondicherry shark	
	877	Carcharhinidae	*Carcharhinus melanopterus*	Blacktip reef shark	
	898	Carcharhinidae	*Prionace glauca*	Blue shark	
	907	Carcharhinidae	*Triaenodon obesus*	Whitetip reef shark	
	5895	Ginglymostomatidae	*Nebrius ferrugineus*	Tawny nurse shark	
Small sharks	860	Carcharhinidae	*Carcharhinus amblyrhynchoides*	Graceful shark	5
	904	Carcharhinidae	*Rhizoprionodon taylori*	Australian sharpnose shark	
	651	Centrophoridae	*Centrophorus moluccensis*	Smallfin gulper shark	
	5904	Hemiscylliidae	*Hemiscyllium freycineti*	Indonesian speckled carpetshark	
	756	Orectolobidae	*Eucrossorhinus dasypogon*	Tasselled wobbegong	
Whaleshark	2081	Rhincodontidae	*Rhincodon typus*	Whale shark	1
Manta ray	2061	Mobulidae	*Manta birostris*	Giant manta	1

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
Rays	15390	Dasyatidae	*Dasyatis leylandi*	Painted maskray	7
	15487	Dasyatidae	*Himantura toshi*	Black-spotted whipray	
	4508	Dasyatididae	*Dasyatis kuhlii*	Bluespotted stingray	
	5399	Dasyatididae	*Taeniura lymma*	Bluespotted ribbontail ray	
	13194	Mobulidae	*Mobula tarapacana*	Chilean devil ray	
	1250	Myliobatidae	*Aetobatus narinari*	Spotted eagle ray	
	25622	Myliobatidae	*Mobula eregoodootenkee*	Pygmy devilray	
Butterflyfish	6525	Chaetodontidae	*Apolemichthys trimaculatus*	Threespot angelfish	57
	5454	Chaetodontidae	*Centropyge bicolor*	Bicolor angelfish	
	5458	Chaetodontidae	*Centropyge bispinosus*	Twospined angelfish	
	5664	Chaetodontidae	*Centropyge flavicauda*	Whitetail angelfish	
	6647	Chaetodontidae	*Centropyge nox*	Midnight angelfish	
	6548	Chaetodontidae	*Centropyge tibicen*	Keyhole angelfish	
	5447	Chaetodontidae	*Centropyge vroliki*	Pearlscale angelfish	
	6515	Chaetodontidae	*Chaetodon adiergastos*	Philippine butterflyfish	
	5557	Chaetodontidae	*Chaetodon auriga*	Threadfin butterflyfish	
	5558	Chaetodontidae	*Chaetodon baronessa*	Eastern triangular butterflyfish	
	5559	Chaetodontidae	*Chaetodon bennetti*	Bluelashed butterflyfish	
	5561	Chaetodontidae	*Chaetodon citrinellus*	Speckled butterflyfish	
	5562	Chaetodontidae	*Chaetodon ephippium*	Saddle butterflyfish	
	5446	Chaetodontidae	*Chaetodon kleinii*	Sunburst butterflyfish	
	5564	Chaetodontidae	*Chaetodon lineolatus*	Lined butterflyfish	
	5565	Chaetodontidae	*Chaetodon lunula*	Raccoon butterflyfish	
	14300	Chaetodontidae	*Chaetodon lunulatus*	Oval butterflyfish	
	5566	Chaetodontidae	*Chaetodon melannotus*	Blackback butterflyfish	
	5568	Chaetodontidae	*Chaetodon meyeri*	Scrawled butterflyfish	
	5569	Chaetodontidae	*Chaetodon ocellicaudus*	Spot-tail butterflyfish	
	5570	Chaetodontidae	*Chaetodon octofasciatus*	Eightband butterflyfish	
	6550	Chaetodontidae	*Chaetodon ornatissimus*	Ornate butterflyfish	
	5472	Chaetodontidae	*Chaetodon oxycephalus*	Spot-nape butterflyfish	
	5571	Chaetodontidae	*Chaetodon punctatofasciatus*	Spotband butterflyfish	
	5573	Chaetodontidae	*Chaetodon rafflesi*	Latticed butterflyfish	
	6634	Chaetodontidae	*Chaetodon selene*	Yellow-dotted butterflyfish	
	5575	Chaetodontidae	*Chaetodon semeion*	Dotted butterflyfish	
	5576	Chaetodontidae	*Chaetodon speculum*	Mirror butterflyfish	
	5578	Chaetodontidae	*Chaetodon trifascialis*	Chevron butterflyfish	
	5580	Chaetodontidae	*Chaetodon ulietensis*	Pacific double-saddle butterflyfish	
	5581	Chaetodontidae	*Chaetodon unimaculatus*	Teardrop butterflyfish	
	5582	Chaetodontidae	*Chaetodon vagabundus*	Vagabond butterflyfish	
	6508	Chaetodontidae	*Chaetodon xanthurus*	Pearlscale butterflyfish	
	10472	Chaetodontidae	*Chaetodontoplus dimidatus*	Black-velvet angelfish	
	5660	Chaetodontidae	*Chaetodontoplus mesoleucus*	Vermiculated angelfish	
	5483	Chaetodontidae	*Chelmon rostratus*	Copperband butterflyfish	
	5583	Chaetodontidae	*Coradion chrysozonus*	Goldengirdled coralfish	
	5584	Chaetodontidae	*Forcipiger flavissimus*	Longnose butterflyfish	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	5585	Chaetodontidae	*Forcipiger longirostris*	Longnose butterflyfish	
	6612	Chaetodontidae	*Genicanthus lamarck*	Blackstriped angelfish	
	8710	Chaetodontidae	*Genicanthus melanospilos*	Spotbreast angelfish	
	5586	Chaetodontidae	*Hemitaurichthys polylepis*	Pyramid butterflyfish	
	5588	Chaetodontidae	*Heniochus acuminatus*	Pennant coralfish	
	5589	Chaetodontidae	*Heniochus chrysostomus*	Threeband pennantfish	
	7769	Chaetodontidae	*Heniochus diphreutes*	False moorish idol	
	5590	Chaetodontidae	*Heniochus monoceros*	Masked bannerfish	
	5591	Chaetodontidae	*Heniochus singularius*	Singular bannerfish	
	5592	Chaetodontidae	*Heniochus varius*	Horned bannerfish	
	5666	Chaetodontidae	*Paracentropyge multifasciatus*	Barred angelfish	
	7887	Chaetodontidae	*Parachaetodon ocellatus*	Sixspine butterflyfish	
	7902	Chaetodontidae	*Pomacanthus annularis*	Bluering angelfish	
	6504	Chaetodontidae	*Pomacanthus imperator*	Emperor angelfish	
	5661	Chaetodontidae	*Pomacanthus navarchus*	Bluegirdled angelfish	
	5663	Chaetodontidae	*Pomacanthus semicirculatus*	Semicircle angelfish	
	6564	Chaetodontidae	*Pomacanthus sexstriatus*	Sixbar angelfish	
	5662	Chaetodontidae	*Pomacanthus xanthometopon*	Yellowface angelfish	
	6572	Chaetodontidae	*Pygoplites diacanthus*	Royal angelfish	
Cleaner wrasse	5109	Labridae	*Labrichthys unilineatus*	Tubelip wrasse	3
	5650	Labridae	*Labroides bicolor*	Bicolor cleaner wrasse	
	5459	Labridae	*Labroides dimidiatus*	Bluestreak cleaner wrasse	
Large pelagic	14497	Belonidae	*Strongylura urvillii*		25
	24904	Bregmacerotidae	*Bregmaceros rarisquamosus*	Big-eye unicorn-cod	
	1452	Chirocentridae	*Chirocentrus nudus*	Whitefin wolf-herring	
	7	Coryphaenidae	*Coryphaena equiselis*	Pompano dolphinfish	
	5512	Elopidae	*Elops machnata*	Tenpounder	
	60182	Exocoetidae	*Cheilopogon antoncichi*		
	10333	Gonostomatidae	*Manducus greyae*		
	16884	Hemiramphidae	*Oxyporhamphus convexus*	Halfbeak	
	10344	Leiognathidae	*Leiognathus rapsoni*	Rapson's ponyfish	
	1732	Molidae	*Mola mola*	Ocean sunfish	
	15974	Myctophidae	*Bolinichthys pyrsobolus*		
	10267	Myctophidae	*Diaphus signatus*		
	24278	Nettastomatidae	*Saurenchelys stylura*		
	340	Polynemidae	*Eleutheronema tetradactylum*	Fourfinger threadfin	
	27617	Pristigasteridae	*Ilisha lunula*		
	238	Salmonidae	*Salmo trutta trutta*	Sea trout	
	114	Scombridae	*Sarda orientalis*	Striped bonito	
	1235	Sphyraenidae	*Sphyraena barracuda*	Great barracuda	
	4827	Sphyraenidae	*Sphyraena jello*	Pickhandle barracuda	
	5736	Sphyraenidae	*Sphyraena novaehollandiae*	Australian barracuda	
	7939	Sphyraenidae	*Sphyraena qenie*	Blackfin barracuda	
	10324	Stomiidae	*Astronesthes chrysophekadion*		
	24527	Stomiidae	*Bathophilus abarbatus*		

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	27411	Stomiidae	*Bathophilus kingi*		
Medium pelagic	8817	Belonidae	*Strongylura krefftii*	Long tom	9
	1316	Belonidae	*Strongylura strongylura*	Spottail needlefish	
	1891	Carangidae	*Alepes vari*	Herring scad	
	1931	Carangidae	*Ulua aurochs*	Silvermouth trevally	
	3544	Echeneidae	*Phtheirichthys lineatus*	Slender suckerfish	
	6415	Elopidae	*Elops hawaiensis*	Hawaiian ladyfish	
	95	Scombridae	*Cybiosarda elegans*	Leaping bonito	
	7937	Sphyraenidae	*Sphyraena flavicauda*	Yellowtail barracuda	
	8079	Toxotidae	*Toxotes chatareus*	Largescale archerfish	
Small pelagic	14937	Atherinidae	*Atherinomorus balabacensis*	Balabac Island silverside	75
	15461	Atherinidae	*Hypoatherina tropicalis*	Whitley's silverside	
	24833	Bregmacerotidae	*Bregmaceros japonicus*	Japanese codlet	
	8422	Bregmacerotidae	*Bregmaceros nectabanus*	Smallscale codlet	
	1890	Carangidae	*Alepes melanoptera*	Blackfin scad	
	60570	Centrolophidae	*Psenopsis humerosa*	Blackspot butterfish	
	10357	Champsodontidae	*Champsodon nudivittis*		
	1620	Clupeidae	*Anodontostoma selangkat*	Indonesian gizzard shad	
	1564	Clupeidae	*Clupeoides venulosus*	West Irian river sprat	
	1488	Clupeidae	*Herklotsichthys castelnaui*	Castelnau's herring	
	1490	Clupeidae	*Herklotsichthys gotoi*	Goto's herring	
	1496	Clupeidae	*Herklotsichthys lippa*	Australian spotted herring	
	1611	Clupeidae	*Nematalosa come*	Western Pacific gizzard shad	
	1652	Clupeidae	*Opisthopterus tardoore*	Tardoore	
	1504	Clupeidae	*Sardinella brachysoma*	Deepbody sardinella	
	1506	Clupeidae	*Sardinella fijiense*	Fiji sardinella	
	1507	Clupeidae	*Sardinella fimbriata*	Fringescale sardinella	
	1513	Clupeidae	*Sardinella melanura*	Blacktip sardinella	
	1459	Clupeidae	*Spratelloides lewisi*	Lewis' round herring	
	7186	Dentatherinidae	*Dentatherina merceri*	Mercer's tusked silverside	
	15316	Exocoetidae	*Cheilopogon abei*		
	15319	Exocoetidae	*Cheilopogon arcticeps*	White-finned flyingfish	
	7509	Exocoetidae	*Cheilopogon atrisignis*	Glider flyingfish	
	7696	Exocoetidae	*Cheilopogon nigricans*	African flyingfish	
	23049	Exocoetidae	*Cheilopogon unicolor*		
	13690	Exocoetidae	*Cypselurus angusticeps*	Narrowhead flyingfish	
	7726	Exocoetidae	*Cypselurus naresii*	Pharao flyingfish	
	5123	Exocoetidae	*Exocoetus monocirrhus*	Barbel flyingfish	
	13727	Exocoetidae	*Fodiator rostratus*		
	13715	Exocoetidae	*Hirundichthys albimaculatus*	Whitespot flyingfish	
	1034	Exocoetidae	*Hirundichthys oxycephalus*	Bony flyingfish	
	1037	Exocoetidae	*Parexocoetus brachypterus*	Sailfin flyingfish	
	4904	Exocoetidae	*Parexocoetus mento*	African sailfin flyingfish	
	15382	Exocoetidae	*Prognichthys brevipinnis*	Shortfin flyingfish	

Table A1.1 - (cont.)

Functional Group	**FishBase species code**	**Family**	**Scientific name**	**Common name**	**No. Spp.**
	5124	Exocoetidae	*Prognichthys sealei*	Sailor flyingfish	
	23694	Gobiidae	*Pandaka lidwilli*		
	16808	Hemiramphidae	*Arrhamphus sclerolepis sclerolepis*	Northern snubnose garfish	
	16811	Hemiramphidae	*Hemiramphus robustus*	Three-by-two garfish	
	16817	Hemiramphidae	*Hyporhamphus neglectissimus*	Black-tipped garfish	
	8262	Hemiramphidae	*Hyporhamphus quoyi*	Quoy's garfish	
	4666	Hemiramphidae	*Rhynchorhamphus georgii*	Long billed half beak	
	17111	Hemiramphidae	*Zenarchopterus caudovittatus*	Long-jawed river garfish	
	17043	Hemiramphidae	*Zenarchopterus dunckeri*	Duncker's river garfish	
	13014	Hemiramphidae	*Zenarchopterus kampeni*	Sepik River halfbeak	
	25579	Hemiramphidae	*Zenarchopterus novaeguineae*	Fly River garfish	
	17114	Hemiramphidae	*Zenarchopterus rasori*		
	363	Lactariidae	*Lactarius lactarius*	False trevally	
	7966	Leiognathidae	*Secutor indicius*		
	25595	Melanotaeniidae	*Chilatherina axelrodi*	Axelrod's rainbowfish	
	25602	Melanotaeniidae	*Chilatherina bulolo*	Bulolo rainbowfish	
	25605	Melanotaeniidae	*Chilatherina campsi*	Highlands rainbowfish	
	25608	Melanotaeniidae	*Chilatherina crassispinosa*	Silver rainbowfish	
	25610	Melanotaeniidae	*Chilatherina fasciata*	Barred rainbowfish	
	25612	Melanotaeniidae	*Chilatherina lorentzii*	Lorentz's rainbowfish	
	9116	Microstomatidae	*Xenophthalmichthys danae*		
	7405	Myctophidae	*Bolinichthys distofax*		
	7428	Myctophidae	*Centrobranchus andreae*	Andre's lanternfish	
	16748	Myctophidae	*Diaphus malayanus*		
	16665	Myctophidae	*Hygophum macrochir*	Large-finned lanternfish	
	7412	Myctophidae	*Lampadena urophaos urophaos*	Sunbeam lampfish	
	10299	Nomeidae	*Psenes arafurensis*	Banded driftfish	
	1641	Pristigasteridae	*Pellona ditchela*	Indian pellona	
	10525	Pseudomugilidae	*Pseudomugil connieae*	Popondetta blue-eye	
	10531	Pseudomugilidae	*Pseudomugil majusculus*	Cape blue-eye	
	25661	Pseudomugilidae	*Pseudomugil novaeguineae*	New Guinea blue-eye	
	25662	Pseudomugilidae	*Pseudomugil paludicola*	Swamp blue-eye	
	128	Scombridae	*Scomberomorus multiradiatus*	Papuan seerfish	
	22972	Scopelosauridae	*Scopelosaurus hoedti*		
	7388	Sternoptychidae	*Danaphos oculatus*	Bottlelights	
	51179	Stomiidae	*Astronesthes quasiindicus*		
	27412	Stomiidae	*Eustomias perplexus*		
	27415	Stomiidae	*Leptostomias leptobolus*		
	11791	Stomiidae	*Photonectes mirabilis*		
	11796	Stomiidae	*Photonectes parvimanus*		
	59890	Terapontidae	*Mesopristes iravi*		
Large reef associated	5951	Acanthuridae	Zebrasoma scopas	Twotone tang	213
	1266	Acanthuridae	Zebrasoma veliferum	Sailfin tang	
	5781	Apogonidae	Cheilodipterus macrodon	Large toothed cardinalfish	
	1309	Aulostomidae	Aulostomus chinensis	Chinese trumpetfish	
	6025	Balistidae	Balistapus undulatus	Orange-lined triggerfish	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	2300	Balistidae	*Balistoides conspicillum*	Clown triggerfish	
	6026	Balistidae	*Balistoides viridescens*	Titan triggerfish	
	4278	Balistidae	*Canthidermis maculatus*	Spotted oceanic triggerfish	
	6027	Balistidae	*Pseudobalistes flavimarginatus*	Yellowmargin triggerfish	
	4466	Balistidae	*Pseudobalistes fuscus*	Yellow-spotted triggerfish	
	5839	Balistidae	*Rhinecanthus aculeatus*	Blackbar triggerfish	
	5840	Balistidae	*Rhinecanthus rectangulus*	Wedge-tail triggerfish	
	6028	Balistidae	*Rhinecanthus verrucosus*	Blackbelly triggerfish	
	6029	Balistidae	*Sufflamen bursa*	Boomerang triggerfish	
	5842	Balistidae	*Sufflamen chrysoptera*	Halfmoon triggerfish	
	1312	Balistidae	*Sufflamen fraenatus*	Masked triggerfish	
	10747	Batrachoididae	*Batrachomeous tripsinosus*	Three-spined frogfish	
	10748	Batrachoididae	*Halophryne diemensis*	Banded frogfish	
	1314	Belonidae	*Platybelone platyura*	Keeled needlefish	
	977	Belonidae	*Tylosurus crocodilus*	Hound needlefish	
	61221	Blenniidae	*Salarias sibogae*		
	7641	Bothidae	*Bothus mancus*	Flowery flounder	
	1321	Bothidae	*Bothus pantherinus*	Leopard flounder	
	918	Caesionidae	*Caesio caerulaurea*	Blue and gold fusilier	
	49419	Callionymidae	*Callionymus pleurostictus*		
	1923	Carangidae	*Carangoides bajad*	Orangespotted trevally	
	1921	Carangidae	*Carangoides ferdau*	Blue trevally	
	1926	Carangidae	*Carangoides fulvoguttatus*	Yellowspotted trevally	
	1910	Carangidae	*Carangoides plagiotaenia*	Barcheek trevally	
	1895	Carangidae	*Caranx ignobilis*	Giant trevally	
	1906	Carangidae	*Caranx melampygus*	Bluefin trevally	
	6360	Carangidae	*Caranx papuensis*	Brassy trevally	
	1917	Carangidae	*Caranx sexfasciatus*	Bigeye trevally	
	1940	Carangidae	*Decapterus kurroides*	Redtail scad	
	4464	Carangidae	*Gnathanodon speciosus*	Golden trevally	
	1951	Carangidae	*Scomberoides lysan*	Doublespotted queenfish	
	1963	Carangidae	*Trachinotus blochii*	Snubnose pompano	
	8212	Centropomidae	*Psammoperca waigiensis*	Waigieu seaperch	
	5831	Cirrhitidae	*Cirrhitus pinnulatus*	Stocky hawkfish	
	23013	Congridae	*Gorgasia maculata*	Whitespotted garden eel	
	12619	Congridae	*Heteroconger haasi*	Spotted garden-eel	
	4485	Dactylopteridae	*Dactyloptena orientalis*	Oriental flying gurnard	
	1022	Diodontidae	*Diodon hystrix*	Spot-fin porcupinefish	
	6552	Diodontidae	*Diodon liturosus*	Black-blotched porcupinefish	
	2467	Echeneidae	*Echeneis naucrates*	Live sharksucker	
	10547	Ephippidae	*Platax batavianus*	Humpback batfish	
	14307	Ephippidae	*Platax boersi*	Golden spadefish	
	5737	Ephippidae	*Platax orbicularis*	Orbicular batfish	
	5739	Ephippidae	*Platax teira*	Tiera batfish	
	5444	Fistulariidae	*Fistularia commersoni*	Bluespotted cornetfish	
	27553	Gobiidae	*Amblygobius esakiae*	Snoutspot goby	
	11618	Gobiidae	*Pleurosicya elongata*	Cling goby	
	59437	Gobiidae	*Pleurosicya labiata*		
	8454	Gobiidae	*Priolepis fallacincta*		

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	61008	Gobiidae	*Trimma anaima*		
	7224	Gobiidae	*Valenciennea helsdingenii*	Twostripe goby	
	4465	Haemulidae	*Diagramma pictum*	Painted sweetlips	
	6364	Haemulidae	*Plectorhinchus chaetodontoides*	Harlequin sweetlips	
	56810	Haemulidae	*Plectorhinchus chrysotaenia*	Yellow-striped sweetlips	
	6366	Haemulidae	*Plectorhinchus gibbosus*	Harry hotlips	
	50052	Haemulidae	*Plectorhinchus lessoni*		
	6940	Haemulidae	*Plectorhinchus lineatus*	Yellowbanded sweetlips	
	6368	Haemulidae	*Plectorhinchus obscurus*	Giant sweetlips	
	8316	Haemulidae	*Plectorhinchus polytaenia*	Ribboned sweetlips	
	60418	Haemulidae	*Plectorhinchus unicolor*		
	25706	Haemulidae	*Plectorhinchus vittatus*	Indian Ocean oriental sweetlips	
	5404	Hemiramphidae	*Hemirhamphus far*	Blackbarred halfbeak	
	17041	Hemiramphidae	*Zenarchopterus buffonis*	Buffon's river-garfish	
	26201	Holocentridae	*Myripristis botche*	Blacktip soldierfish	
	6582	Holocentridae	*Neoniphon opercularis*	Blackfin squirrelfish	
	4911	Holocentridae	*Neoniphon sammara*	Sammara squirrelfish	
	4907	Holocentridae	*Sargocentron caudimaculatum*	Silverspot squirrelfish	
	5406	Holocentridae	*Sargocentron cornutum*	Threespot squirrelfish	
	5345	Holocentridae	*Sargocentron melanospilos*	Blackblotch squirrelfish	
	6625	Holocentridae	*Sargocentron rubrum*	Redcoat	
	6507	Holocentridae	*Sargocentron spiniferum*	Sabre squirrelfish	
	4908	Holocentridae	*Sargocentron tiere*	Blue lined squirrelfish	
	4909	Holocentridae	*Sargocentron violaceum*	Violet squirrelfish	
	5804	Kyphosidae	*Kyphosus bigibbus*	Grey sea chub	
	5805	Kyphosidae	*Kyphosus cinerascens*	Blue seachub	
	5806	Kyphosidae	*Kyphosus vaigiensis*	Brassy chub	
	4888	Labridae	*Anampses caeruleopunctatus*	Bluespotted wrasse	
	4891	Labridae	*Anampses geographicus*	Geographic wrasse	
	4890	Labridae	*Anampses neoguinaicus*	New Guinea wrasse	
	5497	Labridae	*Bodianus anthioides*	Lyretail hogfish	
	5498	Labridae	*Bodianus axillaris*	Axilspot hogfish	
	6580	Labridae	*Bodianus bilunulatus*	Tarry hogfish	
	5500	Labridae	*Bodianus diana*	Diana's hogfish	
	5501	Labridae	*Bodianus mesothorax*	Splitlevel hogfish	
	5598	Labridae	*Cheilinus chlorurus*	Floral wrasse	
	5600	Labridae	*Cheilinus fasciatus*	Redbreast wrasse	
	5603	Labridae	*Cheilinus trilobatus*	Tripletail wrasse	
	5623	Labridae	*Cheilio inermis*	Cigar wrasse	
	5502	Labridae	*Choerodon anchorago*	Orange-dotted tuskfish	
	6433	Labridae	*Choerodon schoenleinii*	Blackspot tuskfish	
	5625	Labridae	*Coris gaimardi*	Yellowtail coris	
	5606	Labridae	*Epibulus insidiator*	Slingjaw wrasse	
	5626	Labridae	*Gomphosus varius*	Bird wrasse	
	12663	Labridae	*Halichoeres hortulanus*	Checkerboard wrasse	
	4856	Labridae	*Halichoeres melasmopomus*	Cheekspot wrasse	
	5635	Labridae	*Hemigymnus fasciatus*	Barred thicklip	
	5636	Labridae	*Hemigymnus melapterus*	Blackeye thicklip	
	5638	Labridae	*Hologymnosus. doliatus*	Pastel ringwrasse	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	5610	Labridae	*Novaculichthys taeniourus*	Rockmover wrasse	
	5597	Labridae	*Oxycheilinus celebicus*	Celebes wrasse	
	5599	Labridae	*Oxycheilinus diagrammus*	Cheeklined wrasse	
	5605	Labridae	*Oxycheilinus unifasciatus*	Ringtail maori wrasse	
	5594	Labridae	*Pseudodax moluccanus*	Chiseltooth wrasse	
	5645	Labridae	*Thalassoma lunare*	Moon wrasse	
	5647	Labridae	*Thalassoma purpureum*	Surge wrasse	
	5613	Labridae	*Xyrichtys pavo*	Peacock wrasse	
	1832	Lethrinidae	*Gnathodentex aurolineatus*	Striped large-eye bream	
	1834	Lethrinidae	*Gymnocranius grandoculus*	Blue-lined large-eye bream	
	1854	Lethrinidae	*Lethrinus atkinsoni*	Pacific yellowtail emperor	
	1862	Lethrinidae	*Lethrinus erythracanthus*	Orange-spotted emperor	
	1842	Lethrinidae	*Lethrinus erythropterus*	Longfin emperor	
	1851	Lethrinidae	*Lethrinus harak*	Thumbprint emperor	
	1857	Lethrinidae	*Lethrinus laticaudis*	Grass emperor	
	1863	Lethrinidae	*Lethrinus lentjan*	Pink ear emperor	
	1847	Lethrinidae	*Lethrinus obsoletus*	Orange-striped emperor	
	1864	Lethrinidae	*Lethrinus olivaceous*	Longface emperor	
	1866	Lethrinidae	*Lethrinus ornatus*	Ornate emperor	
	1849	Lethrinidae	*Lethrinus semicinctus*	Black blotch emperor	
	1852	Lethrinidae	*Lethrinus xanthocheilus*	Yellowlip emperor	
	1869	Lethrinidae	*Monotaxis grandoculis*	Humpnose big-eye bream	
	5795	Malacanthidae	*Malacanthus brevirostris*	Quakerfish	
	5796	Malacanthidae	*Malacanthus latovittatus*	Blue blanquillo	
	59225	Microdesmidae	*Aioliops megastigma*		
	12883	Moringuidae	*Moringua ferruginea*	Rusty spaghetti eel	
	8051	Moringuidae	*Moringua microchir*	Lesser thrush eel	
	5653	Mugilidae	*Crenimugil crenilabis*	Fringelip mullet	
	5656	Mugilidae	*Liza vaigiensis*	Squaretail mullet	
	5983	Mullidae	*Mulloidichthys flavolineatus*	Yellowstripe goatfish	
	5986	Mullidae	*Parupeneus barberinoides*	Bicolor goatfish	
	5987	Mullidae	*Parupeneus barberinus*	Dash-and-dot goatfish	
	60947	Mullidae	*Parupeneus bifasciatus*		
	5990	Mullidae	*Parupeneus cyclostomus*	Goldsaddle goatfish	
	5991	Mullidae	*Parupeneus heptacanthus*	Cinnabar goatfish	
	5992	Mullidae	*Parupeneus indicus*	Indian goatfish	
	5993	Mullidae	*Parupeneus multifasciatus*	Manybar goatfish	
	5994	Mullidae	*Parupeneus pleurostigma*	Sidespot goatfish	
	5443	Mullidae	*Upeneus tragula*	Freckled goatfish	
	5388	Muraenidae	*Echidna nebulosa*	Snowflake moray	
	6494	Muraenidae	*Gymnothorax enigmaticus*	Enigmatic moray	
	6495	Muraenidae	*Gymnothorax fimbriatus*	Fimbriated moray	
	5392	Muraenidae	*Gymnothorax flavimarginatus*	Yellow-edged moray	
	6380	Muraenidae	*Gymnothorax javanicus*	Giant moray	
	7284	Muraenidae	*Gymnothorax melatremus*	Dwarf moray	
	6395	Muraenidae	*Gymnothorax pictus*	Peppered moray	
	8594	Muraenidae	*Rhinomuraena quaesita*	Ribbon moray	
	10217	Muraenidae	*Uropterygius micropterus*	Tidepool snake moray	
	5868	Nemipteridae	*Pentapodus emeryii*	Double whiptail	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	5873	Nemipteridae	*Pentapodus trivittatus*	Three-striped whiptail	
	5890	Nemipteridae	*Scolopsis affinis*	Peters' monocle bream	
	5885	Nemipteridae	*Scolopsis bilineatus*	Two-lined monocle bream	
	5877	Nemipteridae	*Scolopsis lineatus*	Striped monocle bream	
	5878	Nemipteridae	*Scolopsis margaritifer*	Pearly monocle bream	
	5879	Nemipteridae	*Scolopsis monogramma*	Monogrammed monocle bream	
	5880	Nemipteridae	*Scolopsis temporalis*	Bald-spot monocle bream	
	5883	Nemipteridae	*Scolopsis vosmeri*	Whitecheek monocle bream	
	7473	Ophichthidae	*Leiuranus semicinctus*	Saddled snake eel	
	8053	Ophichthidae	*Myrichthys colubrinus*	Harlequin snake eel	
	2650	Ophichthidae	*Myrichthys maculosus*	Tiger snake eel	
	756	Orectolobidae	*Orectolobus dasypogon*	Tasselled wobbegong	
	6555	Ostraciidae	*Ostracion cubicus*	Yellow boxfish	
	6556	Ostraciidae	*Ostracion meleagris*	Whitespotted boxfish	
	7892	Pentacerotidae	*Histiopterus typus*	Sailfin armourhead	
	4433	Pholidichthyidae	*Pholidichthys leucotaenia*	Convict blenny	
	6561	Pinguipedidae	*Parapercis clathrata*	Latticed sandperch	
	6562	Pinguipedidae	*Parapercis cylindrica*	Cylindrical sandperch	
	7866	Pinguipedidae	*Parapercis hexophthalma*	Speckled sandperch	
	6674	Pinguipedidae	*Parapercis tetracantha*	Reticulated sandperch	
	12668	Pinguipedidae	*Parapercis xanthozona*	Yellowbar sandperch	
	15197	Platycephalidae	*Cociella punctata*	Spotted flathead	
	12826	Platycephalidae	*Cymbacephalus beauforti*	Crocodile fish	
	12902	Platycephalidae	*Thysanophrys chiltoni*	Longsnout flathead	
	4706	Plotosidae	*Plotosus lineatus*	Striped eel catfish	
	5687	Pomacentridae	*Abudefduf septemfasciatus*	Banded sergeant	
	5689	Pomacentridae	*Abudefduf sordidus*	Blackspot sergeant	
	5730	Pomacentridae	*Pomacentrus vaiuli*	Ocellate damselfish	
	5791	Priacanthidae	*Priacanthus hamrur*	Moontail bullseye	
	14273	Pseudochromidae	*Pseudoplesiops annae*		
	27610	Ptereleotridae	*Parioglossus philippinus*	Philippine dartfish	
	4698	Scatophagidae	*Scatophagus argus*	Spotted scat	
	5828	Scorpaenidae	*Dendrochirus zebra*	Zebra turkeyfish	
	5195	Scorpaenidae	*Pterois volitans*	Red lionfish	
	5822	Scorpaenidae	*Scorpaenopsis oxycephala*	Tassled scorpionfish	
	4614	Siganidae	*Siganus argenteus*	Streamlined spinefoot	
	4456	Siganidae	*Siganus canaliculatus*	White-spotted spinefoot	
	4611	Siganidae	*Siganus corallinus*	Blue-spotted spinefoot	
	4588	Siganidae	*Siganus guttatus*	Orange-spotted spinefoot	
	4618	Siganidae	*Siganus javus*	Streaked spinefoot	
	4625	Siganidae	*Siganus lineatus*	Golden-lined spinefoot	
	4617	Siganidae	*Siganus puellus*	Masked spinefoot	
	4620	Siganidae	*Siganus punctatissimus*	Peppered spinefoot	
	4621	Siganidae	*Siganus punctatus*	Goldspotted spinefoot	
	4457	Siganidae	*Siganus spinus*	Little spinefoot	
	4624	Siganidae	*Siganus virgatus*	Barhead spinefoot	
	4629	Siganidae	*Siganus vulpinus*	Foxface	
	5826	Synanceiidae	*Inimicus didactylus*	Bearded ghoul	
	6389	Synanceiidae	*Synanceja horrida*	Estuarine stonefish	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	5825	Synanceiidae	*Synanceja verrucosa*	Stonefish	
	5960	Syngnathidae	*Corythoichthys haematopterus*	Messmate pipefish	
	53790	Syngnathidae	*Hippocampus bargibanti*	Pygmy seahorse	
	5955	Syngnathidae	*Hippocampus kuda*	Spotted seahorse	
	5980	Syngnathidae	*Syngnathoides biaculeatus*	Alligator pipefish	
	4534	Synodontidae	*Saurida gracilis*	Gracile lizardfish	
	12620	Synodontidae	*Synodus dermatogenys*	Sand lizardfish	
	5398	Synodontidae	*Synodus variegatus*	Variegated lizardfish	
	4829	Terapontidae	*Terapon theraps*	Largescaled therapon	
	8229	Toxotidae	*Toxotes jaculatrix*	Banded archerfish	
	5950	Zanclidae	*Zanclus cornutus*	Moorish idol	
Med. reef associated	5402	Antennariidae	*Antennarius coccineus*	Scarlet frogfish	176
	7294	Antennariidae	*Antennarius dorhensis*	New Guinean frogfish	
	3089	Antennariidae	*Histrio histrio*	Sargassumfish	
	5766	Apogonidae	*Apogon angustatus*	Broadstriped cardinalfish	
	4837	Apogonidae	*Apogon aureus*	Ring-tailed cardinalfish	
	13003	Apogonidae	*Apogon chrysotaenia*		
	5769	Apogonidae	*Apogon compressus*	Ochre-striped cardinalfish	
	5756	Apogonidae	*Apogon exostigma*	Narrowstripe cardinalfish	
	4838	Apogonidae	*Apogon fleurieu*	Cardinalfish	
	5758	Apogonidae	*Apogon kallopterus*	Iridescent cardinalfish	
	23455	Apogonidae	*Apogon rhodopterus*	Redfin cardinalfish	
	5767	Apogonidae	*Apogon taeniophorus*	Reef-flat cardinalfish	
	12906	Apogonidae	*Apogon talboti*	Flame cardinalfish	
	5748	Apogonidae	*Apogon trimaculatus*	Three-spot cardinalfish	
	5775	Apogonidae	*Archamia biguttata*	Twinspot cardinalfish	
	12876	Apogonidae	*Cheilodipterus alleni*		
	5780	Apogonidae	*Cheilodipterus artus*	Wolf cardinalfish	
	5482	Apogonidae	*Cheilodipterus quinquelineatus*	Five-lined cardinalfish	
	5782	Apogonidae	*Cheilodipterus singapurensis*	Truncate cardinalfish	
	5743	Apogonidae	*Fowleria punctulata*	Spotcheek cardinalfish	
	4362	Apogonidae	*Pseudamia gelatinosa*	Gelatinous cardinalfish	
	1307	Atherinidae	*Hypoatherina temminckii*	Samoan silverside	
	6066	Blenniidae	*Aspidontus taeniatus*	False cleanerfish	
	4387	Blenniidae	*Cirripectes castaneus*	Chestnut eyelash-blenny	
	4398	Blenniidae	*Cirripectes polyzona*		
	4402	Blenniidae	*Cirripectes stigmaticus*	Red-streaked blenny	
	6033	Blenniidae	*Ecsenius bicolor*	Bicolor blenny	
	7664	Blenniidae	*Ecsenius namiyei*	Black comb-tooth	
	6043	Blenniidae	*Entomacrodus striatus*	Reef margin blenny	
	6049	Blenniidae	*Istiblennius edentulus*	Rippled rockskipper	
	6050	Blenniidae	*Istiblennius lineatus*	Lined rockskipper	
	6069	Blenniidae	*Meiacanthus grammistes*	Striped poison-fang blenny	
	6073	Blenniidae	*Petroscirtes breviceps*	Striped poison-fang blenny mimic	
	6071	Blenniidae	*Plagiotremus rhinorhynchus*	Bluestriped fangblenny	
	6072	Blenniidae	*Plagiotremus tapeinosoma*	Piano fangblenny	
	6058	Blenniidae	*Salarias fasciatus*	Jewelled blenny	
	59272	Blenniidae	*Salarias ramosus*	Starry blenny	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	22515	Blenniidae	*Salarias segmentatus*	Segmented blenny	
	388	Carangidae	*Selaroides leptolepis*	Yellowstripe scad	
	6510	Centriscidae	*Centriscus scutatus*	Grooved razor-fish	
	6604	Cirrhitidae	*Cirrhitichthys aprinus*	Spotted hawkfish	
	5833	Cirrhitidae	*Oxycirrhitus typus*	Longnose hawkfish	
	5835	Cirrhitidae	*Paracirrhites arcatus*	Arc-eye hawkfish	
	5952	Cirrhitidae	*Paracirrhites forsteri*	Blackside hawkfish	
	23581	Gobiidae	*Acentrogobius janthinopterus*		
	7230	Gobiidae	*Amblyeleotris fontanesii*	Giant prawn-goby	
	11614	Gobiidae	*Amblyeleotris gymnocephala*	Masked shrimpgoby	
	55505	Gobiidae	*Amblygobius bynoensis*	Byno goby	
	7198	Gobiidae	*Amblygobius phalaena*	Banded goby	
	12679	Gobiidae	*Cryptocentrus fasciatus*	Y-bar shrimp goby	
	370	Gobiidae	*Exyrias bellisimus*	Mud reef-goby	
	377	Gobiidae	*Exyrias puntang*	Puntang goby	
	4328	Gobiidae	*Istigobius decoratus*	Decorated goby	
	4322	Gobiidae	*Istigobius ornatus*	Ornate goby	
	7480	Gobiidae	*Periophthalmus argentilineatus*	Barred mudskipper	
	7482	Gobiidae	*Periophthalmus kalolo*	Common mudskipper	
	7226	Gobiidae	*Valenciennea muralis*	Mural goby	
	7246	Gobiidae	*Valenciennea puellaris*	Maiden goby	
	7227	Gobiidae	*Valenciennea sexguttata*	Sixspot goby	
	6575	Gobiidae	*Valenciennea strigata*	Blueband goby	
	4699	Holocentridae	*Sargocentron diadema*	Crown squirrelfish	
	5622	Labridae	*Anampses melanurus*	White-spotted wrasse	
	4889	Labridae	*Anampses meleagrides*	Spotted wrasse	
	4893	Labridae	*Anampses twistii*	Yellowbreasted wrasse	
	5602	Labridae	*Cheilinus oxycephalus*	Snooty wrasse	
	25688	Labridae	*Coris batuensis*	Batu coris	
	5107	Labridae	*Coris pictoides*	Blackstripe coris	
	5608	Labridae	*Cymolutes torquatus*	Finescale razorfish	
	4857	Labridae	*Halichoeres argus*	Argus wrasse	
	5627	Labridae	*Halichoeres biocellatus*	Red-lined wrasse	
	4859	Labridae	*Halichoeres chloropterus*	Pastel-green wrasse	
	4855	Labridae	*Halichoeres chrysus*	Canary wrasse	
	5628	Labridae	*Halichoeres hartzfeldi*	Hartzfeld's wrasse	
	56811	Labridae	*Halichoeres leucurus*	Greyhead wrasse	
	5630	Labridae	*Halichoeres margaritaceus*	Pink-belly wrasse	
	5631	Labridae	*Halichoeres marginatus*	Dusky wrasse	
	6929	Labridae	*Halichoeres melanochir*		
	4858	Labridae	*Halichoeres melanurus*	Tail-spot wrasse	
	6614	Labridae	*Halichoeres miniatus*	Circle-cheek wrasse	
	6663	Labridae	*Halichoeres nebulosus*	Nebulous wrasse	
	58179	Labridae	*Halichoeres nigrescens*	Bubblefin wrasse	
	56813	Labridae	*Halichoeres papilionaceus*		
	4861	Labridae	*Halichoeres podostigma*	Axil spot wrasse	
	4862	Labridae	*Halichoeres prosopeion*	Twotone wrasse	
	5632	Labridae	*Halichoeres richmondi*	Richmond's wrasse	
	5633	Labridae	*Halichoeres scapularis*	Zigzag wrasse	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	11622	Labridae	*Halichoeres solorensis*	Green wrasse	
	5651	Labridae	*Labroides pectoralis*	Blackspot cleaner wrasse	
	4984	Labridae	*Macropharyngodon meleagris*	Blackspotted wrasse	
	4985	Labridae	*Macropharyngodon negrosensis*	Yellowspotted wrasse	
	5609	Labridae	*Novaculichthys macrolepidotus*	Seagrass wrasse	
	5596	Labridae	*Oxycheilinus bimaculatus*	Two-spot wrasse	
	5601	Labridae	*Oxycheilinus orientalis*	Oriental maori wrasse	
	6924	Labridae	*Pseudocoris philippina*	Philippine wrasse	
	52464	Labridae	*Pteragogus enneacanthus*	Cockerel wrasse	
	6633	Labridae	*Stethojulis interrupta*	Cutribbon wrasse	
	5641	Labridae	*Stethojulis strigiventer*	Three-ribbon wrasse	
	6622	Labridae	*Stethojulis trilineata*	Three-lined rainbowfish	
	5644	Labridae	*Thalassoma jansenii*	Jansen's wrasse	
	5648	Labridae	*Thalassoma quinquevittatum*	Fivestripe wrasse	
	1850	Lethrinidae	*Lethrinus variegatus*	Slender emperor	
	5792	Malacanthidae	*Hoplolatilus cuniculus*	Dusky tilefish	
	15342	Malacanthidae	*Hoplolatilus purpureus*	Purple sand tilefish	
	5794	Malacanthidae	*Hoplolatilus starcki*	Stark's tilefish	
	6496	Muraenidae	*Gymnothorax fuscomaculatus*	Brown spotted moray	
	5876	Nemipteridae	*Scolopsis ciliatus*	Saw-jawed monocle bream	
	5881	Nemipteridae	*Scolopsis trilineatus*	Three-lined monocle bream	
	5882	Nemipteridae	*Scolopsis xenochrous*	Oblique-barred monocle bream	
	6577	Ostraciidae	*Ostracion solorensis*	Reticulate boxfish	
	6670	Pinguipedidae	*Parapercis millepunctata*	Black dotted sand perch	
	14983	Plesiopidae	*Plesiops corallicola*	Bluegill longfin	
	6517	Pomacentridae	*Abudefduf bengalensis*	Bengal sergeant	
	5685	Pomacentridae	*Abudefduf lorenzi*	Black-tail sergeant	
	5686	Pomacentridae	*Abudefduf notatus*	Yellowtail sergeant	
	6655	Pomacentridae	*Acanthochromis polyacantha*	Spiny chromis	
	5477	Pomacentridae	*Amblyglyphidodon curacao*	Staghorn damselfish	
	5691	Pomacentridae	*Amblyglyphidodon leucogaster*	Yellowbelly damselfish	
	5692	Pomacentridae	*Amblyglyphidodon ternatensis*	Ternate damsel	
	4551	Pomacentridae	*Amphiprion chrysopterus*	Orangefin anemonefish	
	5448	Pomacentridae	*Amphiprion clarkii*	Yellowtail clownfish	
	4654	Pomacentridae	*Amphiprion melanopus*	Fire clownfish	
	6509	Pomacentridae	*Amphiprion ocellaris*	Clown anemonefish	
	8086	Pomacentridae	*Amphiprion polymnus*	Saddleback clownfish	
	6523	Pomacentridae	*Amphiprion sandaracinos*	Yellow clownfish	
	6551	Pomacentridae	*Chromis analis*	Yellow chromis	
	5450	Pomacentridae	*Chromis atripectoralis*	Black-axil chromis	
	11858	Pomacentridae	*Chromis cinerascens*		
	5680	Pomacentridae	*Chromis weberi*	Weber's chromis	
	5693	Pomacentridae	*Chrysiptera biocellata*	Twinspot damselfish	
	5112	Pomacentridae	*Dascyllus trimaculatus*	Threespot dascyllus	
	6553	Pomacentridae	*Dischistodus chrysopoecilus*	Lagoon damsel	
	9982	Pomacentridae	*Dischistodus fasciatus*	Banded damsel	
	5703	Pomacentridae	*Dischistodus melanotus*	Black-vent damsel	
	6608	Pomacentridae	*Dischistodus prosopotaenia*	Honey-head damsel	
	5487	Pomacentridae	*Hemiglyphidodon plagiometopon*	Lagoon damselfish	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	12457	Pomacentridae	*Neoglyphidodon crossi*	Cross' damsel	
	5707	Pomacentridae	*Neoglyphidodon melas*	Bowtie damselfish	
	5708	Pomacentridae	*Neoglyphidodon nigroris*	Black-and-gold chromis	
	11988	Pomacentridae	*Neoglyphidodon oxyodon*	Bluestreak damselfish	
	12459	Pomacentridae	*Neopomacentrus filamentosus*	Brown demoiselle	
	5709	Pomacentridae	*Plectroglyphidodon dickii*	Blackbar devil	
	5713	Pomacentridae	*Plectroglyphidodon leucozonus*	Singlebar devil	
	5723	Pomacentridae	*Pomacentrus grammorhynchus*	Bluespot damsel	
	12493	Pomacentridae	*Pomacentrus littoralis*	Smoky damsel	
	10280	Pomacentridae	*Pomacentrus taeniometopon*	Brackish damsel	
	4340	Pomacentridae	*Stegastes albifasciatus*	Whitebar gregory	
	4347	Pomacentridae	*Stegastes fasciolatus*	Pacific gregory	
	4351	Pomacentridae	*Stegastes lividus*	Blunt snout gregory	
	4352	Pomacentridae	*Stegastes nigricans*	Dusky farmerfish	
	4353	Pomacentridae	*Stegastes obreptus*	Western gregory	
	12662	Pseudochromidae	*Labracinus cyclophthalmus*	Fire-tail devil	
	12654	Pseudochromidae	*Pseudochromis bitaeniatus*	Double-striped dottyback	
	24444	Pseudochromidae	*Pseudochromis perspicillatus*	Southeast Asian blackstripe dottyback	
	12714	Pseudochromidae	*Pseudochromis splendens*	Splendid dottyback	
	4377	Ptereleotridae	*Ptereleotris hanae*	Blue hana goby	
	4381	Ptereleotridae	*Ptereleotris microlepis*	Blue gudgeon	
	4384	Ptereleotridae	*Ptereleotris zebra*	Chinese zebra goby	
	4914	Scorpaenidae	*Pterois antennata*	Broadbarred firefish	
	5819	Scorpaenidae	*Scorpaenodes guamensis*	Guam scorpionfish	
	4915	Scorpaenidae	*Scorpaenodes parvipinnis*	Lowfin scorpionfish	
	5820	Scorpaenidae	*Scorpaenopsis macrochir*	Flasher scorpionfish	
	22544	Soleidae	*Soleichthys heterorhinos*		
	5959	Syngnathidae	*Corythoichthys flavofasciatus*	Network pipefish	
	5961	Syngnathidae	*Corythoichthys intestinalis*	Scribbled pipefish	
	5963	Syngnathidae	*Corythoichthys ocellatus*	Ocellated pipefish	
	5965	Syngnathidae	*Corythoichthys schultzi*	Schultz's pipefish	
	5972	Syngnathidae	*Doryrhamphus dactyliophorus*	Ringed pipefish	
	5970	Syngnathidae	*Doryrhamphus janssi*	Janss' pipefish	
	5974	Syngnathidae	*Halicampus dunckeri*	Duncker's pipefish	
	5975	Syngnathidae	*Halicampus mataafae*	Samoan pipefish	
	8119	Synodontidae	*Saurida nebulosa*	Clouded lizardfish	
	7943	Synodontidae	*Synodus jaculum*	Lighthouse lizardfish	
	10706	Synodontidae	*Synodus rubromarmoratus*	Redmarbled lizardfish	
	25701	Tetrarogidae	*Ablabys macracanthus*	waspfish	
	23560	Trichonotidae	*Trichonotus elegans*	Long-rayed sand-diver	
	12670	Trichonotidae	*Trichonotus setiger*	Spotted sand-diver	
Small reef associated	9230	Acanthoclinidae	*Belonepterygium fasciolatum*		206
	14043	Antennariidae	*Histiophryne cryptacanthus*	Cryptic anglerfish	
	5763	Apogonidae	*Apogon bandanensis*	Bigeye cardinalfish	
	25109	Apogonidae	*Apogon cavitiensis*		
	10342	Apogonidae	*Apogon ceramensis*	Ceram cardinalfish	
	58153	Apogonidae	*Apogon chrysopomus*	Spotted-gill cardinalfish	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	12992	Apogonidae	*Apogon crassiceps*	Transparent cardinalfish	
	5759	Apogonidae	*Apogon dispar*	Redspot cardinalfish	
	5753	Apogonidae	*Apogon doryssa*	Longspine cardinalfish	
	5757	Apogonidae	*Apogon fraenatus*	Bridled cardinalfish	
	5771	Apogonidae	*Apogon fragilis*	Fragile cardinalfish	
	59777	Apogonidae	*Apogon fuscus*		
	5760	Apogonidae	*Apogon hartzfeldi*	Hartzfeld's cardinalfish	
	8588	Apogonidae	*Apogon hoeveni*	Frostfin cardinalfish	
	5773	Apogonidae	*Apogon leptacanthus*	Threadfin cardinalfish	
	25370	Apogonidae	*Apogon melanoproctus*	Blackvent cardinalfish	
	11619	Apogonidae	*Apogon multilineatus*	Many-lined cardinalfish	
	25037	Apogonidae	*Apogon nanus*		
	25049	Apogonidae	*Apogon neotes*		
	4836	Apogonidae	*Apogon nigrofasciatus*	Blackstripe cardinalfish	
	8590	Apogonidae	*Apogon notatus*	Spotnape cardinalfish	
	5768	Apogonidae	*Apogon novemfasciatus*	Sevenstriped cardinalfish	
	23452	Apogonidae	*Apogon parvulus*		
	5774	Apogonidae	*Apogon perlitus*	Pearly cardinalfish	
	6230	Apogonidae	*Apogon sealei*	Seale's cardinalfish	
	27037	Apogonidae	*Apogon selas*	Meteor cardinalfish	
	12747	Apogonidae	*Apogon thermalis*	Half-barred cardinal	
	12658	Apogonidae	*Apogon timorensis*	Timor cardinalfish	
	59184	Apogonidae	*Apogon wassinki*		
	5740	Apogonidae	*Apogonichthys ocellatus*	Ocellated cardinalfish	
	5776	Apogonidae	*Archamia fucata*	Orangelined cardinalfish	
	59188	Apogonidae	*Archamia macropterus*	Dusky-tailed cardinalfish	
	5777	Apogonidae	*Archamia zosterophora*	Blackbelted cardinalfish	
	14876	Apogonidae	*Cercamia eremia*	Glassy cardinalfish	
	12878	Apogonidae	*Cheilodipterus nigrotaeniatus*		
	8010	Apogonidae	*Fowleria aurita*	Crosseyed cardinalfish	
	5787	Apogonidae	*Gymnapogon urospilotus*	B-spot cardinalfish	
	4363	Apogonidae	*Pseudamia hayashi*	Hayashi's cardinalfish	
	5747	Apogonidae	*Rhabdamia gracilis*	Luminous cardinalfish	
	5778	Apogonidae	*Sphaeramia nematoptera*	Pajama cardinalfish	
	17462	Blenniidae	*Atrosalarias fuscus*		
	4389	Blenniidae	*Cirripectes filamentosus*	Filamentous blenny	
	4399	Blenniidae	*Cirripectes quagga*	Squiggly blenny	
	7560	Blenniidae	*Crossosalarias macrospilus*	Triplespot blenny	
	12633	Blenniidae	*Ecsenius bandanus*	Banda comb-tooth	
	12692	Blenniidae	*Ecsenius bathi*	Bath's comb-tooth	
	7661	Blenniidae	*Ecsenius lividinalis*		
	7663	Blenniidae	*Ecsenius stigmatura*		
	12640	Blenniidae	*Ecsenius trilineatus*	Three-lined blenny	
	6036	Blenniidae	*Ecsenius yaeyamensis*	Yaeyama blenny	
	46625	Blenniidae	*Meiacanthus crinitus*		
	59273	Blenniidae	*Salarias patzneri*	Patzner's blenny	
	7299	Bythitidae	*Brosmophyciops pautzkei*	Slimy cuskeel	
	17464	Callionymidae	*Anaora tentaculata*	Tentacled dragonet	
	17468	Callionymidae	*Callionymus ennactis*	Mangrove dragonet	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	12643	Callionymidae	*Synchiropus morrisoni*	Morrison's dragonet	
	7981	Callionymidae	*Synchiropus ocellatus*	Ocellated dragonet	
	12644	Callionymidae	*Synchiropus splendidus*	Mandarinfish	
	7873	Caracanthidae	*Caracanthus maculatus*	Spotted coral croucher	
	10744	Carapidae	*Onuxodon margaritiferae*	Bivalve pearlfish	
	5445	Cirrhitidae	*Cirrhitichthys falco*	Dwarf hawkfish	
	5830	Cirrhitidae	*Cirrhitichthys oxycephalus*	Coral hawkfish	
	12891	Gobiesocidae	*Diademichthys lineatus*	Urchin clingfish	
	7494	Gobiesocidae	*Discotrema crinophila*	Crinoid clingfish	
	7229	Gobiidae	*Amblyeleotris fasciata*	Red-banded prawn-goby	
	6671	Gobiidae	*Amblyeleotris guttata*	Spotted prawn-goby	
	47046	Gobiidae	*Amblyeleotris latifasciata*		
	7231	Gobiidae	*Amblyeleotris periophthalma*	Periophthalma prawn-goby	
	7195	Gobiidae	*Amblyeleotris steinitzi*	Steinitz' prawn-goby	
	7196	Gobiidae	*Amblyeleotris wheeleri*	Gorgeous prawn-goby	
	46531	Gobiidae	*Amblyeleotris yanoi*	Flagtail shrimpgoby	
	56800	Gobiidae	*Amblygobius buanensis*	Buan goby	
	7197	Gobiidae	*Amblygobius decussatus*	Orange-striped goby	
	7243	Gobiidae	*Amblygobius nocturnus*	Nocturn goby	
	5478	Gobiidae	*Amblygobius rainfordi*	Old glory	
	58617	Gobiidae	*Asterropteryx bipunctatus*	Orange-spotted goby	
	7200	Gobiidae	*Asterropteryx semipunctatus*	Starry goby	
	7202	Gobiidae	*Bathygobius cocosensis*	Cocos frill-goby	
	11801	Gobiidae	*Bathygobius cyclopterus*	Spotted frillgoby	
	7203	Gobiidae	*Bryaninops amplus*	Large whip goby	
	52430	Gobiidae	*Bryaninops loki*	Loki whip-goby	
	7205	Gobiidae	*Bryaninops natans*	Redeye goby	
	7251	Gobiidae	*Bryaninops yongei*	Whip coral goby	
	26684	Gobiidae	*Callogobius inframaculatus*		
	7206	Gobiidae	*Callogobius maculipinnis*	Ostrich goby	
	17056	Gobiidae	*Coryphopterus duospilus*	Barenape goby	
	7215	Gobiidae	*Coryphopterus neophytus*	Common fusegoby	
	7513	Gobiidae	*Coryphopterus signipinnis*	Signalfin goby	
	7233	Gobiidae	*Cryptocentroides insignis*	Insignia prawn-goby	
	7208	Gobiidae	*Cryptocentrus cinctus*	Yellow prawn-goby	
	25799	Gobiidae	*Cryptocentrus leptocephalus*	Pink-speckled shrimpgoby	
	13767	Gobiidae	*Cryptocentrus leucostictus*	Saddled prawn-goby	
	7209	Gobiidae	*Cryptocentrus strigilliceps*	Target shrimp goby	
	7237	Gobiidae	*Ctenogobiops aurocingulus*	Gold-streaked prawn-goby	
	7238	Gobiidae	*Ctenogobiops feroculus*	Sandy prawn-goby	
	7210	Gobiidae	*Ctenogobiops pomastictus*	Gold-specked prawn-goby	
	7259	Gobiidae	*Eviota albolineata*	Spotted fringefin goby	
	7213	Gobiidae	*Eviota bifasciata*	Twostripe pygmy goby	
	25452	Gobiidae	*Eviota guttata*	Spotted pygmy goby	
	7214	Gobiidae	*Eviota nigriventris*	Blackbelly goby	
	7269	Gobiidae	*Eviota pellucida*	Pellucida pygmy goby	
	7270	Gobiidae	*Eviota prasina*	Green bubble goby	
	7271	Gobiidae	*Eviota prasites*	Prasites pygmy goby	
	7275	Gobiidae	*Eviota sebreei*	Sebree's pygmy goby	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	7635	Gobiidae	*Eviota sparsa*	Speckled pygmy goby	
	23595	Gobiidae	*Gnatholepis anjerensis*		
	9950	Gobiidae	*Gnatholepis cauerensis*	Eyebar goby	
	7217	Gobiidae	*Gobiodon okinawae*	Okinawa goby	
	59869	Gobiidae	*Gobiodon unicolor*		
	4324	Gobiidae	*Istigobius rigilius*	Rigilius goby	
	23719	Gobiidae	*Luposicya lupus*		
	1246	Gobiidae	*Macrodontogobius wilburi*	Largetooth goby	
	7240	Gobiidae	*Mahidolia mystacina*	Flagfin prawn goby	
	7218	Gobiidae	*Oplopomus oplopomus*	Spinecheek goby	
	61315	Gobiidae	*Phyllogobius platycephalops*	Slender spongegoby	
	23079	Gobiidae	*Pleurosicya mossambica*	Toothy goby	
	7245	Gobiidae	*Signigobius biocellatus*	Twinspot goby	
	4311	Gobiidae	*Stonogobiops xanthorhinica*	Yellownose prawn-goby	
	59924	Gobiidae	*Sueviota atronasus*		
	23644	Gobiidae	*Tomiyamichthys oni*	Monster shrimpgoby	
	28081	Gobiidae	*Trimma benjamini*	Redface dwarfgoby	
	25541	Gobiidae	*Trimma emeryi*	Emery's goby	
	26320	Gobiidae	*Trimma macrophthalma*	Flame goby	
	7222	Gobiidae	*Trimma okinawae*	Okinawa rubble goby	
	58619	Gobiidae	*Trimma rubromaculata*		
	7223	Gobiidae	*Trimma striata*	Stripehead goby	
	12752	Gobiidae	*Trimma taylori*	Yellow cave goby	
	12754	Gobiidae	*Trimma tevegae*	Blue-striped cave goby	
	12607	Gobiidae	*Valenciennea bella*		
	12613	Gobiidae	*Valenciennea randalli*	Greenband goby	
	23645	Gobiidae	*Vanderhorstia lanceolata*	Lanceolate shrimpgoby	
	5499	Labridae	*Bodianus bimaculatus*	Twospot hogfish	
	54179	Labridae	*Cirrhilabrus condei*		
	46517	Labridae	*Cirrhilabrus flavidorsalis*	Yellowfin fairy wrasse	
	59640	Labridae	*Cirrhilabrus tonozukai*		
	5108	Labridae	*Diproctacanthus xanthurus*	Yellowtail tubelip	
	56789	Labridae	*Halichoeres pallidus*	Pale wrasse	
	4863	Labridae	*Labropsis alleni*	Allen's tubelip	
	27014	Labridae	*Parachelinus cyaneus*		
	5615	Labridae	*Pseudocheilinops ataenia*	Pelvic-spot wrasse	
	5616	Labridae	*Pseudocheilinus evanidus*	Striated wrasse	
	5617	Labridae	*Pseudocheilinus hexataenia*	Pyjama wrasse	
	57494	Labridae	*Pseudojuloides kaleidos*		
	5620	Labridae	*Pteragogus cryptus*	Cryptic wrasse	
	4869	Labridae	*Wetmorella albofasciata*	Whitebanded sharpnose wrasse	
	7587	Microdesmidae	*Gunnelichthys pleurotaenia*	Onestripe wormfish	
	4606	Pegasidae	*Eurypegasus draconis*	Short dragonfish	
	8005	Plesiopidae	*Plesiops coeruleolineatus*	Crimsontip longfin	
	54180	Pomacentridae	*Amblyglyphidodon batunai*		
	9721	Pomacentridae	*Amblypomacentrus breviceps*	Black-banded demoiselle	
	2024	Pomacentridae	*Amphiprion perideraion*	Pink anemonefish	
	5684	Pomacentridae	*Cheiloprion labiatus*	Big-lip damsel	

Table A.1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	5670	Pomacentridae	*Chromis alpha*	Yellow-speckled chromis	
	5671	Pomacentridae	*Chromis amboinensis*	Ambon chromis	
	4982	Pomacentridae	*Chromis atripes*	Dark-fin chromis	
	5672	Pomacentridae	*Chromis caudalis*	Blue-axil chromis	
	5673	Pomacentridae	*Chromis delta*	Deep reef chromis	
	4983	Pomacentridae	*Chromis elerae*	Twinspot chromis	
	5128	Pomacentridae	*Chromis lineata*	Lined chromis	
	5676	Pomacentridae	*Chromis retrofasciata*	Black-bar chromis	
	5677	Pomacentridae	*Chromis ternatensis*	Ternate chromis	
	12521	Pomacentridae	*Chrysiptera bleekeri*	Bleeker's damsel	
	56326	Pomacentridae	*Chrysiptera brownriggii*	Surge demoiselle	
	5695	Pomacentridae	*Chrysiptera cyanea*	Sapphire devil	
	12448	Pomacentridae	*Chrysiptera parasema*	Goldtail demoiselle	
	5699	Pomacentridae	*Chrysiptera rex*	King demoiselle	
	12450	Pomacentridae	*Chrysiptera springeri*	Springer's demoiselle	
	5702	Pomacentridae	*Chrysiptera unimaculata*	Onespot demoiselle	
	5113	Pomacentridae	*Dascyllus reticulatus*	Reticulate dascyllus	
	10227	Pomacentridae	*Neopomacentrus azysron*	Yellow-tail demoiselle	
	12458	Pomacentridae	*Neopomacentrus bankieri*	Chinese demoiselle	
	8209	Pomacentridae	*Neopomacentrus cyanomos*	Regal demoiselle	
	5712	Pomacentridae	*Plectroglyphidodon lacrymatus*	Whitespotted devil	
	12476	Pomacentridae	*Pomacentrus adelus*	Obscure damsel	
	12483	Pomacentridae	*Pomacentrus auriventris*	Goldbelly damsel	
	5719	Pomacentridae	*Pomacentrus burroughi*	Burrough's damsel	
	5721	Pomacentridae	*Pomacentrus chrysurus*	Whitetail damsel	
	12488	Pomacentridae	*Pomacentrus cuneatus*	Wedgespot damsel	
	10277	Pomacentridae	*Pomacentrus opisthostigma*	Brown damsel	
	5727	Pomacentridae	*Pomacentrus philippinus*	Philippine damsel	
	5728	Pomacentridae	*Pomacentrus reidi*	Reid's damsel	
	5729	Pomacentridae	*Pomacentrus simsiang*	Blueback damsel	
	10279	Pomacentridae	*Pomacentrus smithi*	Smith's damsel	
	8277	Pomacentridae	*Pomacentrus tripunctatus*	Threespot damsel	
	14271	Pseudochromidae	*Amsichthys knighti*		
	12645	Pseudochromidae	*Cypho purpurescens*	Oblique-lined dottyback	
	12656	Pseudochromidae	*Lubbockichthys multisquamatus*	Fine-scaled dottyback	
	14279	Pseudochromidae	*Pseudochromis cyanotaenia*	Surge dottyback	
	46486	Pseudochromidae	*Pseudochromis elongatus*		
	6627	Pseudochromidae	*Pseudochromis fuscus*	Brown dottyback	
	7323	Pseudochromidae	*Pseudochromis marshallensis*	Marshall Is. dottyback	
	7461	Pseudochromidae	*Pseudochromis porphyreus*	Magenta dottyback	
	14274	Pseudochromidae	*Pseudochromis tapienosoma*	Blackmargin dottyback	
	17480	Ptereleotridae	*Parioglossus formosus*	Beautiful hover goby	
	5815	Scorpaenidae	*Scorpaenodes hirsutus*	Hairy scorpionfish	
	5811	Scorpaenidae	*Sebastapistes cyanostigma*	Yellowspotted scorpionfish	
	5814	Scorpaenidae	*Sebastapistes strongia*	Barchin scorpionfish	
	5824	Scorpaenidae	*Taenianotus triacanthus*	Leaf scorpionfish	
	5958	Syngnathidae	*Choeroichthys brachysoma*	Short-bodied pipefish	
	7742	Syngnathidae	*Phoxocampus belcheri*	Rock pipefish	
	7745	Syngnathidae	*Phoxocampus tetrophthalmus*		

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	7192	Syngnathidae	*Siokunichthys nigrolineatus*		
	51555	Tripterygiidae	*Enneapterygius rubricauda*	Redtail triplefin	
	47048	Tripterygiidae	*Enneapterygius ziegleri*	Ziegler's triplefin	
	47204	Tripterygiidae	*Ucla xenogrammus*	Largemouth triplefin	
	13766	Xenisthmidae	*Xenisthmus polyzonatus*	Bullseye wriggler	
Large demersal	7693	Emmelichthyidae	*Erythrocles schlegelii*	Japanese rubyfish	10
	4463	Gerreidae	*Gerres filamentosus*	Whipfin silverbiddy	
	59331	Gobiidae	*Amblyeleotris arcupinna*		
	59344	Gobiidae	*Trimma griffthsi*		
	61010	Gobiidae	*Trimma halonevum*		
	17227	Muraenidae	*Gymnothorax polyuranodon*	Freshwater moray	
	5397	Muraenidae	*Gymnothorax zonipectus*	Barredfin moray	
	8291	Peristediidae	*Satyrichthys rieffeli*	Spotted armoured-gurnard	
	10335	Platycephalidae	*Inegocia japonica*	Japanese flathead	
	4458	Terapontidae	*Terapon jarbua*	Jarbua terapon	
Small demersal	6383	Apistidae	*Apistus carinatus*	Ocellated waspfish	11
	4838	Apogonidae	*Apogon fleurieu*	Cardinalfish	
	25034	Apogonidae	*Apogon ocellicaudus*		
	8239	Dactylopteridae	*Dactyloptena macracantha*	Spotwing flying gurnard	
	7235	Gobiidae	*Cryptocentrus octofasciatus*	Blue-speckled prawn goby	
	51738	Labridae	*Choerodon zosterophorus*		
	25449	Pempheridae	*Pempheris mangula*	Black-edged sweeper	
	10310	Platycephalidae	*Sorsogona tuberculata*	Tuberculated flathead	
	5705	Pomacentridae	*Neopomacentrus taeniurus*	Freshwater demoiselle	
	10580	Serranidae	*Symphysanodon typus*	Insular shelf beauty	
	49509	Tripterygiidae	*Enneapterygius philippinus*		
Large planktivore	6017	Acanthuridae	*Paracanthurus hepatus*	Palette surgeonfish	51
	1303	Atherinidae	*Atherinomorus lacunosus*	Hardyhead silverside	
	1311	Balistidae	*Odonus niger*	Redtoothed triggerfish	
	919	Caesionidae	*Caesio cuning*	Redbelly yellowtail fusilier	
	920	Caesionidae	*Caesio lunaris*	Lunar fusilier	
	923	Caesionidae	*Caesio teres*	Yellow and blueback fusilier	
	933	Caesionidae	*Pterocaesio digramma*	Double-lined fusilier	
	935	Caesionidae	*Pterocaesio marri*	Marr's fusilier	
	936	Caesionidae	*Pterocaesio pisang*	Banana fusilier	
	938	Caesionidae	*Pterocaesio tessellata*	One-stripe fusilier	
	939	Caesionidae	*Pterocaesio tile*	Dark-banded fusilier	
	993	Carangidae	*Decapterus macarellus*	Mackerel scad	
	412	Carangidae	*Elegatis bipinnulatus*	Rainbow runner	
	1954	Carangidae	*Selar boops*	Oxeye scad	
	387	Carangidae	*Selar crumenophthalmus*	Bigeye scad	
	1619	Clupeidae	*Anodontostoma chacunda*	Chacunda gizzard shad	
	1494	Clupeidae	*Herklotsichthys quadrimaculatus*	Bluestripe herring	
	1595	Clupeidae	*Hilsa kelee*	Kelee shad	
	1613	Clupeidae	*Nematalosa flyensis*	Fly river gizzard shad	
	1617	Clupeidae	*Nematalosa papuensis*	Strickland river gizzard shad	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	6	Coryphaenidae	*Coryphaena hippurus*	Common dolphinfish	
	5738	Ephippidae	*Platax pinnatus*	Dusky batfish	
	7695	Exocoetidae	*Cheilopogon cyanopterus*	Margined flyingfish	
	1028	Exocoetidae	*Cheilopogon furcatus*	Spotfin flyingfish	
	15346	Exocoetidae	*Cheilopogon intermedius*		
	15358	Exocoetidae	*Cheilopogon spilopterus*	Manyspotted flyingfish	
	15362	Exocoetidae	*Cypselurus hexazona*		
	15365	Exocoetidae	*Cypselurus oligolepis*	Largescale flyingfish	
	5159	Exocoetidae	*Cypselurus opisthopus*	Black-finned flyingfish	
	5122	Exocoetidae	*Cypselurus poecilopterus*	Yellow-wing flyingfish	
	1032	Exocoetidae	*Exocoetus volitans*	Tropical two-wing flyingfish	
	1036	Exocoetidae	*Hirundichthys speculiger*	Mirrorwing flyingfish	
	3156	Hemiramphidae	*Euleptorhamphus viridis*	Ribbon halfbeak	
	12895	Hemiramphidae	*Hyporhamphus. dussumieri*	Dussumier's halfbeak	
	12112	Hemiramphidae	*Oxyporhamphus micropterus micropterus*	Bigwing halfbeak	
	6506	Holocentridae	*Myripristis adusta*	Shadowfin soldierfish	
	4910	Holocentridae	*Myripristis berndti*	Blotcheye soldierfish	
	7305	Holocentridae	*Myripristis hexagona*	Doubletooth soldierfish	
	7306	Holocentridae	*Myripristis kuntee*	Shoulderbar soldierfish	
	5408	Holocentridae	*Myripristis murdjan*	Pinecone soldierfish	
	7308	Holocentridae	*Myripristis pralinia*	Scarlet soldierfish	
	7309	Holocentridae	*Myripristis violacea*	Lattice soldierfish	
	6505	Holocentridae	*Myripristis vittata*	Whitetip soldierfish	
	11620	Labridae	*Pseudocoris heteroptera*	Torpedo wrasse	
	5643	Labridae	*Thalassoma hardwicke*	Sixbar wrasse	
	84	Lutjanidae	*Aprion virescens*	Green jobfish	
	7536	Osteoglossidae	*Scleropages jardinii*	Australian bonytongue	
	10350	Pempheridae	*Pempheris vanicolensis*	Vanikoro sweeper	
	6630	Pomacentridae	*Abudefduf vaigiensis*	Indo-Pacific sergeant	
	1633	Pristigasteridae	*Ilisha melastoma*	Indian ilisha	
	7463	Pseudochromidae	*Pseudoplesiops typus*	Hidden basslet	
	4544	Sillaginidae	*Sillago sihama*	Silver sillago	
Small planktivore	4600	Apogonidae	*Apogon cyanosoma*	Yellowstriped cardinalfish	62
	5746	Apogonidae	*Rhabdamia cypselurus*	Swallowtail cardinalfish	
	4926	Apogonidae	*Sphaeramia orbicularis*	Orbiculate cardinalfish	
	15462	Atherinidae	*Hypoatherina valenciennei*	Sumatran silverside	
	6067	Blenniidae	*Meiacanthus atrodorsalis*	Forktail blenny	
	6068	Blenniidae	*Meiacanthus ditrema*	One-striped poison-fang blenny	
	8421	Bregmacerotidae	*Bregmaceros mcclellandii*	Spotted codlet	
	928	Caesionidae	*Dipterygonatus balteatus*	Mottled fusilier	
	929	Caesionidae	*Gymnocaesio gymnoptera*	Slender fusilier	
	6503	Centriscidae	*Aeoliscus strigatus*	Razorfish	
	7764	Cirrhitidae	*Cyprinocirrhites polyactis*	Swallowtail hawkfish	
	1563	Clupeidae	*Clupeoides papuensis*	Papuan river sprat	
	1522	Clupeidae	*Escualosa thoracata*	White sardine	
	1457	Clupeidae	*Spratelloides delicatulus*	Delicate round herring	
	1458	Clupeidae	*Spratelloides gracilis*	Silver-stripe round herring	

Table A.1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	1459	Clupeidae	*Spratelloides lewisi*	Lewis' round herring	
	58618	Gobiidae	*Asterropteryx striatus*		
	7282	Gobiidae	*Bryaninops tigris*	Black coral goby	
	22495	Gobiidae	*Trimma naudei*	Naude's rubble goby	
	5106	Labridae	*Cirrhilabrus cyanopleura*	Blueside wrasse	
	5614	Labridae	*Cirrhilabrus exquisitus*	Exquisite wrasse	
	10576	Labridae	*Leptojulis cyanopleura*	Shoulder-spot wrasse	
	4844	Labridae	*Parachelinus filamentosus*	Filamentous wrasse	
	5639	Labridae	*Pseudocoris yamashiroi*	Redspot wrasse	
	5640	Labridae	*Stethojulis bandanensis*	Red shoulder wrasse	
	5642	Labridae	*Thalassoma amblycephalum*	Bluntheaded wrasse	
	5803	Pempheridae	*Parapriacanthus ransonneti*	Pigmy sweeper	
	7872	Pinguipedidae	*Parapercis schauinslandi*	Redspotted sandperch	
	5688	Pomacentridae	*Abudefduf sexfasciatus*	Scissortail sergeant	
	5690	Pomacentridae	*Amblyglyphidodon aureus*	Golden damselfish	
	5674	Pomacentridae	*Chromis lepidolepis*	Scaly chromis	
	5675	Pomacentridae	*Chromis margaritifer*	Bicolor chromis	
	12431	Pomacentridae	*Chromis scotochiloptera*	Philippines chromis	
	5679	Pomacentridae	*Chromis viridis*	Blue green damselfish	
	5681	Pomacentridae	*Chromis xanthochira*	Yellow-axil chromis	
	5682	Pomacentridae	*Chromis xanthura*	Paletail chromis	
	6919	Pomacentridae	*Chrysiptera hemicyanea*	Azure demoiselle	
	5698	Pomacentridae	*Chrysiptera oxycephala*	Blue-spot demoiselle	
	5486	Pomacentridae	*Chrysiptera rollandi*	Rolland's demoiselle	
	5700	Pomacentridae	*Chrysiptera talboti*	Talbot's demoiselle	
	5110	Pomacentridae	*Dascyllus aruanus*	Whitetail dascyllus	
	5111	Pomacentridae	*Dascyllus melanurus*	Blacktail humbug	
	5683	Pomacentridae	*Lepidozygus tapeinosoma*	Fusilier damselfish	
	6922	Pomacentridae	*Neoglyphidodon thoracotaeniatus*	Barhead damsel	
	12462	Pomacentridae	*Neopomacentrus nemurus*	Coral demoiselle	
	5715	Pomacentridae	*Pomacentrus amboinensis*	Ambon damsel	
	5717	Pomacentridae	*Pomacentrus bankanensis*	Speckled damselfish	
	5718	Pomacentridae	*Pomacentrus brachialis*	Charcoal damsel	
	5720	Pomacentridae	*Pomacentrus coelestis*	Neon damselfish	
	6620	Pomacentridae	*Pomacentrus lepidogenys*	Scaly damsel	
	5724	Pomacentridae	*Pomacentrus moluccensis*	Lemon damsel	
	5716	Pomacentridae	*Pomacentrus nagasakiensis*	Nagasaki damsel	
	5725	Pomacentridae	*Pomacentrus nigromanus*	Goldback damsel	
	6621	Pomacentridae	*Pomacentrus nigromarginatus*	Blackmargined damsel	
	5726	Pomacentridae	*Pomacentrus pavo*	Sapphire damsel	
	6632	Pomacentridae	*Premnas biaculeatus*	Spinecheek anemonefish	
	15169	Pseudomugilidae	*Pseudomugil inconspicuus*	Inconspicuous blue-eye	
	6629	Ptereleotridae	*Nemateleotris magnifica*	Fire goby	
	4375	Ptereleotridae	*Ptereleotris evides*	Blackfin dartfish	
	4378	Ptereleotridae	*Ptereleotris heteroptera*	Blacktail goby	
	23333	Serranidae	*Holanthias borbonius*	Checked swallowtail	
	8514	Tripterygiidae	*Helcogramma striata*	Tropical striped triplefin	

Table A1.1 - (cont.)

Functional Group	**FishBase species code**	**Family**	**Scientific name**	**Common name**	**No. Spp.**
Anchovy	605	Engraulidae	*Papuengraulis micropinna*	Littlefin anchovy	17
	611	Engraulidae	*Setipinna taty*	Scaly hairfin anchovy	
	612	Engraulidae	*Setipinna tenuifilis*	Common hairfin anchovy	
	561	Engraulidae	*Stolephorus andhraensis*	Andhra anchovy	
	1690	Engraulidae	*Stolephorus brachycephalus*	Broadhead anchovy	
	564	Engraulidae	*Stolephorus carpentariae*	Gulf of Carpenteria anchovy	
	566	Engraulidae	*Stolephorus commersonnii*	Commerson's anchovy	
	569	Engraulidae	*Stolephorus indicus*	Indian anchovy	
	578	Engraulidae	*Stolephorus waitei*	Spotty-face anchovy	
	581	Engraulidae	*Thryssa aestuaria*	Estuarine thryssa	
	583	Engraulidae	*Thryssa brevicauda*	Short-tail thryssa	
	587	Engraulidae	*Thryssa encrasicholoides*	False baelama anchovy	
	589	Engraulidae	*Thryssa hamiltonii*	Hamilton's thryssa	
	594	Engraulidae	*Thryssa mystax*	Moustached thryssa	
	597	Engraulidae	*Thryssa rastrosa*	Fly river thryssa	
	598	Engraulidae	*Thryssa scratchleyi*	New Guinea thryssa	
	599	Engraulidae	*Thryssa setirostris*	Longjaw thryssa	
Deepwater fish	10338	Acropomatidae	*Synagrops philippinensis*		58
	5064	Alepocephalidae	*Xenodermichthys copei*	Bluntsnout smooth-head	
	2308	Anoplogastridae	*Anoplogaster cornuta*	Common fangtooth	
	1984	Carangidae	*Uraspis uraspis*	Whitetongue jack	
	10358	Champsodontidae	*Champsodon guentheri*	Günther's sabre-gills	
	9061	Congridae	*Bathyuroconger vicinus*	Large-toothed conger	
	1041	Gempylidae	*Gempylus serpens*	Snake mackerel	
	3907	Gempylidae	*Nealotus tripes*	Black snake mackerel	
	7573	Gempylidae	*Nesiarchus nasutus*	Black gemfish	
	8486	Gempylidae	*Rexea bengalensis*	Bengal escolar	
	7698	Gempylidae	*Thyrsitoides marleyi*	Black snoek	
	27376	Gibberichthyidae	*Gibberichthys pumilus*	Gibberfish	
	7383	Gonostomatidae	*Gonostoma elongatum*	Elongated bristlemouth fish	
	10285	Holocentridae	*Ostichthys kaianus*	Deepwater soldier	
	1870	Lethrinidae	*Wattsia mossambica*	Mozambique large-eye bream	
	7516	Lophiidae	*Lophiodes mutilus*	Smooth angler	
	16854	Melamphaidae	*Melamphaes danae*	Bigscale	
	15709	Melamphaidae	*Poromitra oscitans*	Yawning	
	10284	Melamphaidae	*Scopelogadus mizolepis mizolepis*		
	8302	Monacanthidae	*Thamnaconus tessellatus*		
	11687	Moridae	*Physiculus roseus*		
	7423	Myctophidae	*Benthosema fibulatum*	Spinycheek lanternfish	
	10238	Myctophidae	*Benthosema pterotum*	Skinnycheek lanternfish	
	6589	Myctophidae	*Benthosema suborbitale*	Smallfin lanternfish	
	10329	Myctophidae	*Diaphus coeruleus*	Blue lantern fish	
	10264	Myctophidae	*Diaphus effulgens*	Headlight fish	
	7437	Myctophidae	*Diaphus fragilis*	Fragile lantern fish	
	10265	Myctophidae	*Diaphus garmani*		
	10266	Myctophidae	*Diaphus lucidus*		
	10174	Myctophidae	*Diaphus splendidus*		
	7411	Myctophidae	*Lampadena luminosa*		

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	4488	Myctophidae	*Myctophum asperum*	Prickly lanternfish	
	10699	Myctophidae	*Myctophum brachygnathum*	Short-jawed lanternfish	
	7441	Myctophidae	*Nannobrachium nigrum*	Black lantern fish	
	5099	Nemichthyidae	*Avocettina infans*	Avocet snipe-eel	
	2660	Nemichthyidae	*Nemichthys scolopaceus*	Slender snipe eel	
	5049	Nomeidae	*Cubiceps pauciradiatus*	Longfin fathead	
	24766	Oneirodidae	*Oneirodes sabex*		
	56351	Ophidiidae	*Mastigopterus imperator*		
	10170	Paralepididae	*Lestidium atlanticum*	Atlantic barracudina	
	10441	Peristediidae	*Peristedion liorhynchus*	Armoured gurnard	
	10538	Peristediidae	*Peristedion moluccense*	Black-finned armoured-gurnard	
	27620	Sternoptychidae	*Polyipnus unispinus*		
	10325	Stomiidae	*Astronesthes cyanea*		
	10211	Stomiidae	*Astronesthes indicus*		
	1786	Stomiidae	*Chauliodus sloani*	Sloane's viperfish	
	10214	Stomiidae	*Echiostoma barbatum*		
	10326	Stomiidae	*Eustomias bifilis*		
	56549	Stomiidae	*Eustomias monoclonus*		
	10157	Stomiidae	*Malacosteus niger*	Stoplight loosejaw	
	7395	Stomiidae	*Melanostomias valdiviae*	Valdivia black dragon fish	
	10327	Stomiidae	*Photonectes albipennis*		
	10261	Stomiidae	*Stomias nebulosus*	Alcock's boafish	
	3263	Trachipteridae	*Desmodema polystictum*	Polka-dot ribbonfish	
	8546	Trichiuridae	*Benthodesmus macrophthalmus*	Bigeye frostfish	
	8547	Trichiuridae	*Benthodesmus neglectus*	Neglected frostfish	
	8563	Trichiuridae	*Benthodesmus tenuis*	Slender frostfish	
	8566	Trichiuridae	*Benthodesmus vityazi*	Vityaz' frostfish	
Macro-algal browsing	5808	Characidae	*Piaractus brachypomus*	Pirapitinga	3
	1612	Clupeidae	*Nematalosa erebi*	Australian river gizzard shad	
	4817	Mugilidae	*Valamugil buchanani*	Bluetail mullet	
Eroding grazers	5537	Scaridae	*Bolbometopon muricatum*	Green humphead parrotfish	2
	60479	Scaridae	*Scarus microhinos*		
Scraping grazers	4307	Acanthuridae	*Acanthurus bariene*	Black-spot surgeonfish	82
	4750	Acanthuridae	*Acanthurus blochi*	Ringtail surgeonfish	
	4745	Acanthuridae	*Acanthurus fowleri*	Fowler's surgeonfish	
	4741	Acanthuridae	*Acanthurus leucocheilus*	Palelipped surgeonfish	
	1258	Acanthuridae	*Acanthurus lineatus*	Lined surgeonfish	
	4746	Acanthuridae	*Acanthurus maculiceps*	White-freckled surgeonfish	
	1255	Acanthuridae	*Acanthurus mata*	Elongate surgeonfish	
	6011	Acanthuridae	*Acanthurus nigricans*	Whitecheek surgeonfish	
	4747	Acanthuridae	*Acanthurus nigricaudus*	Epaulette surgeonfish	
	4739	Acanthuridae	*Acanthurus nigrofuscus*	Brown surgeonfish	
	4744	Acanthuridae	*Acanthurus olivaceus*	Orangespot surgeonfish	
	4742	Acanthuridae	*Acanthurus pyroferus*	Chocolate surgeonfish	
	4734	Acanthuridae	*Acanthurus thompsoni*	Thompson's surgeonfish	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	1260	Acanthuridae	*Acanthurus triostegus*	Convict surgeonfish	
	1261	Acanthuridae	*Acanthurus xanthopterus*	Yellowfin surgeonfish	
	6012	Acanthuridae	*Ctenochaetus binotatus*	Twospot surgeonfish	
	1262	Acanthuridae	*Ctenochaetus striatus*	Striated surgeonfish	
	6015	Acanthuridae	*Ctenochaetus strigosus*	Spotted surgeonfish	
	6016	Acanthuridae	*Ctenochaetus tominiensis*	Tomini surgeonfish	
	6019	Acanthuridae	*Naso annulatus*	Whitemargin unicornfish	
	6020	Acanthuridae	*Naso brachycentron*	Humpback unicornfish	
	6021	Acanthuridae	*Naso brevirostris*	Spotted unicornfish	
	27318	Acanthuridae	*Naso caeruleacauda*		
	1263	Acanthuridae	*Naso hexacanthus*	Sleek unicornfish	
	1264	Acanthuridae	*Naso lituratus*	Orangespine unicornfish	
	6022	Acanthuridae	*Naso lopezi*	Elongate unicornfish	
	6933	Acanthuridae	*Naso minor*	Slender unicorn	
	6932	Acanthuridae	*Naso thynnoides*	Oneknife unicornfish	
	1265	Acanthuridae	*Naso unicornis*	Bluespine unicornfish	
	6024	Acanthuridae	*Naso vlamingii*	Bignose unicornfish	
	7849	Monacanthidae	*Acreichthys tomentosus*	Bristle-tail file-fish	
	4275	Monacanthidae	*Aluterus scriptus*	Scrawled filefish	
	6672	Monacanthidae	*Amanses scopas*	Broom filefish	
	5836	Monacanthidae	*Cantherines dumerilii*	Whitespotted filefish	
	7842	Monacanthidae	*Cantherines fronticinctus*	Spectacled filefish	
	6635	Monacanthidae	*Cantherines pardalis*	Honeycomb filefish	
	6559	Monacanthidae	*Oxymonacanthus longirostris*	Harlequin filefish	
	6560	Monacanthidae	*Paraluteres prionurus*	Blacksaddle filefish	
	7977	Monacanthidae	*Paramonacanthus japonicus*	Hairfinned leatherjacket	
	4368	Monacanthidae	*Pervagor janthinosoma*	Blackbar filefish	
	4370	Monacanthidae	*Pervagor melanocephalus*	Redtail filefish	
	4371	Monacanthidae	*Pervagor nigrolineatus*	Blacklined filefish	
	10598	Monacanthidae	*Pseudomonacanthus macrurus*	Strap-weed file-fish	
	4355	Scaridae	*Calotomus carolinus*	Carolines parrotfish	
	5538	Scaridae	*Cetoscarus bicolor*	Bicolour parrotfish	
	4976	Scaridae	*Chlorurus bleekeri*	Bleeker's parrotfish	
	5542	Scaridae	*Chlorurus bowersi*	Bower's parrotfish	
	4978	Scaridae	*Chlorurus japanensis*	Palecheek parrotfish	
	60479	Scaridae	*Chlorurus microrhinos*		
	5556	Scaridae	*Chlorurus sordidus*	Daisy parrotfish	
	5539	Scaridae	*Hipposcarus longiceps*	Pacific longnose parrotfish	
	4360	Scaridae	*Leptoscarus vaigiensis*	Marbled parrotfish	
	5543	Scaridae	*Scarus chameleon*	Chameleon parrotfish	
	4973	Scaridae	*Scarus dimidiatus*	Yellowbarred parrotfish	
	4968	Scaridae	*Scarus flavipectoralis*	Yellowfin parrotfish	
	5545	Scaridae	*Scarus forsteni*	Forsten's parrotfish	
	5546	Scaridae	*Scarus frenatus*	Bridled parrotfish	
	5548	Scaridae	*Scarus ghobban*	Blue-barred parrotfish	
	4970	Scaridae	*Scarus globiceps*	Globehead parrotfish	
	12707	Scaridae	*Scarus hypselopterus*	Yellow-tail parrotfish	
	5550	Scaridae	*Scarus niger*	Dusky parrotfish	
	5551	Scaridae	*Scarus oviceps*	Dark capped parrotfish	

Table A1.1 - (cont.)

Functional Group	FishBase species code	Family	Scientific name	Common name	No. Spp.
	4971	Scaridae	*Scarus prasiognathos*	Singapore parrotfish	
	5553	Scaridae	*Scarus psittacus*	Common parrotfish	
	5554	Scaridae	*Scarus quoyi*	Quoy's parrotfish	
	4969	Scaridae	*Scarus rivulatus*	Rivulated parrotfish	
	5555	Scaridae	*Scarus rubroviolaceus*	Ember parrotfish	
	4975	Scaridae	*Scarus schlegeli*	Yellowband parrotfish	
	4974	Scaridae	*Scarus spinus*	Greensnout parrotfish	
	6438	Scaridae	*Scarus tricolor*	Tricolour parrotfish	
	13051	Tetraodontidae	*Arothron caeruleopunctatus*	Blue-spotted puffer	
	5425	Tetraodontidae	*Arothron hispidus*	White-spotted puffer	
	7187	Tetraodontidae	*Arothron manilensis*	Narrow-lined puffer	
	7857	Tetraodontidae	*Arothron mappa*	Map puffer	
	6400	Tetraodontidae	*Arothron nigropunctatus*	Blackspotted puffer	
	6526	Tetraodontidae	*Arothron stellatus*	Starry toadfish	
	7840	Tetraodontidae	*Canthigaster amboinensis*	Spider-eye puffer	
	6541	Tetraodontidae	*Canthigaster bennetti*	Bennett's sharpnose puffer	
	6542	Tetraodontidae	*Canthigaster compressa*	Compressed toby	
	6543	Tetraodontidae	*Canthigaster janthinoptera*	Honeycomb toby	
	55072	Tetraodontidae	*Canthigaster papua*	Papuan toby	
	6544	Tetraodontidae	*Canthigaster valentini*	Valentinni's sharpnose puffer	
Detritivore fish	5838	Balistidae	*Melichthys vidua*	Pinktail triggerfish	7
	6047	Blenniidae	*Blenniella chrysospilos*	Red-spotted blenny	
	5807	Monodactylidae	*Monodactylus argenteus*	Silver moony	
	15762	Mugilidae	*Rhinomugil nasutus*	Shark mullet	
	5659	Mugilidae	*Valamugil seheli*	Bluespot mullet	
	5704	Pomacentridae	*Dischistodus perspicillatus*	White damsel	

Appendix A2 - Fish family data

Table A2.1 - Fish families present in Raja Ampat (RA) model; number of species in RA models. Morphological and feeding characteristics utilized by the diet allocation algorithm are presented. Body morphology of families is determined based on representative species for which FishBase has morphological information. 'Main feeding mode' indicates the majority (>50%) feeding mode of member species. Piscivory and planktivory are determined respectively at the species level using characteristics listed in the MainFood and FeedingType fields of the FishBase Ecology table and the comments field of the FishBase Species table. Total length (TL); piscivorous (pisc.).

			Diet algorithm			
Fish family	**Common family name**	**# spp. in RA model**	**Body morphology**	**Average length (TL; cm)**	**Main feeding mode**	**% pisc. spp.**
Orectolobidae	Wobbeongs	1	Elongated	125.0	Piscivore	100%
Hemiscylliidae	Carpetsharks	1	Elongated	46.0	Piscivore	100%
Ginglymostomatidae	Nurse sharks	1	Elongated	320.0	Piscivore	100%
Carcharhinidae	Requiem sharks	7	Elongated	211.0	Piscivore	86%
Dasyatididae	Rays	2	Flattened	70.0	Piscivore	100%
Myliobatidae	Eagle and manta rays	2	Flattened	880.0	Piscivore	50%
Mobulidae	Manta rays	2	Flattened	0.0	Piscivore	100%
Moringuidae	Eels	2	Eel-like	0.0	Piscivore	100%
Muraenidae	Morays	12	Eel-like	86.5	Piscivore	92%
Ophichthidae	Snake eels	3	Eel-like	87.7	Piscivore	100%
Congridae	Conger and garden eels	3	Eel-like	66.0	Planktivore	33%
Clupeidae	Herrings, shads, sardines	22	Fusiform compressed	18.9	Piscivore	57%
Plotosidae	Catfish	1	No data	32.0	Piscivore	100%
Synodontidae	Lizardfish	6	Elongated circular	26.8	Piscivore	83%
Carapidae	Pearlfish	1	Eel-like compressed	10.0	Planktivore	0%
Bythitidae	Cuskeels	1	Elongated compressed	7.0	Piscivore	100%
Batrachoididae	Toadfish	2	Deep oval	28.0	Piscivore	100%
Antennariidae	Frogfish	4	Deep compressed	14.0	Piscivore	100%
Gobiesocidae	Clingfish	2	Elongated circular	5.4	Piscivore	100%
Atherinidae	Silversides	5	Elongated compressed	13.7	Piscivore	80%
Belonidae	Needlefishes	5	Eel-like	82.4	Piscivore	100%
Hemiramphidae	Halfbeaks	17	Elongated oval	26.3	Piscivore	88%
Holocentridae	Squirrelfishes, soldierfishes	20	Deep compressed	32.7	Piscivore	100%
Pegasidae	Dragonfish	1	Flattened	10.0	Planktivore	0%
Aulostomidae☐	Trumpetfish	1	Eel-like compressed	80.0	Planktivore	0%
Fistulariidae	Cornetfish	1	Eel-like flattened	0.0	Planktivore	0%
Centriscidae	Razorfish	2	Elongated compressed	15.0	Piscivore	100%
Syngnathidae	Pipefish/seahorses	16	Eel-like	15.6	Piscivore	94%
Scorpaenidae	Scorpionfish	11	Fusiform normal	17.9	Piscivore	55%
Tetrarogidae	Waspfish	1	No data	20.0	Planktivore	0%
Synanceiidae	Stonefish/ghouls	3	Fusiform normal	44.0	Piscivore	67%
Caracanthidae	Crouchers	1	No data	5.0	Planktivore	0%
Dactylopteridae	Flying gurnards	2	Elongated circular	35.0	Piscivore	100%

Table A2.1 - (cont.)

			Diet algorithm			
Fish family	**Common family name**	**# spp. in RA model**	**Body morphology**	**Average length (TL;cm)**	**Main feeding mode**	**% pisc. spp.**
Platycephalidae	Flatheads	5	Elongated	29.8	Piscivore	100%
Centropomidae	Seaperch	1	Elongated compressed	47.0	Piscivore	100%
Serranidae	Sea basses	54	Fusiform compressed	52.9	Piscivore	94%
Pseudochromidae	Dottybacks	15	Fusiform normal	12.4	Piscivore	100%
Plesiopidae	Longfins	2	Fusiform normal	13.0	Piscivore	100%
Acanthoclinidae	Spiny basslets	1	Elongated oval	5.0	Piscivore	100%
Cirrhitidae	Hawkfish	8	Fusiform normal	16.2	Piscivore	100%
Terapontidae	Grunters or tigerperches	4	Fusiform oval	31.0	Piscivore	100%
Priacanthidae	Bullseyes	1	Deep compressed	45.0	Planktivore	0%
Apogonidae	Cardinalfishes	61	Fusiform compressed	10.1	Piscivore	84%
Sillaginidae	Sillagos/smelts/whitings	1	Elongated circular	35.2	Piscivore	100%
Malacanthidae	Tilefish	5	Elongated	25.6	Piscivore	100%
Echeneidae	Remoras	2	Eel-like	93.0	Piscivore	100%
Carangidae	Jacks and pomanos	21	Fusiform normal	81.8	Piscivore	90%
Lutjanidae	Snappers	33	Fusiform normal	62.4	Piscivore	94%
Caesionidae	Fusilier	11	Fusiform compressed	31.6	Piscivore	100%
Gerreidae	Silverbiddy	2	Eel-like	32.5	Piscivore	100%
Haemulidae	Sweetlips	10	Deep compressed	72.4	Piscivore	60%
Lethrinidae	Emperors or scavengers	16	Fusiform oval	55.2	Piscivore	94%
Nemipteridae	Whiptails/breams/false snappers	12	Fusiform oval	25.8	Piscivore	58%
Mullidae	Goatfish	10	Fusiform oval	39.7	Planktivore	20%
Pempheridae	Sweepers	3	Deep normal	15.3	Piscivore	100%
Toxotidae	Archerfishes	2	Deep normal	38.5	Piscivore	100%
Kyphosidae	Chubs	3	Fusiform normal	65.0	Piscivore	100%
Monodactylidae	Moonyfishes or fingerfishes	1	Deep compressed	25.0	Piscivore	50%
Chaetodontidae	Butterflyfish/angelfish	57	Deep compressed	21.3	Piscivore	96%
Mugilidae	Mullets	5	Elongated oval	70.8	Piscivore	100%
Pomacentridae	Damselfish/demoiselles/sergeants	109	Deep oval	11.3	Piscivore	83%
Labridae	Parrotfish/rainbowfish/wrasses	97	Deep compressed	25.9	Piscivore	82%
Scaridae	Parrotfish	27	Elongated compressed	50.6	Piscivore	93%
Trichonotidae	Sanddivers	2	Elongated compressed	21.5	Piscivore	50%
Pinguipedidae	Sandperch	7	Elongated oval	23.0	Piscivore	71%
Pholidichthyidae	Convict blennies	1	Elongated compressed	34.0	Piscivore	100%
Tripterygiidae	Threadfin blennies	5	Fusiform oval	4.3	Piscivore	60%
Blenniidae	Blennies	32	Elongated oval	10.3	Piscivore	100%
Callionymidae	Dragonets/scotter blennies	6	Elongated circular	7.0	Piscivore	100%
Gobiidae	Gobies	97	Elongated	7.3	Piscivore	94%
Microdesmidae	Wormfish	2	Fusiform normal	9.0	Piscivore	100%
Ptereleotridae	Dart gobies	8	Elongated	11.0	Piscivore	100%
Toxotidae	Archerfishes	2	Deep normal	38.5	Piscivore	100%
Xenisthmidae	Wrigglers	1	No Data	3.0	Piscivore	100%
Ephippidae	Batfish	5	Deep	51.0	Piscivore	100%
Scatophagidae	Scats	1	Deep	38.0	Piscivore	100%

Table A2.1 - (cont.)

			Diet algorithm			
Fish family	**Common family name**	**# spp. in RA model**	**Body morphology**	**Average length (TL; cm)**	**Main feeding mode**	**% pisc. spp.**
Siganidae	Spinefoots	12	Deep compressed	35.5	Piscivore	100%
Zanclidae	Moorish idol	1	Deep compressed	23.0	Piscivore	100%
Acanthuridae	Surgeonfish/unicornfish/tangs	33	Deep compressed	41.6	Piscivore	79%
Sphyraenidae	Barracudas	5	Elongated	136.0	Piscivore	100%
Scombridae	Tuna-like	23	Fusiform oval	140.3	Piscivore	92%
Bothidae	Flounders	2	Deep	40.5	Piscivore	100%
Soleidae	Soles	1	Deep compressed	15.0	Piscivore	100%
Balistidae	Triggerfish	14	Deep oval	41.9	Piscivore	93%
Monacanthidae	Filefishes	14	Deep	25.1	Piscivore	71%
Ostraciidae	Boxfish	3	Deep	27.0	Piscivore	67%
Tetraodontidae	Puffers	12	Deep circular	39.5	Piscivore	75%
Coryphaenidae	Dolphinfishes	2	Elongated compressed	168.5	Piscivore	100%
Dasyatidae	Stingrays	2	Flattened	25.0	Piscivore	100%
Engraulidae	Anchovies	17	Elongated compressed	16.3	Piscivore	76%
Exocoetidae	Flyingfishes	26	Elongated	26.8	Piscivore	81%
Istiophoridae	Billfishes	5	Eel-like	384.2	Piscivore	100%
Nemichthyidae	Snipe eels	2	Eel-like	102.3	Piscivore	50%
Nomeidae	Driftfishes	2	Deep	22.5	Piscivore	50%
Polynemidae	Threadfins	1	Elongated compressed	200.0	Piscivore	100%
Rhincodontidae	Whaleshark	1	Elongated	2000.0	Planktivore	0%
Salmonidae	Salmonids	1	Fusiform oval	164.5	Piscivore	100%
Stomiidae	Dragonfishes	18	Elongated compressed	22.9	Piscivore	100%
Xiphiidae	Swordfish	1	Elongated	505.8	Piscivore	100%
Acropomatidae	Lanternbellies	1	Elongated compressed	13.0	Piscivore	100%
Alepocephalidae	Fangtooths	1	Elongated	23.7	Piscivore	100%
Apistidae	Waspfishes	1	Fusiform normal	20.0	Piscivore	100%
Bregmacerotidae	Codlets	4	Elongated	9.8	Piscivore	50%
Centrolophidae	Medusafishes	1	Deep compressed	23.0	Piscivore	100%
Centrophoridae	Gulpersharks	1	Elongated	100.0	Piscivore	100%
Champsodontidae	Benttooths and gapers	1	Elongated	12.8	Piscivore	100%
Characidae	Characins	1	Deep compressed	88.0	Piscivore	100%
Chirocentridae	Wolf herring	1	Elongated compressed	117.5	Piscivore	100%
Dentatherinidae	Tusked silversides	1	No data	5.8	Piscivore	100%
Elopidae	Tenpounders	2	Elongated	107.0	Piscivore	100%
Emmelichthyidae	Rovers	1	Elongated	72.0	Planktivore	0%
Gempylidae	Snake mackerels	5	Eel-like	105.0	Piscivore	100%
Gibberichthyidae	Gibberfishes	1	Fusiform normal	12.0	Piscivore	100%
Gonostomatidae	Bristlemouths	2	Elongated	27.5	Piscivore	100%
Lactariidae	False trevallies	1	Deep compressed	40.0	Piscivore	100%
Leiognathidae	Slimys, slipmouths	2	Deep compressed	10.2	Piscivore	100%
Lophiidae	Goosefish	1	Deep	45.0	Piscivore	100%
Melamphaidae	Bigscale fishes or ridgeheads	3	Fusiform	7.6	Piscivore	67%
Melanotaeniidae	Rainbowfishes, blueeyes	6	No data	10.4	Piscivore	100%
Microstomatidae	Deep sea smelts	1	Elongated	11.6	Piscivore	100%
Molidae	Ocean sunfishes	1	Deep compressed	333.0	Piscivore	100%

Table A2.1 - (cont.)

			Diet algorithm			
Fish family	**Common family name**	**# spp. in RA model**	**Body morphology**	**Average length (TL;cm)**	**Common family name**	**# spp. in RA model**
Moridae	Morid cods	1	Elongated	0.0	Piscivore	100%
Myctophidae	Lanternfish	21	Fusiform	11.1	Piscivore	86%
Nettastomatidae	Duck-bill eels	1	Eel-like	0.0	Piscivore	100%
Oneirodidae	Dreamers	1	Deep	14.1	Piscivore	100%
Ophidiidae	Cusk-eels	1	Elongated compressed	62.8	Piscivore	100%
Osteoglossidae	Arowanas	1	Elongated	105.7	Planktivore	0%
Paralepididae	Barracudinas	1	Eel-like	25.0	Piscivore	100%
Pentacerotidae	Armorheads	1	Deep	42.0	Piscivore	100%
Peristediidae	Armored searobins / gurnards	3	Elongated	41.7	Piscivore	100%
Pristigasteridae	Pristigasterids	3	Fusiform	19.3	Piscivore	67%
Pseudomugilidae	Blue-eyes	5	Fusiform	4.4	Piscivore	80%
Scopelosauridae	Waryfishes	1	No data	16.3	Piscivore	100%
Sternoptychidae	Hatchetfishes	2	Fusiform normal	4.9	Piscivore	100%
Tetragonuridae	Squaretails	1	No data	0.0	Piscivore	100%
Trachipteridae	Ribbonfishes	1	Elongated	110.0	Piscivore	100%
Trichiuridae	Cutlassfishes	4	Eel-like compressed	111.6	Piscivore	100%
Anoplogastridae	Fangtooths	1	Deep compressed	17.7	Piscivore	100%
Champsodontidae	Benttooths and gapers	1	Elongated	12.8	Piscivore	100%

Appendix A3 - Ecopath parameters: 2006 RA model

Table A3.1 - Functional groups for 2006 Raja Ampat model.

Description	No.	Group name	Rationale
Mammals / birds / reptiles	1	Mysticetae	Conservation interest
	2	Piscivorous odontocetae	Conservation interest
	3	Deepdiving odontocetae	Conservation interest
	4	Dugongs	Conservation interest
	5	Birds	Conservation interest
	6	Reef associated turtles	Conservation interest
	7	Green turtles	Conservation interest
	8	Oceanic turtles	Conservation interest
	9	Crocodiles	Conservation interest
Highly commercial fish	10	Adult groupers	Commercial
	11	Subadult groupers	Commercial
	12	Juvenile groupers	Immature life history stanza
	13	Adult snappers	Commercial
	14	Subadult snappers	Commercial
	15	Juvenile snappers	Immature life history stanza
	16	Adult Napoleon wrasse	Commercial
	17	Subadult Napoleon wrasse	Commercial
	18	Juvenile Napoleon wrasse	Immature life history stanza
	19	Skipjack tuna	Commercial
	20	Other tuna	Commercial
	21	Mackerel	Commercial
	22	Billfish	Commercial
	23	Adult coral trout	Commercial
	24	Juvenile coral trout	Immature life history stanza
	25	Adult large sharks	Commercial/conservation interest
	26	Juvenile large sharks	Immature life history stanza
	27	Adult small sharks	Commercial/conservation interest
	28	Juvenile small sharks	Immature life history stanza
Predator fish	29	Whale shark	Conservation interest
	30	Manta ray	Conservation interest
	31	Adult rays	Conservation interest
	32	Juvenile rays	Immature life history stanza
	33	Adult butterflyfish	Keystone species
	34	Juvenile butterflyfish	Immature life history stanza
	35	Cleaner wrasse	Non-trophic functional role
	36	Adult large pelagic	Aggregate group
	37	Juvenile large pelagic	Immature life history stanza
	38	Adult medium pelagic	Aggregate group
	39	Juvenile medium pelagic	Immature life history stanza
	40	Adult small pelagic	Aggregate group
	41	Juvenile small pelagic	Immature life history stanza
	42	Adult large reef associated	Aggregate group
	43	Juvenile large reef associated	Immature life history stanza
	44	Adult medium reef associated	Aggregate group
	45	Juvenile medium reef assoc.	Immature life history stanza
	46	Adult small reef associated	Aggregate group
	47	Juvenile small reef associated	Immature life history stanza
	48	Adult large demersal	Aggregate group

Table A3.1 – (cont.)

Description	No.	Group name	Rationale
	49	Juvenile large demersal	Immature life history stanza
	50	Adult small demersal	Aggregate group
	51	Juvenile small demersal	Immature life history stanza
	52	Adult large planktivore	Aggregate group
	53	Juvenile large planktivore	Immature life history stanza
	54	Adult small planktivore	Aggregate group
	55	Juvenile small planktivore	Immature life history stanza
	56	Adult anchovy	Subsistence use
	57	Juvenile anchovy	Immature life history stanza
	58	Adult deepwater fish	Aggregate group
	59	Juvenile deepwater fish	Immature life history stanza
Herbivorous fish	60	Adult macro algal browsing	Keystone species
	61	Juvenile macro algal browsing	Immature life history stanza
	62	Adult eroding grazers	Non-trophic functional role
	63	Juvenile eroding grazers	Immature life history stanza
	64	Adult scraping grazers	Non-trophic functional role
	65	Juvenile scraping grazers	Immature life history stanza
	66	Detritivore fish	Energy cycling
Structure forming benthos	67	Azooxanthellate corals	Non-trophic role/conservation interest
	68	Hermatypic scleractinian corals	Non-trophic role/conservation interest
	69	Non reef building scleractinian corals	Conservation interest
	70	Soft corals	Non-trophic functional role
	71	Calcareous algae	Non-trophic functional role
	72	Anemones	Non-trophic functional role
Other invertebrates	73	Penaeid shrimps	Commercial
	74	Shrimps and prawns	Commercial
	75	Squid	Commercial
	76	Octopus	Commercial
	77	Sea cucumbers	Commercial
	78	Lobsters	Commercial
	79	Large crabs	Commercial
	80	Small crabs	Commercial
	81	Crown of thorns	Keystone species
	82	Giant triton	Keystone species
	83	Herbivorous echinoids	Keystone species
	84	Bivalves	Commercial
	85	Sessile filter feeders	Aggregate group
	86	Epifaunal detritivorous invertebrates	Energy cycling/aggregate group
	87	Epifaunal carnivorous invertebrates	Aggregate group
	88	Infaunal invertebrates	Aggregate group
Nekton	89	Jellyfish and hydroids	Secondary production
	90	Carnivorous zooplankton	Secondary production
	91	Large herbivorous zooplankton	Secondary production
	92	Small herbivorous zooplankton	Secondary production
Primary producers	93	Phytoplankton	Basal group
	94	Macro algae	Basal group
	95	Sea grass	Non-trophic role/basal group
	96	Mangroves	Non-trophic role/conservation interest
Detritus	97	Fishery discards	Energy cycling
	98	Detritus	Energy cycling

Table A3.2 - Basic parameters for 2006 Raja Ampat model.

		Biomass ($t\cdot km^{-2}$)	**P/B ($year^{-1}$)**	**P/B based on *n* spp.**	**Q/B ($year^{-1}$)**	**Q/B based on *n* spp.**	**EE**
1	Mysticetae	0.033	0.055	6	4.850	6	0.02
2	Pisc. odontocetae	0.052	0.035	13	6.105	13	0.02
3	Deep. odontocetae	0.091	0.020	5	3.599	5	0.02
4	Dugongs	0.054	0.025	1	11.012	1	0
5	Birds	0.366	0.381	11	63.949	11	0.02
6	Reef assoc. turtles	0.043	0.143		3.500		0.06
7	Green turtles	0.082	0.053		3.500		0.27
8	Oceanic turtles	0.087	0.050		3.500		0.27
9	Crocodiles	0.001	0.408		6.500		0.46
10	Ad. groupers	0.184	0.225	10	9.086	41	0.95
11	Sub. groupers	0.057	0.400	-	13.110	-	0.72
12	Juv. groupers	0.016	1.200	-	26.675	-	0.85
13	Ad. snappers	0.081	0.400	18	7.105	29	0.82
14	Sub. snappers	0.042	1.100	-	11.085	-	0.91
15	Juv. snappers	0.030	1.447	-	21.377	-	0.86
16	Ad. Napoleon wrasse	0.011	0.500	1	8.900		0.96
17	Sub. Napoleon wrasse	0.020	0.500	-	12.845		0.86
18	Juv. Napoleon wrasse	0.004	1.200	-	29.599		0.89
19	Skipjack tuna	0.693	2.000	1	6.644	1	0.42
20	Other tuna	0.541	1.408	8	4.693	9	0.4
21	Mackerel	0.086	2.913	9	9.712	10	0.84
22	Billfish	0.825	0.956	4	3.187	5	0.2
23	Ad. coral trout	0.033	0.350	2	3.303	6	0.64
24	Juv. coral trout	0.007	0.700	-	7.476	-	0.40
25	Ad. large sharks	0.061	1.100	2	3.600	5	0.5
26	Juv. large sharks	0.053	1.300	-	6.451	-	0.45
27	Ad. small sharks	0.041	1.200	1	4.000	3	0.20
28	Juv. small sharks	0.017	2.432	-	7.321	-	0.93
29	Whale shark	0.003	0.068		0.228	1	0.02
30	Manta ray	0.003	0.600		2.000		0.02
31	Adult rays	0.177	0.960		2.416	5	0.96
32	Juv. rays	0.068	1.200		5.227	-	0.90
33	Ad. butterflyfish	0.243	1.004	2	6.720	49	0.78
34	Juv. butterflyfish	0.081	1.600	-	10.906	-	0.85
35	Cleaner wrasse	0.009	3.779		13.097		0.76
36	Ad. large pelagic	0.054	0.800	9	2.667	12	0.96
37	Juv. large pelagic	0.032	1.079	-	4.544	-	0.99
38	Ad. medium pelagic	0.011	1.000		5.000	5	0.93
39	Juv. medium pelagic	0.017	1.500		7.860	-	0.83
40	Ad. small pelagic	0.071	2.000	11	13.266	8	0.61
41	Juv. small pelagic	0.108	3.980	-	25.284	-	0.43
42	Ad. large reef assoc.	7.128	0.400	45	4.000	147	0.77
43	Juv. large reef assoc.	4.512	0.600	-	5.696	-	0.88
44	Ad. medium reef assoc.	2.853	0.800	10	5.000	88	0.95
45	Juv. medium reef assoc.	2.355	1.400	-	8.114	-	0.87
46	Ad. small reef assoc.	0.259	3.000	4	15.000	77	0.86
47	Juv. small reef assoc.	0.135	4.000	-	30.345	-	0.96
48	Ad. large demersal	0.127	0.600	2	3.100	4	0.60
49	Juv. large demersal	0.135	0.920	-	5.140	-	0.94
50	Ad. small demersal	0.192	2.000		8.600	1	0.968

Table A3.2 – (cont.)

		Biomass ($t \cdot km^{-2}$)	**P/B ($year^{-1}$)**	**P/B based on *n* spp.**	**Q/B ($year^{-1}$)**	**Q/B based on *n* spp.**	**EE**
51	Juv. small demersal	0.135	2.568		15.718	-	0.95
52	Ad. large planktivore	1.000	1.500	17	4.500	38	0.69
53	Juv. large planktivore	0.887	2.000	-	7.511	-	0.92
54	Ad. small planktivore	0.414	2.000	6	6.000	54	0.40
55	Juv. small planktivore	0.614	2.000	-	7.373	-	0.78
56	Ad. anchovy	1.500	3.370	8	14.625	9	0.58
57	Juv. anchovy	2.237	3.370	-	26.706	-	0.21
58	Ad. deepwater fish	0.600	1.100	6	3.667	17	0.86
59	Juv. deepwater fish	0.794	1.000	-	5.316	-	0.96
60	Ad. macro algal browsing	0.250	1.339	2	13.760	3	0.33
61	Juv. macro algal browsing	0.500	1.400	-	18.888	-	0.40
62	Ad. eroding grazers	0.526	0.435	1	1.451	1	0.83
63	Juv. eroding grazers	0.256	1.000	-	2.200	-	0.89
64	Ad. scraping grazers	0.348	2.339	18	12.740	50	0.64
65	Juv. scraping grazers	1.656	3.000		22.729	-	0.37
66	Detritivore fish	0.016	2.339		8.333	4	0.92
67	Azooxanthellate corals	0.600	1.440		3.600		0.94
68	Hermatypic corals	0.875	2.160		3.600		0.97
69	Non reef building corals	0.600	1.398		2.330		0.96
70	Soft corals	0.600	0.917		1.913		0.89
71	Calcareous algae	0.100	0.475		-		0.95
72	Anemonies	0.500	0.050		0.069		0.97
73	Penaeid shrimps	2.000	3.824	4	37.900		0.76
74	Shrimps and prawns	2.000	2.228	3	20.000		0.91
75	Squid	0.237	4.348	7	14.792	3	0.95
76	Octopus	1.000	2.327	1	13.240	6	0.86
77	Sea cucumbers	0.971	0.740	2	8.248	20	0.98
78	Lobsters	0.219	0.446	4	15.207		0.99
79	Large crabs	0.286	0.953	3	14.558		0.95
80	Small crabs	0.286	2.610	10	20.208		0.90
81	Crown of thorns	0.219	0.920	1	9.423		0.96
82	Giant triton	0.050	1.224		4.080		0.93
83	Herbivorous echinoids	0.722	0.541	21	9.423	2	0.94
84	Bivalves	9.189	2.514	31	5.617		0.95
85	Sessile filter feeders	4.580	1.480		5.268		0.98
86	Epifaunal det. inverts.	1.400	1.178	29	18.250		0.99
87	Epifaunal carn. inverts	5.600	2.640	1	10.521		0.97
88	Infaunal inverts.	27.422	4.014		19.267		0.89
89	Jellyfish and hydroids	0.100	10.230		26.462	1	0.91
90	Carn. zooplankton	1.000	63.875		195.815		0.95
91	Large herb. zooplankton	0.560	31.000	2	256.773	2	0.99
92	Small herb. zooplankton	2.430	91.250	4 sites	265.810		0.95
93	Phytoplankton	26.100	109.119		-		0.32
94	Macro algae	39.389	10.225	8 sites	-		0.38
95	Sea grass	20.157	13.758	1	-		0.82
96	Mangroves	19.136	0.066	1	-		0.02
97	Fishery discards	20.000	-		-		1.00
98	Detritus	100.000	-		-		0.14

Table A3.3 - Multi-stanza life history information for 2006 Raja Ampat model

Total mortality (Z); consumption over biomass (Q/B); von Bertalanffy growth constant (K); weight at maturity (WMAT); weight at infinity (W∞).

Group	Age, start (months)	Biomass (t·km^{-2})	Z (yr^{-1})	Q/B (yr^{-1})	Growth constant (K)	K based on *n* spp.	$W_{MAT}/W_?$	$W_{MAT}/W_?$ based on *n* spp.
Juv. groupers	0	0.016	1.2	26.675	0.32	5	0.12	16
Sub. groupers	24	0.057	0.4	13.110	-	-	-	-
Ad. groupers	56	0.184	0.225	9.086	-	-	-	-
Juv. snappers	0	0.030	1.447	21.377	0.29	10	0.27	22
Sub. snappers	24	0.042	1.1	11.085	-	-	-	-
Ad. snappers	48	0.081	0.4	7.105	-	-	-	-
Juv. Napoleon wrasse	0	0.004	1.2	29.599	0.25	1	0.09	1
Sub. Napoleon wrasse	24	0.020	0.5	12.845	-	-	-	-
Ad. Napoleon wrasse	72	0.011	0.5	8.9	-	-	-	-
Juv. coral trout	0	0.007	0.7	7.476	0.17	1	0.10	2
Ad. coral trout	48	0.033	0.35	3.303	-	-	-	-
Juv. large sharks	0	0.053	1.3	6.451	0.51	2	0.38	7
Ad. large sharks	24	0.061	1.1	3.6	-	-	-	-
Juv. small sharks	0	0.017	2.432	7.321	1.18	1	0.38	2
Ad. small sharks	12	0.041	1.2	4	-	-	-	-
Juv. rays	0	0.068	1.2	5.227	0.25	0	0.44	2
Ad. rays	24	0.177	0.96	2.416	-	-	-	-
Juv. butterflyfish	0	0.081	1.6	10.906	1.50	1	0.42	2
Ad. butterflyfish	12	0.243	1.004	6.72	-	-	-	-
Juv. large pelagic	0	0.032	1.079	4.544	0.62	5	0.08	7
Ad. large pelagic	24	0.054	0.8	2.667	-	-	-	-
Juv. medium pelagic	0	0.017	1.5	7.860	0.93	0	0.18	0
Ad. medium pelagic	24	0.011	1	5	-	-	-	-
Juv. small pelagic	0	0.108	3.980	25.284	1.24	5	0.28	6
Ad. small pelagic	12	0.071	2	13.266	-	-	-	-
Juv. large reef assoc.	0	4.512	0.6	5.696	0.58	16	0.13	42
Ad. large reef assoc.	48	7.128	0.4	4	-	-	-	-
Juv. medium reef assoc.	0	2.355	1.4	8.114	0.83	5	0.13	14
Ad. medium reef assoc.	24	2.853	0.8	5	-	-	-	-
Juv. small reef assoc.	0	0.135	4	30.345	1.08	1	0.09	6
Ad. small reef assoc.	8	0.259	3	15	-	-	-	-
Juv. large demersal	0	0.135	0.92	5.140	0.50	1	0.12	2
Ad. large demersal	36	0.127	0.6	3.1	-	-	-	-
Juv. small demersal	0	0.135	2.568	15.718	1	0	0.09	0
Ad. small demersal	12	0.192	2	8.6	-	-	-	-
Juv. large planktivore	0	0.887	2	7.511	1.11	8	0.22	13
Ad. large planktivore	15	1.000	1.5	4.5	-	-	-	-
Juv. small planktivore	0	0.614	2	7.373	4.56	2	0.16	5
Ad. small planktivore	10	0.414	2	6	-	-	-	-
Juv. anchovy	0	2.237	3.37	26.706	0.94	2	0.25	2
Ad. anchovy	12	1.500	3.37	14.625	-	-	-	-
Juv. deepwater fish	0	0.794	1	5.316	1	3	0.17	11
Ad. deepwater fish	24	0.600	1.1	3.667	-	-	-	-
Juv. macro algal browsing	0	0.500	1.4	18.888	1.59	1	0.02	1
Ad. macro algal browsing	20	0.250	1.339	13.76	-	-	-	-
Juv. eroding grazers	0	0.256	1	2.200	1	0	0.21	0
Ad. eroding grazers	24	0.526	0.435	1.451	-	-	-	-
Juv. scraping grazers	0	1.656	3	22.729	1.03	6	0.21	6
Ad. scraping grazers	18	0.348	2.339	12.740	-	-	-	-

Table A3.4 - Ecopath landings (t·km^{-2}) matrix for 2006 Raja Ampat model including targeted catch and bycatch sold at port. EwE Fisheries on x axis.

Group Name	**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**	**Set line**	**Lift net**	**Foreign fleet**	**Shrimp trawl**	**Total**
Ad. groupers	9.6E-04				1.9E-03		1.9E-03	4.8E-03	4.8E-03	9.6E-04				1.9E-03				0.017
Sub. groupers	4.9E-04				9.7E-04		9.7E-04	2.4E-03	2.4E-03	4.9E-04				9.7E-04				8.7E-03
Juv. groupers	3.2E-04				6.5E-04					3.2E-04				6.5E-04				1.9E-03
Ad. snappers	1.7E-03		3.5E-03		3.5E-03		3.5E-03			1.7E-03								0.014
Sub. snappers	1.7E-03		3.5E-03		3.5E-03		3.5E-03			1.7E-03								0.014
Juv. snappers	3.8E-04		7.7E-04		7.7E-04		7.7E-04			3.8E-04								3.1E-03
Ad. Nap. wrasse								4.2E-04	4.2E-04	8.5E-05								9.3E-04
Sub. Nap. wrasse								4.2E-04	4.2E-04	8.5E-05								9.3E-04
Juv. Nap. wrasse										2.1E-04								2.1E-04
Skipjack tuna											0.102	0.026	0.131	0.043		0.046		0.348
Other tuna											0.012	6.1E-03	0.014	7.4E-03		7.6E-03		0.047
Mackerel											0.021	5.5E-03	0.028			9.7E-03		0.064
Billfish											0.050							0.050
Ad. coral trout	3.1E-04		3.1E-04	3.1E-04	3.1E-04	3.1E-04				8.2E-05								1.6E-03
Juv. coral trout	3.1E-05		3.1E-05	3.1E-05	3.1E-05	3.1E-05				8.2E-06								1.6E-04
Ad. large sharks														0.025				0.025
Juv. large sharks														2.8E-03				2.8E-03
Ad. small sharks														5.6E-03				5.6E-03
Juv. small sharks														6.2E-04				6.2E-04
Adult rays			4.8E-03	4.8E-03	4.8E-03	4.8E-03												0.019
Juv. rays			4.8E-04	4.8E-04	4.8E-04	4.8E-04												1.9E-03
Ad. butterflyfish	3.0E-03		3.0E-03	3.0E-03	3.0E-03	3.0E-03				7.8E-04								0.016
Juv. butterflyfish	3.0E-04		3.0E-04	3.0E-04	3.0E-04	3.0E-04				7.8E-05								1.6E-03
Cleaner wrasse			1.9E-04	1.9E-04	1.9E-04	1.9E-04				5.1E-05								8.2E-04
Ad. large pelagic			7.8E-03	6.2E-03	4.7E-03	4.7E-03									7.8E-03			0.031

Table A3.4 - (cont.)

Group Name	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	Set line	Lift net	Foreign fleet	Shrimp trawl	Total
Juv. large pelagic			1.0E-03	8.3E-04	6.2E-04	6.2E-04									1.0E-03			4.1E-03
Ad. medium pelagic			1.7E-03	1.4E-03	1.0E-03	1.0E-03									1.7E-03			6.9E-03
Juv. medium pelagic			7.7E-04	6.1E-04	4.6E-04	4.6E-04									7.7E-04			3.1E-03
Ad. small pelagic			6.8E-03	6.8E-03	5.1E-03	5.1E-03				1.7E-03					8.5E-03			0.034
Juv. small pelagic			7.5E-04	7.5E-04	5.6E-04	5.6E-04				1.9E-04					9.4E-04			3.8E-03
Ad. large reef assoc.	0.110		0.110	0.110	0.110	0.110				0.029								0.577
Juv. large reef assoc.	0.021		0.021	0.021	0.021	0.021				5.6E-03								0.112
Ad. medium reef assoc.	0.067		0.067	0.067	0.067	0.067				0.018								0.350
Juv. medium reef assoc.	6.7E-03		6.7E-03	6.7E-03	6.7E-03	6.7E-03				1.8E-03								0.035
Ad. small reef assoc.	0.029		0.029	0.029	0.029	0.029				7.5E-03								0.150
Juv. small reef assoc.	2.9E-03		2.9E-03	2.9E-03	2.9E-03	2.9E-03				7.5E-04								0.015
Ad. large demersal	7.3E-03				7.3E-03	7.3E-03				1.9E-03								0.024
Juv. large demersal	1.5E-03				1.5E-03	1.5E-03				3.8E-04								4.8E-03
Ad. small demersal	8.7E-03				8.7E-03	8.7E-03				2.3E-03								0.028
Juv. small demersal	9.7E-04				9.7E-04	9.7E-04				2.6E-04								3.2E-03
Ad. large planktivore	0.057		0.057	0.057	0.057	0.057				0.015								0.300
Juv. large planktivore	5.7E-03		5.7E-03	5.7E-03	5.7E-03	5.7E-03				1.5E-03								0.030
Ad. small planktivore	2.4E-03		2.4E-03	2.4E-03	2.4E-03	2.4E-03				6.4E-04								0.013
Juv. small planktivore	2.7E-04		2.7E-04	2.7E-04	2.7E-04	2.7E-04				7.1E-05								1.4E-03
Ad. anchovy			0.114	0.091	0.069	0.069									0.166			0.509
Juv. anchovy			0.013	0.010	7.6E-03	7.6E-03									0.013			0.051

Table A3.4 - (cont.)

Group Name	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	Set line	Lift net	Foreign fleet	Shrimp trawl	Total
Juv. anchovy			0.013	0.010	7.6E-03	7.6E-03									0.013			0.051
Ad. deepwater fish			2.1E-03	2.1E-03	2.1E-03	2.1E-03												8.3E-03
Juv. deepwater fish			2.3E-04	2.3E-04	2.3E-04	2.3E-04												9.2E-04
Ad. macro algal brows			2.0E-04	2.0E-04	2.0E-04	2.0E-04				2.6E-05								8.2E-04
Juv. macro algal brows			1.9E-05	1.9E-05	1.9E-05	1.9E-05				5.1E-06								8.2E-05
Ad. eroding grazers			6.6E-05	6.6E-05	6.6E-05	6.6E-05				8.7E-06								2.7E-04
Juv. eroding grazers			6.4E-06	6.4E-06	6.4E-06	6.4E-06				1.7E-06								2.7E-05
Ad. scraping grazers			5.4E-03	5.4E-03	5.4E-03	5.4E-03				7.1E-04								0.022
Juv. scraping grazers			5.3E-04	5.3E-04	5.3E-04	5.3E-04				1.4E-04								2.2E-03
Detritivore fish			4.6E-04	4.6E-04	4.6E-04	4.6E-04				6.1E-05								1.9E-03
Hermatypic corals										1.0E-03								1.0E-03
Penaeid shrimps																	0.145	0.145
Shrimps and prawns																	0.017	0.017
Squid															6.3E-03			6.3E-03
Octopus	2.3E-06	7.4E-06					2.5E-06			1.2E-07								1.2E-05
Sea cucumbers	1.2E-03	3.9E-03					1.3E-03			6.5E-05								6.5E-03
Lobsters		0.033					0.011			5.5E-04								0.044
Large crabs		2.0E-03					6.8E-04			3.4E-05								2.8E-03
Small crabs		2.0E-03					6.8E-04			3.4E-05								2.8E-03
Giant triton		2.6E-03					8.5E-04			4.3E-05								3.5E-03
Herbivorous echinoids		2.0E-03					6.8E-04			3.4E-05								2.8E-03
Bivalves		5.9E-03																5.9E-03
Sessile filter feeders		1.0E-03																1.0E-03
Epifaunal det. inverts.		2.3E-03					7.6E-04			3.8E-05								3.1E-03
Epifaunal carn. inverts		2.7E-03					8.9E-04			4.4E-05								3.6E-03
Sum	0.330	0.057	0.472	0.437	0.437	0.426	0.027	8.1E-03	8.1E-03	0.096	0.185	0.038	0.173	0.088	0.206	0.063	0.162	3.213

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Table A3.5 - Ecopath price matrix for the 2006 Raja Ampat model.
Source: DKP and Trade and Industry Office. Values are in thousands of Rupiah per kg.

	EwE Fisheries																
Group Name	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	Set line	Lift net	Foreign fleet	Shrimp trawl
Ad. groupers	2.89				18.57		18.57	68.40	68.40	18.57				18.57			
Sub. groupers	2.89				2.89		2.89	68.40	68.40	2.89				2.89			
Juv. groupers	2.89				2.89					2.89				2.89			
Ad. snappers	2.25		2.25		31.13		31.13			31.13							
Sub. snappers	2.25		2.25		31.13		31.13			31.13							
Juv. snappers	2.25		2.25		2.25		2.25			2.25							
Ad. Napoleon wrasse								21.46	21.46	12.17							
Sub. Napoleon wrasse								21.46	21.46	12.17							
Juv. Napoleon wrasse								21.46	21.46	2.89							
Skipjack tuna											3.33	3.33	3.33	3.33			
Other tuna											0.90	0.90	0.90	0.90			
Mackerel											3.16	3.16	3.16				
Billfish											10.17						
Ad. coral trout	2.90		2.90	2.90	3.47	3.47				3.47							
Juv. coral trout	2.90		2.90	2.90	2.90	2.90				2.90							
Ad. large sharks														4.44			
Juv. large sharks														2.51			
Ad. small sharks														3.28			
Juv. small sharks														3.28			
Adult rays			3.28	3.28	4.93	4.93											
Ad. butterflyfish	2.90		2.90	2.90	3.47	3.47				3.47							
Juv. butterflyfish	2.90		2.90	2.90	2.90	2.90				2.90							
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.	2.90		2.90	2.90	2.95	2.95				2.95							
Juv. large reef assoc.	2.90		2.90	2.90	2.90	2.90				2.90							
Ad. medium reef assoc.	2.90		2.90	2.90	3.17	3.17				3.17							
Juv. medium reef assoc.	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							
Juv. small reef assoc.	2.90		2.90	2.90	2.90	2.90				2.90							
Ad. large demersal	2.90				3.04	3.04				3.04							
Juv. large demersal	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	2.90		2.90	2.90	2.90	2.90				2.90							
Juv. large planktivore	2.90		2.90	2.90	2.90	2.90				2.90							
Ad. small planktivore	2.90		2.90	2.90	2.90	2.90				2.90							
Juv. small planktivore	2.90		2.90	2.90	2.90	2.90				2.90							
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. macro algal browsing			2.90	2.90	3.47	3.47											
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			2.90	2.90	3.47	3.47											
Penaeid shrimps																	32.76
Shrimps and prawns																	7.16
Squid															25.72		
Octopus	6.50	6.50					67.99			67.99							
Sea cucumbers	30.42	30.42					65.85			65.85							
Lobsters		18.95					20.35			20.35							
Large crabs		4.05					4.05			4.05							
Small crabs		4.05					4.05			4.05							
Giant triton		5.00															
Herbivorous echinoids		6.08					6.08			6.08							
Bivalves		5.75															
Sessile filter feeders		1.15															
Epifaunal det. inverts.		1.15					1.15			1.15							
Epifaunal carn. inverts		1.15					1.15			1.15							

Table A3.6 - RA model trophic linkages: diet composition and flow parameters. Diet column shows the percentage of each prey in the diet of the predator (2000 RA model); vulnerabilities refer to the fitted 1990 matrix, which was extended to the 2000 model.

Predator	Prey	Diet %	Vulnerability
Mysticetae	Juv. medium pelagic	1.65	2.00
	Juv. small pelagic	4.53	2.00
	Squid	13.40	2.00
	Carn. zooplankton	20.00	2.00
	Large herb. zooplankton	40.21	2.00
	Small herb. zooplankton	20.21	2.00
Pisc. odontocetae	Skipjack tuna	2.38	2.00
	Ad. large pelagic	0.70	2.00
	Juv. large pelagic	1.50	2.00
	Ad. medium pelagic	0.10	2.00
	Juv. medium pelagic	1.00	2.00
	Ad. small pelagic	2.00	2.00
	Juv. small pelagic	20.00	2.00
	Ad. large demersal	0.50	2.00
	Ad. small demersal	10.00	2.00
	Juv. large planktivore	23.37	2.00
	Juv. small planktivore	14.77	2.00
	Ad. deepwater fish	10.00	2.00
	Squid	13.68	2.00
Deep. odontocetae	Ad. large pelagic	0.50	2.00
	Juv. large pelagic	0.50	2.00
	Juv. large demersal	3.00	2.00
	Juv. deepwater fish	9.70	2.00
	Squid	25.58	2.00
	Octopus	9.70	2.00
	Epifaunal det. inverts.	15.24	2.00
	Epifaunal carn. inverts	29.09	2.00
Dugongs	Sea grass	100.00	2.00
Birds	Mackerel	0.27	2.00
	Juv. small pelagic	1.42	2.00
	Juv. small planktivore	5.40	2.00
	Juv. anchovy	45.00	2.00
	Sessile filter feeders	5.65	2.00
	Epifaunal det. inverts.	4.64	2.00
	Epifaunal carn. inverts	13.31	2.00
	Fishery discards	4.00	2.00
Reef assoc. turtles	Penaeid shrimps	4.43	2.00
	Shrimps and prawns	4.43	2.00
	Sea cucumbers	11.08	2.00
	Large crabs	0.23	2.00
	Small crabs	0.23	2.00
	Herbivorous echinoids	3.50	2.00
	Sessile filter feeders	60.58	2.00
	Epifaunal det. inverts.	4.43	2.00
	Epifaunal carn. inverts	5.54	2.00
	Infaunal inverts.	5.54	2.00
Green turtles	Jellyfish and hydroids	8.00	2.00
	Carn. zooplankton	1.02	2.00
	Large herb. zooplankton	1.02	2.00
	Macro algae	38.84	2.00
	Sea grass	51.11	2.00
Oceanic turtles	Sea cucumbers	13.07	2.00
	Large crabs	0.62	2.00
	Small crabs	0.68	2.00
	Sessile filter feeders	26.14	2.00
	Epifaunal det. inverts.	13.07	2.00
	Epifaunal carn. inverts	13.07	2.00
	Infaunal inverts.	13.07	2.00
	Jellyfish and hydroids	20.29	2.00
Crocodiles	Birds	6.06	2.00
	Reef assoc. turtles	1.21	2.00
	Green turtles	1.21	2.00
	Oceanic turtles	1.21	2.00
	Juv. large pelagic	5.49	2.00
	Juv. small pelagic	12.11	2.00
	Juv. large planktivore	12.11	2.00
	Juv. small planktivore	12.11	2.00
	Penaeid shrimps	12.11	2.00
	Lobsters	8.02	2.00
	Large crabs	3.35	2.00
Ad. groupers	Ad. groupers	0.18	7.62
	Sub. groupers	0.01	7.62
	Juv. groupers	0.10	7.62
	Ad. snappers	0.01	7.62
	Sub. snappers	0.05	7.62
	Ad. butterflyfish	2.00	7.62
	Juv. butterflyfish	0.30	7.62
	Cleaner wrasse	0.20	7.62
	Ad. large reef assoc.	9.88	7.62
	Juv. large reef assoc.	11.90	7.62
	Ad. medium reef assoc.	10.52	7.62
	Juv. medium reef assoc.	8.08	2.00
	Ad. small reef assoc.	1.42	7.62
	Ad. large demersal	0.04	7.62
	Ad. small demersal	0.54	7.62
	Ad. large planktivore	3.00	7.62
	Ad. small planktivore	2.39	7.62
	Ad. anchovy	0.58	7.62
	Juv. anchovy	2.90	7.62
	Ad. deepwater fish	2.90	7.62
	Juv. deepwater fish	2.90	7.62
	Ad. macro algal browsing	0.11	7.62
	Ad. eroding grazers	0.08	7.62
	Ad. scraping grazers	7.92	7.62
	Detritivore fish	0.28	7.62
	Penaeid shrimps	5.62	7.62
	Shrimps and prawns	4.55	7.62
	Squid	0.14	7.62
	Octopus	0.14	7.62
	Lobsters	0.28	7.62
	Large crabs	0.27	7.62
	Small crabs	1.15	7.62
	Giant triton	0.80	7.62
	Bivalves	0.14	7.62
	Epifaunal det. inverts.	3.80	7.62
	Epifaunal carn. inverts	4.53	7.62
	Infaunal inverts.	3.96	7.62
	Carn. zooplankton	6.33	7.62
Sub. groupers	Ad. groupers	0.11	5.2E+21
	Sub. groupers	0.05	5.2E+21
	Juv. groupers	0.20	5.2E+21
	Ad. snappers	0.01	5.2E+21
	Sub. snappers	0.10	5.2E+21
	Ad. butterflyfish	2.00	5.2E+21
	Juv. butterflyfish	0.20	5.2E+21
	Cleaner wrasse	0.24	5.2E+21
	Ad. large reef assoc.	3.50	1.01
	Juv. large reef assoc.	11.53	5.2E+21
	Ad. medium reef assoc.	7.22	5.2E+21
	Juv. medium reef assoc.	17.90	2.00
	Ad. small reef assoc.	0.63	5.2E+21
	Juv. small reef assoc.	5.00	5.2E+21
	Ad. large demersal	0.02	5.2E+21
	Ad. small demersal	1.32	5.2E+21
	Ad. large planktivore	3.30	5.2E+21
	Ad. small planktivore	1.16	5.2E+21
	Ad. anchovy	1.32	5.2E+21
	Juv. anchovy	5.30	5.2E+21
	Ad. deepwater fish	2.90	5.2E+21
	Juv. deepwater fish	3.29	5.2E+21
	Ad. macro algal browsing	0.09	5.2E+21
	Ad. eroding grazers	0.02	5.2E+21
	Ad. scraping grazers	4.84	5.2E+21
	Detritivore fish	0.13	5.2E+21
	Penaeid shrimps	6.40	5.2E+21
	Shrimps and prawns	2.52	5.2E+21
	Squid	0.17	5.2E+21
	Octopus	0.17	5.2E+21
	Lobsters	0.11	5.2E+21
	Large crabs	0.12	5.2E+21

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Small crabs	0.38	5.2E+21
	Giant triton	0.33	5.2E+21
	Bivalves	0.67	5.2E+21
	Epifaunal det. inverts.	3.17	5.2E+21
	Epifaunal carn. inverts	6.51	5.2E+21
	Infaunal inverts.	2.07	5.2E+21
	Carn. zooplankton	5.00	5.2E+21
Juv. groupers	Ad. groupers	0.03	1.00
	Sub. groupers	0.10	1.00
	Juv. groupers	0.10	1.00
	Ad. snappers	0.05	1.00
	Sub. snappers	0.10	1.00
	Ad. butterflyfish	1.80	1.00
	Juv. butterflyfish	0.10	1.00
	Cleaner wrasse	0.42	1.00
	Ad. large reef assoc.	3.45	1.00
	Juv. large reef assoc.	10.62	1.00
	Ad. medium reef assoc.	2.10	1.00
	Juv. medium reef assoc.	8.56	1.00
	Ad. small reef assoc.	1.05	1.00
	Juv. small reef assoc.	10.00	1.00
	Ad. large demersal	0.02	1.00
	Ad. small demersal	1.85	1.00
	Ad. large planktivore	4.25	1.00
	Ad. small planktivore	0.86	1.00
	Ad. anchovy	2.12	1.00
	Juv. anchovy	10.35	1.00
	Ad. deepwater fish	1.33	1.00
	Juv. deepwater fish	6.37	1.00
	Ad. macro algal browsing	0.02	1.00
	Ad. scraping grazers	4.47	1.00
	Detritivore fish	0.13	1.00
	Penaeid shrimps	1.06	1.00
	Shrimps and prawns	1.33	1.00
	Squid	4.70	1.00
	Lobsters	0.10	1.00
	Large crabs	0.10	1.00
	Small crabs	2.34	1.00
	Giant triton	0.26	1.00
	Epifaunal det. inverts.	4.01	1.00
	Epifaunal carn. inverts	5.55	1.00
	Infaunal inverts.	5.30	1.00
	Carn. zooplankton	5.00	2.00
Ad. snappers	Ad. groupers	0.24	2.03
	Sub. groupers	0.05	2.03
	Juv. groupers	0.10	2.03
	Ad. snappers	0.50	2.03
	Sub. snappers	0.20	2.03
	Juv. snappers	0.07	2.03
	Juv. Napoleon wrasse	0.05	2.03
	Skipjack tuna	0.05	2.03
	Other tuna	0.27	2.03
	Mackerel	0.41	2.03
	Billfish	0.09	2.03
	Juv. coral trout	0.05	2.03
	Juv. rays	0.09	2.03
	Ad. butterflyfish	2.88	2.03
	Juv. butterflyfish	1.00	2.03
	Cleaner wrasse	0.20	2.03
	Ad. large pelagic	0.02	2.03
	Juv. large pelagic	0.16	2.03
	Ad. medium pelagic	0.05	2.03
	Ad. small pelagic	0.57	2.03
	Ad. large reef assoc.	7.68	2.03
	Juv. large reef assoc.	8.31	2.03
	Ad. medium reef assoc.	2.43	2.03
	Juv. medium reef assoc.	1.72	2.03
	Ad. small reef assoc.	2.08	2.03
	Juv. small reef assoc.	0.07	2.03
	Ad. large demersal	0.09	2.03
	Juv. large demersal	0.07	2.03
	Ad. small demersal	0.55	2.03
	Juv. small demersal	0.07	2.03
	Ad. large planktivore	3.42	2.03
	Juv. large planktivore	0.07	2.03
	Ad. small planktivore	3.75	2.03
	Juv. small planktivore	0.11	2.03
	Ad. anchovy	0.82	2.03
	Juv. anchovy	3.43	2.03
	Ad. deepwater fish	3.56	2.03
	Juv. deepwater fish	3.56	2.03
	Ad. macro algal browsing	0.05	2.03
	Juv. macro algal browsing	0.05	2.03
	Ad. eroding grazers	0.02	2.03
	Juv. eroding grazers	0.01	2.03
	Ad. scraping grazers	6.17	2.03
	Juv. scraping grazers	0.07	2.03
	Detritivore fish	0.46	2.03
	Penaeid shrimps	2.60	2.03
	Shrimps and prawns	2.60	2.03
	Squid	5.08	2.03
	Octopus	0.12	2.03
	Sea cucumbers	0.05	2.03
	Lobsters	0.30	2.03
	Large crabs	0.39	2.03
	Small crabs	9.97	2.03
	Crown of thorns	0.04	2.03
	Giant triton	1.08	2.03
	Herbivorous echinoids	0.05	2.03
	Bivalves	1.56	2.03
	Sessile filter feeders	7.96	2.03
	Epifaunal det. inverts.	2.77	2.03
	Epifaunal carn. inverts	3.25	2.03
	Infaunal inverts.	2.74	2.03
	Jellyfish and hydroids	0.27	2.03
	Carn. zooplankton	2.22	2.03
	Large herb. zooplankton	0.58	2.03
	Small herb. zooplankton	0.55	2.03
Sub. snappers	Ad. groupers	0.02	3.4E+09
	Sub. groupers	0.10	3.4E+09
	Ad. snappers	0.10	3.4E+09
	Sub. snappers	0.50	3.4E+09
	Juv. snappers	0.09	3.4E+09
	Juv. Napoleon wrasse	0.07	3.4E+09
	Other tuna	0.04	3.4E+09
	Mackerel	0.17	3.4E+09
	Juv. coral trout	0.02	3.4E+09
	Juv. rays	0.16	3.4E+09
	Ad. butterflyfish	1.34	3.4E+09
	Juv. butterflyfish	0.40	3.4E+09
	Cleaner wrasse	0.09	3.4E+09
	Ad. large pelagic	< 0.01	3.4E+09
	Juv. large pelagic	0.01	3.4E+09
	Ad. medium pelagic	0.10	3.4E+09
	Ad. small pelagic	1.09	3.4E+09
	Ad. large reef assoc.	4.53	3.4E+09
	Juv. large reef assoc.	4.27	3.4E+09
	Ad. medium reef assoc.	< 0.01	3.4E+09
	Juv. medium reef assoc.	0.96	3.4E+09
	Ad. small reef assoc.	1.61	3.4E+09
	Juv. small reef assoc.	15.63	3.4E+09
	Ad. large demersal	0.03	3.4E+09
	Juv. large demersal	0.09	3.4E+09
	Ad. small demersal	1.17	3.4E+09
	Juv. small demersal	0.09	3.4E+09
	Ad. large planktivore	3.52	3.4E+09
	Juv. large planktivore	0.09	3.4E+09
	Ad. small planktivore	1.98	3.4E+09
	Juv. small planktivore	0.94	3.4E+09
	Ad. anchovy	1.00	3.4E+09

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Juv. anchovy	1.00	3.4E+09
	Ad. deepwater fish	3.19	3.4E+09
	Juv. deepwater fish	3.19	3.4E+09
	Ad. macro algal browsing	0.02	3.4E+09
	Juv. macro algal browsing	0.05	3.4E+09
	Ad. eroding grazers	< 0.01	3.4E+09
	Juv. eroding grazers	0.02	3.4E+09
	Ad. scraping grazers	4.34	3.4E+09
	Juv. scraping grazers	0.09	3.4E+09
	Detritivore fish	0.25	3.4E+09
	Penaeid shrimps	7.19	3.4E+09
	Shrimps and prawns	3.19	3.4E+09
	Squid	6.22	3.4E+09
	Octopus	0.14	3.4E+09
	Sea cucumbers	0.07	3.4E+09
	Lobsters	0.21	3.4E+09
	Large crabs	0.18	3.4E+09
	Small crabs	0.55	3.4E+09
	Crown of thorns	0.05	3.4E+09
	Giant triton	0.52	3.4E+09
	Herbivorous echinoids	0.04	3.4E+09
	Bivalves	1.84	3.4E+09
	Sessile filter feeders	9.73	3.4E+09
	Epifaunal det. inverts.	3.02	3.4E+09
	Epifaunal carn. inverts	6.81	3.4E+09
	Infaunal inverts.	3.35	3.4E+09
	Jellyfish and hydroids	0.34	3.4E+09
	Carn. zooplankton	2.72	3.4E+09
	Large herb. zooplankton	0.67	3.4E+09
	Small herb. zooplankton	0.67	3.4E+09
Juv. snappers	Ad. groupers	0.02	1.00
	Sub. groupers	0.05	1.00
	Ad. snappers	0.05	1.00
	Sub. snappers	0.42	1.00
	Ad. butterflyfish	1.23	1.00
	Juv. butterflyfish	0.30	1.00
	Cleaner wrasse	0.07	1.00
	Ad. large reef assoc.	3.54	1.00
	Juv. large reef assoc.	3.54	1.00
	Ad. medium reef assoc.	0.10	1.00
	Juv. medium reef assoc.	0.50	2.00
	Ad. small reef assoc.	0.78	1.00
	Juv. small reef assoc.	5.82	1.00
	Ad. large demersal	0.02	5.00
	Ad. small demersal	0.31	1.00
	Ad. large planktivore	0.92	1.00
	Ad. small planktivore	1.03	1.00
	Ad. anchovy	0.10	1.00
	Juv. anchovy	0.10	1.00
	Ad. deepwater fish	1.08	1.00
	Juv. deepwater fish	0.92	1.00
	Ad. macro algal browsing	0.03	1.00
	Ad. eroding grazers	0.01	1.00
	Ad. scraping grazers	2.87	1.00
	Detritivore fish	0.13	1.00
	Penaeid shrimps	4.62	1.00
	Shrimps and prawns	5.70	1.00
	Large crabs	0.11	1.00
	Small crabs	0.47	1.00
	Carn. zooplankton	65.16	1.00
Ad. Napoleon wrasse	Ad. groupers	0.13	2.00
	Sub. groupers	0.50	2.00
	Juv. groupers	0.13	2.00
	Ad. snappers	1.00	2.00
	Sub. snappers	1.56	2.00
	Juv. snappers	0.13	2.00
	Ad. Napoleon wrasse	0.64	2.00
	Sub. Napoleon wrasse	0.64	2.00
	Juv. Napoleon wrasse	0.13	2.00
	Juv. coral trout	0.13	2.00
	Juv. rays	0.13	2.00
	Ad. butterflyfish	0.77	2.00
	Juv. butterflyfish	1.15	2.00
	Ad. large reef assoc.	0.64	2.00
	Juv. large reef assoc.	0.77	2.00
	Ad. medium reef assoc.	0.77	2.00
	Juv. medium reef assoc.	0.03	2.00
	Ad. small reef assoc.	2.64	2.00
	Juv. small reef assoc.	0.13	2.00
	Ad. large demersal	0.28	2.00
	Juv. large demersal	0.13	2.00
	Ad. small demersal	6.40	2.00
	Juv. small demersal	0.13	2.00
	Ad. large planktivore	3.19	2.00
	Juv. large planktivore	0.13	2.00
	Ad. small planktivore	6.40	2.00
	Juv. small planktivore	0.13	2.00
	Juv. anchovy	3.00	2.00
	Ad. deepwater fish	1.28	2.00
	Juv. deepwater fish	1.28	2.00
	Ad. macro algal browsing	2.56	2.00
	Juv. macro algal browsing	0.10	2.00
	Ad. eroding grazers	0.13	2.00
	Juv. eroding grazers	0.03	2.00
	Ad. scraping grazers	0.64	2.00
	Juv. scraping grazers	0.13	2.00
	Detritivore fish	0.52	2.00
	Squid	2.56	2.00
	Octopus	2.56	2.00
	Sea cucumbers	2.56	2.00
	Lobsters	0.86	2.00
	Large crabs	0.34	2.00
	Small crabs	2.59	2.00
	Crown of thorns	8.17	2.00
	Giant triton	2.60	2.00
	Herbivorous echinoids	12.81	2.00
	Bivalves	5.12	2.00
	Sessile filter feeders	7.04	2.00
	Epifaunal det. inverts.	2.56	2.00
	Epifaunal carn. inverts	2.56	2.00
	Infaunal inverts.	2.56	2.00
	Carn. zooplankton	6.65	2.00
Sub. Napoleon wrasse	Ad. groupers	0.14	2.00
	Sub. groupers	0.10	2.00
	Juv. groupers	0.09	2.00
	Ad. snappers	0.40	2.00
	Sub. snappers	0.96	2.00
	Juv. snappers	0.09	2.00
	Ad. Napoleon wrasse	0.41	2.00
	Sub. Napoleon wrasse	0.68	2.00
	Juv. Napoleon wrasse	0.09	2.00
	Juv. coral trout	0.02	2.00
	Juv. rays	0.09	2.00
	Ad. butterflyfish	0.81	2.00
	Juv. butterflyfish	0.63	2.00
	Juv. large reef assoc.	0.09	2.00
	Ad. medium reef assoc.	0.58	2.00
	Juv. medium reef assoc.	0.02	2.00
	Ad. small reef assoc.	3.22	2.00
	Juv. small reef assoc.	0.09	2.00
	Juv. large demersal	0.09	2.00
	Ad. small demersal	10.30	2.00
	Juv. small demersal	0.09	2.00
	Juv. large planktivore	0.09	2.00
	Ad. small planktivore	4.50	2.00
	Juv. small planktivore	0.09	2.00
	Ad. deepwater fish	0.68	2.00
	Juv. deepwater fish	0.68	2.00
	Ad. macro algal browsing	0.27	2.00
	Juv. macro algal browsing	0.05	2.00

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Ad. eroding grazers	0.03	2.00
	Juv. eroding grazers	0.02	2.00
	Ad. scraping grazers	0.14	2.00
	Juv. scraping grazers	0.09	2.00
	Detritivore fish	0.11	2.00
	Squid	2.72	2.00
	Octopus	2.72	2.00
	Sea cucumbers	5.43	2.00
	Lobsters	0.38	2.00
	Large crabs	0.57	2.00
	Small crabs	5.43	2.00
	Crown of thorns	2.85	2.00
	Giant triton	1.83	2.00
	Herbivorous echinoids	13.58	2.00
	Bivalves	8.15	2.00
	Sessile filter feeders	7.47	2.00
	Epifaunal det. inverts.	5.43	2.00
	Epifaunal carn. inverts	5.43	2.00
	Infaunal inverts.	5.43	2.00
	Carn. zooplankton	6.89	2.00
Juv. Napoleon wrasse	Ad. groupers	0.01	2.00
	Sub. groupers	0.37	2.00
	Ad. snappers	0.37	2.00
	Sub. snappers	0.37	2.00
	Ad. Napoleon wrasse	0.37	2.00
	Sub. Napoleon wrasse	0.37	2.00
	Ad. butterflyfish	0.31	2.00
	Juv. butterflyfish	0.31	2.00
	Ad. medium reef assoc.	< 0.01	2.00
	Ad. small reef assoc.	1.34	2.00
	Ad. small demersal	0.61	2.00
	Ad. small planktivore	0.42	2.00
	Ad. deepwater fish	0.31	2.00
	Juv. deepwater fish	0.73	2.00
	Ad. macro algal browsing	0.12	2.00
	Ad. eroding grazers	0.02	2.00
	Ad. scraping grazers	0.10	2.00
	Detritivore fish	0.10	2.00
	Squid	1.22	2.00
	Octopus	2.44	2.00
	Sea cucumbers	6.09	2.00
	Lobsters	0.69	2.00
	Large crabs	0.36	2.00
	Small crabs	6.09	2.00
	Crown of thorns	4.96	2.00
	Giant triton	1.66	2.00
	Herbivorous echinoids	7.64	2.00
	Bivalves	6.09	2.00
	Sessile filter feeders	6.60	2.00
	Epifaunal det. inverts.	9.74	2.00
	Epifaunal carn. inverts	9.74	2.00
	Infaunal inverts.	9.74	2.00
	Carn. zooplankton	9.76	2.00
	Large herb. zooplankton	2.44	2.00
	Small herb. zooplankton	2.42	2.00
	Detritus	6.11	2.00
Skipjack tuna	Skipjack tuna	0.69	7.0E+08
	Other tuna	1.53	1.00
	Mackerel	0.20	7.0E+08
	Ad. large pelagic	0.01	7.0E+08
	Juv. large pelagic	0.02	7.0E+08
	Ad. medium pelagic	< 0.01	7.0E+08
	Juv. medium pelagic	< 0.01	7.0E+08
	Ad. small pelagic	0.02	7.0E+08
	Juv. small pelagic	0.38	7.0E+08
	Ad. large planktivore	0.09	7.0E+08
	Juv. large planktivore	3.16	7.0E+08
	Ad. small planktivore	0.12	7.0E+08
	Juv. small planktivore	1.00	7.0E+08
	Ad. anchovy	10.00	1.02
	Juv. anchovy	0.10	1.01
	Ad. deepwater fish	2.41	7.0E+08
	Juv. deepwater fish	1.00	1.01
	Penaeid shrimps	1.48	7.0E+08
	Shrimps and prawns	0.15	7.0E+08
	Squid	0.06	7.0E+08
	Octopus	0.24	7.0E+08
	Lobsters	0.02	7.0E+08
	Large crabs	< 0.01	7.0E+08
	Small crabs	0.01	7.0E+08
	Giant triton	< 0.01	7.0E+08
	Bivalves	0.24	7.0E+08
	Epifaunal det. inverts.	0.30	7.0E+08
	Epifaunal carn. inverts	0.32	7.0E+08
	Infaunal inverts.	0.32	7.0E+08
	Carn. zooplankton	0.18	7.0E+08
	Large herb. zooplankton	0.18	7.0E+08
	Small herb. zooplankton	0.24	7.0E+08
Other tuna	Other tuna	0.12	1.00
	Juv. large sharks	< 0.01	1.00
	Juv. small sharks	0.05	1.00
	Juv. rays	0.01	1.00
	Ad. large pelagic	< 0.01	1.00
	Juv. large pelagic	0.01	1.00
	Ad. medium pelagic	0.02	1.00
	Juv. medium pelagic	0.10	1.00
	Ad. small pelagic	< 0.01	1.00
	Juv. small pelagic	0.10	1.00
	Ad. large planktivore	0.01	1.00
	Juv. large planktivore	3.71	1.00
	Ad. small planktivore	0.07	1.00
	Juv. small planktivore	1.00	1.00
	Ad. anchovy	10.00	1.00
	Juv. anchovy	0.01	1.00
	Ad. deepwater fish	0.45	1.00
	Juv. deepwater fish	0.09	1.00
	Anemonies	< 0.01	1.00
	Penaeid shrimps	0.28	1.00
	Shrimps and prawns	0.05	1.00
	Squid	0.05	1.00
	Octopus	0.07	1.00
	Sea cucumbers	< 0.01	1.00
	Lobsters	< 0.01	1.00
	Large crabs	< 0.01	1.00
	Small crabs	0.01	1.00
	Crown of thorns	< 0.01	1.00
	Giant triton	< 0.01	1.00
	Herbivorous echinoids	< 0.01	1.00
	Bivalves	0.07	1.00
	Sessile filter feeders	< 0.01	1.00
	Epifaunal det. inverts.	0.13	1.00
	Epifaunal carn. inverts	0.23	1.00
	Infaunal inverts.	0.26	1.00
	Jellyfish and hydroids	< 0.01	1.00
	Carn. zooplankton	8.64	1.0E+05
	Large herb. zooplankton	3.51	1.00
	Small herb. zooplankton	0.44	1.00
	Macro algae	< 0.01	1.00
	Sea grass	< 0.01	1.00
Mackerel	Ad. groupers	< 0.01	1.00
	Sub. groupers	0.01	1.00
	Ad. snappers	< 0.01	1.00
	Sub. snappers	0.03	1.00
	Ad. Napoleon wrasse	< 0.01	1.00
	Sub. Napoleon wrasse	0.01	1.00
	Other tuna	0.57	1.00
	Mackerel	0.89	1.00
	Ad. butterflyfish	< 0.01	1.00
	Juv. butterflyfish	0.40	1.00
	Cleaner wrasse	0.01	1.00

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Ad. large pelagic	0.14	1.00
	Juv. large pelagic	0.13	1.00
	Ad. medium pelagic	0.05	1.00
	Juv. medium pelagic	0.29	2.00
	Ad. small pelagic	0.72	1.00
	Juv. small pelagic	1.09	1.00
	Ad. large reef assoc.	0.29	1.00
	Juv. large reef assoc.	1.72	1.00
	Ad. medium reef assoc.	< 0.01	1.00
	Juv. medium reef assoc.	0.17	1.00
	Ad. small reef assoc.	0.20	1.00
	Ad. large demersal	< 0.01	1.00
	Ad. small demersal	0.06	1.00
	Ad. large planktivore	0.03	1.00
	Ad. small planktivore	0.29	1.00
	Juv. small planktivore	4.09	1.00
	Ad. anchovy	10.00	1.00
	Juv. anchovy	7.59	4.00
	Ad. deepwater fish	0.03	1.00
	Juv. deepwater fish	0.17	1.00
	Ad. macro algal browsing	0.03	1.00
	Ad. eroding grazers	< 0.01	1.00
	Ad. scraping grazers	0.11	1.00
	Detritivore fish	0.02	1.00
	Shrimps and prawns	0.08	1.00
	Squid	0.11	1.00
Billfish	Skipjack tuna	4.26	5.2E+21
	Other tuna	2.49	5.2E+21
	Mackerel	< 0.01	5.2E+21
	Billfish	0.29	5.2E+21
	Ad. large pelagic	< 0.01	5.2E+21
	Ad. medium pelagic	0.03	5.2E+21
	Ad. small pelagic	0.01	5.2E+21
	Juv. small pelagic	0.20	5.2E+21
	Ad. large planktivore	0.12	1.01
	Ad. small planktivore	0.10	5.2E+21
	Juv. small planktivore	2.00	5.2E+21
	Ad. anchovy	10.00	1.00
	Juv. anchovy	0.10	5.2E+21
	Ad. deepwater fish	0.02	5.2E+21
	Juv. deepwater fish	1.09	5.2E+21
	Shrimps and prawns	< 0.01	5.2E+21
	Squid	0.12	5.2E+21
	Lobsters	< 0.01	5.2E+21
	Large crabs	< 0.01	5.2E+21
	Small crabs	< 0.01	5.2E+21
	Giant triton	< 0.01	5.2E+21
	Epifaunal det. inverts.	< 0.01	5.2E+21
	Epifaunal carn. inverts	0.02	5.2E+21
	Infaunal inverts.	0.02	5.2E+21
Ad. coral trout	Ad. groupers	0.11	2.00
	Sub. groupers	0.20	2.00
	Ad. snappers	0.68	2.00
	Sub. snappers	2.93	2.00
	Ad. Napoleon wrasse	0.11	2.00
	Sub. Napoleon wrasse	0.11	2.00
	Ad. butterflyfish	3.83	2.00
	Juv. butterflyfish	2.80	2.00
	Cleaner wrasse	0.18	2.00
	Ad. large reef assoc.	20.28	2.00
	Juv. large reef assoc.	18.93	2.00
	Ad. medium reef assoc.	0.70	2.00
	Ad. small reef assoc.	2.28	2.00
	Juv. small reef assoc.	10.82	2.00
	Ad. large demersal	0.36	2.00
	Ad. small demersal	0.57	2.00
	Ad. large planktivore	3.27	2.00
	Ad. small planktivore	2.26	2.00
	Ad. anchovy	0.45	2.00
	Juv. anchovy	3.27	2.00
	Ad. deepwater fish	3.04	2.00
	Juv. deepwater fish	3.04	2.00
	Ad. macro algal browsing	0.11	2.00
	Ad. eroding grazers	0.04	2.00
	Ad. scraping grazers	11.72	2.00
	Detritivore fish	1.76	2.00
	Penaeid shrimps	1.01	2.00
	Shrimps and prawns	1.01	2.00
	Squid	2.30	2.00
	Lobsters	0.16	2.00
	Large crabs	0.03	2.00
	Small crabs	0.09	2.00
	Giant triton	0.19	2.00
	Epifaunal det. inverts.	0.45	2.00
	Epifaunal carn. inverts	0.45	2.00
	Infaunal inverts.	0.45	2.00
Juv. coral trout	Ad. groupers	0.01	2.00
	Sub. groupers	0.15	2.00
	Ad. snappers	0.15	2.00
	Sub. snappers	0.30	2.00
	Ad. butterflyfish	0.15	2.00
	Juv. butterflyfish	15.00	2.00
	Cleaner wrasse	1.09	2.00
	Ad. large reef assoc.	0.15	2.00
	Juv. large reef assoc.	33.21	2.00
	Ad. medium reef assoc.	< 0.01	2.00
	Juv. medium reef assoc.	7.30	2.00
	Ad. small reef assoc.	2.02	2.00
	Ad. large demersal	< 0.01	2.00
	Ad. small demersal	2.00	2.00
	Ad. large planktivore	3.54	2.00
	Ad. small planktivore	5.12	2.00
	Ad. anchovy	0.74	2.00
	Juv. anchovy	13.29	2.00
	Ad. deepwater fish	1.33	2.00
	Juv. deepwater fish	5.87	2.00
	Ad. macro algal browsing	0.15	2.00
	Juv. macro algal browsing	6.53	2.00
	Ad. eroding grazers	0.06	2.00
	Ad. scraping grazers	0.12	2.00
	Detritivore fish	0.12	2.00
	Shrimps and prawns	0.73	2.00
	Squid	0.87	2.00
Ad. large sharks	Mysticetae	0.02	2.00
	Pisc. odontocetae	0.02	2.00
	Deep. odontocetae	0.02	2.00
	Birds	< 0.01	2.00
	Reef assoc. turtles	0.11	2.00
	Green turtles	0.11	2.00
	Oceanic turtles	0.11	2.00
	Crocodiles	0.11	2.00
	Ad. groupers	0.02	2.00
	Sub. groupers	0.09	2.00
	Ad. snappers	0.07	2.00
	Sub. snappers	0.30	2.00
	Ad. Napoleon wrasse	0.02	2.00
	Sub. Napoleon wrasse	0.05	2.00
	Skipjack tuna	0.02	2.00
	Other tuna	0.23	2.00
	Mackerel	0.16	2.00
	Billfish	0.09	2.00
	Ad. large sharks	0.01	1.01
	Juv. large sharks	0.10	2.00
	Ad. small sharks	< 0.01	2.00
	Juv. small sharks	0.10	2.00
	Whale shark	< 0.01	2.00
	Manta ray	0.02	2.00
	Adult rays	< 0.01	2.00
	Ad. butterflyfish	0.41	2.00
	Juv. butterflyfish	0.37	2.00

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Cleaner wrasse	0.01	2.00
	Ad. large pelagic	0.03	2.00
	Ad. medium pelagic	0.01	2.00
	Ad. small pelagic	0.03	2.00
	Ad. large reef assoc.	3.08	2.00
	Juv. large reef assoc.	5.47	2.00
	Ad. medium reef assoc.	< 0.01	2.00
	Ad. small reef assoc.	0.22	2.00
	Ad. large demersal	0.05	2.00
	Ad. small demersal	0.05	2.00
	Ad. large planktivore	0.76	2.00
	Ad. small planktivore	0.32	2.00
	Ad. anchovy	0.07	2.00
	Juv. anchovy	0.46	2.00
	Ad. deepwater fish	0.90	2.00
	Juv. deepwater fish	0.46	2.00
	Ad. macro algal browsing	< 0.01	2.00
	Ad. eroding grazers	< 0.01	2.00
	Ad. scraping grazers	1.37	2.00
	Detritivore fish	0.08	2.00
	Anemonies	< 0.01	2.00
	Shrimps and prawns	0.14	2.00
	Squid	2.85	2.00
	Octopus	0.39	2.00
	Sea cucumbers	< 0.01	2.00
	Lobsters	0.04	2.00
	Large crabs	< 0.01	2.00
	Small crabs	0.01	2.00
	Crown of thorns	< 0.01	2.00
	Giant triton	0.10	2.00
	Herbivorous echinoids	< 0.01	2.00
	Bivalves	0.12	2.00
	Sessile filter feeders	< 0.01	2.00
	Epifaunal det. inverts.	0.23	2.00
	Epifaunal carn. inverts	0.23	2.00
	Infaunal inverts.	0.23	2.00
	Jellyfish and hydroids	< 0.01	2.00
	Carn. zooplankton	0.16	2.00
	Large herb. zooplankton	< 0.01	2.00
	Small herb. zooplankton	< 0.01	2.00
	Macro algae	0.16	2.00
	Sea grass	0.16	2.00
	Fishery discards	0.01	2.00
	Detritus	0.03	2.00
Juv. large sharks	Ad. groupers	< 0.01	2.00
	Sub. groupers	< 0.01	2.00
	Ad. snappers	< 0.01	2.00
	Sub. snappers	0.04	2.00
	Ad. Napoleon wrasse	< 0.01	2.00
	Sub. Napoleon wrasse	< 0.01	2.00
	Ad. small sharks	0.04	2.00
	Juv. small sharks	0.05	2.00
	Ad. butterflyfish	0.02	2.00
	Juv. butterflyfish	0.50	2.00
	Cleaner wrasse	0.02	2.00
	Ad. large reef assoc.	0.06	2.00
	Juv. large reef assoc.	6.97	2.00
	Ad. medium reef assoc.	< 0.01	2.00
	Juv. medium reef assoc.	2.00	2.00
	Ad. small reef assoc.	0.31	2.00
	Ad. large demersal	< 0.01	2.00
	Juv. large demersal	< 0.01	2.00
	Ad. small demersal	0.06	2.00
	Ad. large planktivore	0.10	2.00
	Juv. large planktivore	1.97	2.00
	Ad. small planktivore	0.04	2.00
	Juv. small planktivore	0.81	2.00
	Ad. anchovy	0.06	2.00
	Juv. anchovy	0.94	2.00
	Ad. deepwater fish	0.02	2.00
	Juv. deepwater fish	0.25	2.00
	Ad. macro algal browsing	0.02	2.00
	Juv. macro algal browsing	1.00	2.00
	Ad. eroding grazers	< 0.01	2.00
	Ad. scraping grazers	< 0.01	2.00
	Juv. scraping grazers	1.98	2.00
	Detritivore fish	0.02	2.00
	Penaeid shrimps	0.33	2.00
	Shrimps and prawns	0.33	2.00
	Squid	0.08	2.00
	Octopus	0.06	2.00
	Lobsters	< 0.01	2.00
	Large crabs	< 0.01	2.00
	Small crabs	< 0.01	2.00
	Giant triton	< 0.01	2.00
	Bivalves	0.06	2.00
	Epifaunal det. inverts.	0.08	2.00
	Epifaunal carn. inverts	0.08	2.00
	Infaunal inverts.	0.08	2.00
	Carn. zooplankton	1.79	2.00
	Large herb. zooplankton	0.02	2.00
	Small herb. zooplankton	0.02	2.00
Ad. small sharks	Skipjack tuna	0.24	2.00
	Other tuna	2.36	2.00
	Mackerel	1.79	2.00
	Billfish	1.07	2.00
	Juv. large sharks	2.00	2.00
	Ad. large pelagic	0.24	2.00
	Ad. medium pelagic	0.01	2.00
	Ad. small pelagic	0.86	2.00
	Juv. small pelagic	0.51	2.00
	Ad. large demersal	0.21	2.00
	Ad. large planktivore	0.05	2.00
	Ad. small planktivore	2.57	2.00
	Ad. anchovy	0.35	2.00
	Juv. anchovy	4.63	2.00
	Ad. deepwater fish	0.38	2.00
	Juv. deepwater fish	2.22	2.00
	Penaeid shrimps	0.11	2.00
	Shrimps and prawns	0.14	2.00
	Squid	0.51	2.00
	Octopus	0.80	2.00
	Lobsters	0.08	2.00
	Large crabs	0.02	2.00
	Small crabs	0.05	2.00
	Giant triton	0.10	2.00
	Epifaunal det. inverts.	0.24	2.00
	Epifaunal carn. inverts	0.24	2.00
	Infaunal inverts.	0.24	2.00
Juv. small sharks	Skipjack tuna	0.21	2.00
	Other tuna	1.17	2.00
	Mackerel	0.31	2.00
	Billfish	0.87	2.00
	Ad. coral trout	0.06	2.00
	Juv. large sharks	0.31	2.00
	Ad. small sharks	0.25	2.00
	Juv. butterflyfish	0.50	2.00
	Ad. large pelagic	< 0.01	2.00
	Ad. medium pelagic	0.01	2.00
	Ad. small pelagic	0.13	2.00
	Juv. small pelagic	4.69	2.00
	Ad. large planktivore	0.04	2.00
	Juv. large planktivore	6.27	2.00
	Ad. small planktivore	0.07	2.00
	Juv. small planktivore	1.77	2.00
	Ad. anchovy	0.25	2.00
	Juv. anchovy	2.75	2.00
	Ad. deepwater fish	< 0.01	2.00
	Juv. deepwater fish	0.13	2.00
	Shrimps and prawns	0.02	2.00

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Large crabs	< 0.01	2.00
	Small crabs	0.12	2.00
	Epifaunal det. inverts.	0.02	2.00
	Epifaunal carn. inverts	0.02	2.00
	Infaunal inverts.	0.02	2.00
Whale shark	Skipjack tuna	0.10	2.00
	Other tuna	1.51	2.00
	Mackerel	0.89	2.00
	Ad. medium pelagic	0.01	2.00
	Ad. small pelagic	0.44	2.00
	Ad. small planktivore	1.69	2.00
	Ad. anchovy	0.10	2.00
	Ad. deepwater fish	0.76	2.00
	Juv. deepwater fish	0.30	2.00
	Shrimps and prawns	0.30	2.00
	Squid	5.52	2.00
	Jellyfish and hydroids	1.09	2.00
	Carn. zooplankton	1.33	2.00
	Large herb. zooplankton	0.65	2.00
	Small herb. zooplankton	1.33	2.00
	Phytoplankton	4.03	2.00
Manta ray	Ad. medium pelagic	0.01	2.00
	Ad. small pelagic	0.51	2.00
	Ad. large planktivore	0.25	2.00
	Ad. small planktivore	1.59	2.00
	Ad. anchovy	2.00	2.00
	Juv. anchovy	< 0.01	2.00
	Penaeid shrimps	2.24	2.00
	Shrimps and prawns	1.25	2.00
	Squid	2.24	2.00
	Jellyfish and hydroids	2.49	2.00
	Carn. zooplankton	2.49	2.00
	Large herb. zooplankton	1.18	2.00
	Small herb. zooplankton	2.49	2.00
	Phytoplankton	1.25	2.00
Adult rays	Ad. groupers	< 0.01	5.2E+21
	Sub. groupers	0.02	5.2E+21
	Ad. snappers	0.02	5.2E+21
	Sub. snappers	0.02	5.2E+21
	Ad. butterflyfish	0.02	5.2E+21
	Juv. butterflyfish	0.02	5.2E+21
	Cleaner wrasse	< 0.01	5.2E+21
	Ad. large reef assoc.	0.12	5.2E+21
	Juv. large reef assoc.	0.14	5.2E+21
	Ad. medium reef assoc.	< 0.01	5.2E+21
	Ad. small reef assoc.	0.02	5.2E+21
	Ad. large demersal	< 0.01	5.2E+21
	Ad. small demersal	< 0.01	5.2E+21
	Ad. large planktivore	0.02	5.2E+21
	Ad. small planktivore	0.02	5.2E+21
	Ad. anchovy	< 0.01	5.2E+21
	Juv. anchovy	0.02	5.2E+21
	Ad. deepwater fish	0.02	5.2E+21
	Juv. deepwater fish	0.02	5.2E+21
	Ad. macro algal browsing	< 0.01	5.2E+21
	Ad. eroding grazers	< 0.01	5.2E+21
	Ad. scraping grazers	0.08	5.2E+21
	Detritivore fish	< 0.01	5.2E+21
	Penaeid shrimps	1.59	5.2E+21
	Shrimps and prawns	3.15	5.2E+21
	Squid	0.01	5.2E+21
	Octopus	< 0.01	5.2E+21
	Lobsters	0.07	5.2E+21
	Large crabs	0.09	5.2E+21
	Small crabs	0.08	5.2E+21
	Giant triton	0.08	5.2E+21
	Bivalves	6.30	5.2E+21
	Epifaunal det. inverts.	2.38	5.2E+21
	Epifaunal carn. inverts	2.38	5.2E+21
	Infaunal inverts.	2.38	5.2E+21
	Carn. zooplankton	0.91	5.2E+21
Juv. rays	Ad. small reef assoc.	0.27	2.00
	Ad. small demersal	0.64	2.00
	Penaeid shrimps	0.50	2.00
	Shrimps and prawns	0.51	2.00
	Octopus	1.92	2.00
	Sea cucumbers	1.28	2.00
	Lobsters	0.10	2.00
	Large crabs	0.08	2.00
	Small crabs	0.13	2.00
	Crown of thorns	0.11	2.00
	Herbivorous echinoids	0.82	2.00
	Sessile filter feeders	1.28	2.00
	Epifaunal det. inverts.	4.64	2.00
	Epifaunal carn. inverts	3.85	2.00
	Infaunal inverts.	3.85	2.00
Ad. butterflyfish	Juv. groupers	0.06	10.70
	Juv. snappers	0.06	10.70
	Juv. Napoleon wrasse	< 0.01	10.70
	Juv. coral trout	< 0.01	10.70
	Juv. rays	0.04	10.70
	Juv. butterflyfish	0.06	10.70
	Juv. large reef assoc.	0.06	10.70
	Juv. medium reef assoc.	1.00	10.70
	Juv. small reef assoc.	0.01	10.70
	Juv. large demersal	0.06	10.70
	Juv. small demersal	0.06	10.70
	Juv. large planktivore	0.06	10.70
	Juv. small planktivore	0.02	10.70
	Juv. macro algal browsing	0.14	10.70
	Juv. eroding grazers	0.01	10.70
	Juv. scraping grazers	0.06	10.70
	Azooxanthellate corals	0.50	10.70
	Hermatypic corals	0.13	10.70
	Non reef building corals	0.50	10.70
	Soft corals	0.50	10.70
	Anemonies	0.50	10.70
	Penaeid shrimps	0.87	10.70
	Shrimps and prawns	0.10	10.70
	Squid	0.50	10.70
	Octopus	0.56	10.70
	Sea cucumbers	0.07	10.70
	Lobsters	0.01	10.70
	Large crabs	0.02	10.70
	Small crabs	0.40	10.70
	Crown of thorns	0.05	10.70
	Giant triton	0.04	10.70
	Herbivorous echinoids	0.10	10.70
	Bivalves	0.84	10.70
	Sessile filter feeders	12.42	10.70
	Epifaunal det. inverts.	0.87	10.70
	Epifaunal carn. inverts	8.00	10.70
	Infaunal inverts.	18.00	10.70
	Jellyfish and hydroids	0.50	10.70
	Carn. zooplankton	10.64	10.70
	Large herb. zooplankton	1.04	10.70
	Small herb. zooplankton	9.85	10.70
	Phytoplankton	9.64	10.70
	Macro algae	15.00	10.70
	Sea grass	2.96	10.70
	Fishery discards	0.01	10.70
	Detritus	3.67	10.70
Juv. butterflyfish	Juv. groupers	0.01	1.1E+12
	Juv. snappers	0.01	1.1E+12
	Juv. Napoleon wrasse	< 0.01	1.1E+12
	Juv. coral trout	< 0.01	1.1E+12
	Juv. rays	0.01	1.1E+12
	Juv. butterflyfish	0.03	1.1E+12
	Juv. large reef assoc.	0.01	1.1E+12
	Juv. medium reef assoc.	3.70	1.1E+12

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Juv. small reef assoc.	0.21	1.1E+12
	Juv. large demersal	0.01	1.1E+12
	Juv. small demersal	0.01	1.1E+12
	Juv. large planktivore	3.02	1.1E+12
	Juv. small planktivore	< 0.01	1.1E+12
	Juv. macro algal browsing	0.01	1.1E+12
	Juv. eroding grazers	< 0.01	1.1E+12
	Juv. scraping grazers	2.15	1.1E+12
	Azooxanthellate corals	0.32	1.1E+12
	Hermatypic corals	0.02	1.1E+12
	Non reef building corals	0.32	1.1E+12
	Soft corals	0.32	1.1E+12
	Anemonies	0.01	1.1E+12
	Shrimps and prawns	0.12	1.1E+12
	Squid	< 0.01	1.1E+12
	Octopus	0.57	1.1E+12
	Sea cucumbers	0.02	1.1E+12
	Lobsters	< 0.01	1.1E+12
	Large crabs	< 0.01	1.1E+12
	Small crabs	< 0.01	1.1E+12
	Crown of thorns	0.02	1.1E+12
	Giant triton	< 0.01	1.1E+12
	Herbivorous echinoids	0.01	1.1E+12
	Bivalves	0.57	1.1E+12
	Sessile filter feeders	0.84	1.1E+12
	Epifaunal det. inverts.	0.10	1.1E+12
	Epifaunal carn. inverts	11.47	1.1E+12
	Infaunal inverts.	23.96	1.1E+12
	Jellyfish and hydroids	0.15	1.1E+12
	Carn. zooplankton	2.53	1.1E+12
	Large herb. zooplankton	1.96	1.1E+12
	Small herb. zooplankton	1.50	1.1E+12
	Phytoplankton	25.00	1.1E+12
	Macro algae	14.18	1.1E+12
	Sea grass	6.80	1.1E+12
Cleaner wrasse	Ad. groupers	< 0.01	2.00
	Sub. groupers	0.15	2.00
	Ad. butterflyfish	< 0.01	2.00
	Juv. butterflyfish	< 0.01	2.00
	Ad. large reef assoc.	0.36	2.00
	Juv. large reef assoc.	0.36	2.00
	Ad. medium reef assoc.	< 0.01	2.00
	Ad. small reef assoc.	3.17	2.00
	Juv. small reef assoc.	5.00	2.00
	Ad. large demersal	0.10	2.00
	Ad. small demersal	0.29	2.00
	Ad. large planktivore	0.29	2.00
	Ad. small planktivore	2.12	2.00
	Ad. anchovy	0.87	2.00
	Juv. anchovy	0.29	2.00
	Ad. deepwater fish	0.51	2.00
	Juv. deepwater fish	0.51	2.00
	Ad. scraping grazers	0.12	2.00
	Detritivore fish	0.05	2.00
	Azooxanthellate corals	14.56	2.00
	Hermatypic corals	4.44	2.00
	Non reef building corals	11.78	2.00
	Epifaunal det. inverts.	10.56	2.00
	Epifaunal carn. inverts	22.23	2.00
	Infaunal inverts.	22.23	2.00
Ad. large pelagic	Ad. groupers	< 0.01	22.90
	Sub. groupers	0.05	22.90
	Ad. snappers	< 0.01	22.90
	Sub. snappers	0.12	22.90
	Ad. Napoleon wrasse	< 0.01	22.90
	Sub. Napoleon wrasse	< 0.01	22.90
	Skipjack tuna	0.24	22.90
	Other tuna	6.71	22.90
	Mackerel	2.04	22.90
	Billfish	1.32	22.90
	Ad. large sharks	< 0.01	22.90
	Juv. large sharks	< 0.01	22.90
	Ad. small sharks	< 0.01	22.90
	Juv. small sharks	< 0.01	22.90
	Adult rays	< 0.01	22.90
	Juv. rays	< 0.01	22.90
	Ad. butterflyfish	0.01	22.90
	Juv. butterflyfish	2.28	22.90
	Cleaner wrasse	0.06	22.90
	Ad. large pelagic	0.05	22.90
	Juv. large pelagic	0.27	22.90
	Ad. medium pelagic	0.20	22.90
	Juv. medium pelagic	< 0.01	22.90
	Ad. small pelagic	1.03	22.90
	Juv. small pelagic	< 0.01	22.90
	Ad. large reef assoc.	0.60	22.90
	Juv. large reef assoc.	9.59	22.90
	Ad. medium reef assoc.	< 0.01	22.90
	Juv. medium reef assoc.	0.65	22.90
	Ad. small reef assoc.	2.00	22.90
	Juv. small reef assoc.	1.56	22.90
	Ad. large demersal	0.01	22.90
	Ad. small demersal	0.24	22.90
	Ad. large planktivore	0.30	22.90
	Juv. large planktivore	< 0.01	22.90
	Ad. small planktivore	0.24	22.90
	Juv. small planktivore	4.56	22.90
	Ad. anchovy	5.02	22.90
	Juv. anchovy	7.31	22.90
	Ad. deepwater fish	0.60	22.90
	Juv. deepwater fish	7.31	22.90
	Ad. macro algal browsing	0.17	22.90
	Ad. eroding grazers	0.01	22.90
	Ad. scraping grazers	0.20	22.90
	Detritivore fish	0.10	22.90
	Shrimps and prawns	12.36	22.90
	Squid	0.24	22.90
	Octopus	1.32	22.90
	Lobsters	0.03	22.90
	Large crabs	< 0.01	22.90
	Small crabs	0.02	22.90
	Giant triton	< 0.01	22.90
	Bivalves	0.05	22.90
	Epifaunal det. inverts.	0.48	22.90
	Epifaunal carn. inverts	0.60	22.90
	Infaunal inverts.	0.60	22.90
	Carn. zooplankton	1.44	22.90
	Large herb. zooplankton	0.72	22.90
	Small herb. zooplankton	1.32	22.90
	Macro algae	< 0.01	22.90
	Sea grass	< 0.01	22.90
Juv. large pelagic	Ad. groupers	< 0.01	1.00
	Sub. groupers	0.01	1.00
	Ad. snappers	< 0.01	1.00
	Sub. snappers	0.06	1.00
	Skipjack tuna	0.11	1.00
	Other tuna	2.28	1.00
	Mackerel	1.48	1.00
	Billfish	0.91	1.00
	Ad. butterflyfish	0.11	1.00
	Juv. butterflyfish	2.00	1.00
	Cleaner wrasse	0.06	1.00
	Ad. large pelagic	0.04	1.00
	Ad. medium pelagic	< 0.01	1.00
	Ad. small pelagic	0.47	1.00
	Juv. small pelagic	0.40	1.00
	Ad. large reef assoc.	0.23	1.00
	Juv. large reef assoc.	21.70	1.00
	Ad. medium reef assoc.	< 0.01	1.00
	Juv. medium reef assoc.	1.64	1.00

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Ad. small reef assoc.	0.49	1.00
	Juv. small reef assoc.	3.41	1.00
	Ad. large demersal	0.01	1.00
	Juv. large demersal	0.57	1.00
	Ad. small demersal	0.23	1.00
	Ad. large planktivore	0.28	1.00
	Ad. small planktivore	0.60	1.00
	Juv. small planktivore	2.73	1.00
	Ad. anchovy	8.18	1.00
	Juv. anchovy	44.32	1.00
	Ad. deepwater fish	0.11	1.00
	Juv. deepwater fish	0.57	1.00
	Ad. macro algal browsing	0.05	1.00
	Ad. eroding grazers	< 0.01	1.00
	Ad. scraping grazers	0.09	1.00
	Juv. scraping grazers	2.50	1.00
	Detritivore fish	0.05	1.00
	Shrimps and prawns	0.01	1.00
	Squid	0.12	1.00
	Lobsters	0.02	1.00
	Large crabs	< 0.01	1.00
	Small crabs	< 0.01	1.00
	Giant triton	0.03	1.00
	Epifaunal det. inverts.	2.37	1.00
	Epifaunal carn. inverts	0.07	1.00
	Infaunal inverts.	0.07	1.00
	Carn. zooplankton	1.60	1.00
Ad. medium pelagic	Other tuna	2.09	1.49
	Mackerel	1.58	1.49
	Billfish	< 0.01	1.49
	Juv. butterflyfish	0.33	1.49
	Ad. large pelagic	0.09	1.49
	Juv. large pelagic	0.42	1.49
	Ad. medium pelagic	< 0.01	1.49
	Juv. medium pelagic	0.08	1.49
	Ad. small pelagic	3.48	1.49
	Juv. small pelagic	19.63	1.49
	Ad. large planktivore	0.13	1.49
	Ad. small planktivore	0.62	1.49
	Juv. small planktivore	11.77	1.49
	Ad. anchovy	14.65	1.49
	Juv. anchovy	39.12	1.49
	Ad. deepwater fish	0.52	1.49
	Juv. deepwater fish	1.70	1.49
	Shrimps and prawns	1.05	1.49
	Squid	0.02	1.49
	Lobsters	0.14	1.49
	Large crabs	0.26	1.49
	Small crabs	0.70	1.49
	Giant triton	0.17	1.49
	Epifaunal det. inverts.	0.39	1.49
	Epifaunal carn. inverts	0.39	1.49
	Infaunal inverts.	0.66	1.49
Juv. medium pelagic	Other tuna	0.22	1.00
	Mackerel	0.22	1.00
	Juv. large sharks	0.22	1.00
	Juv. small sharks	0.22	1.00
	Juv. rays	0.01	1.00
	Juv. butterflyfish	0.31	1.00
	Ad. large pelagic	0.01	1.00
	Juv. large pelagic	0.09	1.00
	Ad. medium pelagic	< 0.01	1.00
	Juv. medium pelagic	0.03	1.00
	Ad. small pelagic	1.20	1.00
	Juv. small pelagic	0.08	1.00
	Ad. large planktivore	0.11	1.00
	Juv. large planktivore	0.22	1.00
	Ad. small planktivore	0.14	1.00
	Juv. small planktivore	0.22	1.00
	Ad. anchovy	11.88	1.00
	Juv. anchovy	0.32	1.00
	Ad. deepwater fish	0.27	1.00
	Juv. deepwater fish	1.03	1.00
	Shrimps and prawns	0.04	1.00
	Squid	0.22	1.00
	Lobsters	0.07	1.00
	Large crabs	0.01	1.00
	Small crabs	0.01	1.00
	Giant triton	< 0.01	1.00
	Epifaunal det. inverts.	0.11	1.00
	Epifaunal carn. inverts	0.22	1.00
	Infaunal inverts.	0.22	1.00
	Jellyfish and hydroids	1.30	1.00
	Carn. zooplankton	27.00	1.00
	Large herb. zooplankton	27.00	1.00
	Small herb. zooplankton	16.20	1.00
	Phytoplankton	10.80	1.00
Ad. small pelagic	Juv. large sharks	0.04	2.00
	Juv. small sharks	0.04	2.00
	Juv. rays	0.04	2.00
	Juv. large pelagic	0.02	2.00
	Juv. medium pelagic	0.01	2.00
	Juv. small pelagic	< 0.01	2.00
	Juv. large planktivore	0.04	2.00
	Juv. small planktivore	0.02	2.00
	Juv. anchovy	< 0.01	2.00
	Juv. deepwater fish	0.04	2.00
	Shrimps and prawns	0.05	2.00
	Squid	0.06	2.00
	Lobsters	0.03	2.00
	Large crabs	< 0.01	2.00
	Small crabs	< 0.01	2.00
	Giant triton	< 0.01	2.00
	Epifaunal det. inverts.	0.10	2.00
	Epifaunal carn. inverts	0.03	2.00
	Infaunal inverts.	0.51	2.00
	Jellyfish and hydroids	0.05	2.00
	Carn. zooplankton	49.17	2.00
	Large herb. zooplankton	1.00	2.00
	Small herb. zooplankton	48.71	2.00
Juv. small pelagic	Juv. large sharks	0.20	2.00
	Juv. small sharks	0.31	2.00
	Juv. rays	0.01	2.00
	Cleaner wrasse	0.07	2.00
	Juv. large pelagic	0.03	2.00
	Juv. medium pelagic	0.04	2.00
	Juv. small pelagic	0.06	2.00
	Juv. large planktivore	0.31	2.00
	Juv. small planktivore	0.17	2.00
	Juv. anchovy	5.12	2.00
	Juv. deepwater fish	0.61	2.00
	Shrimps and prawns	0.04	2.00
	Squid	< 0.01	2.00
	Lobsters	0.02	2.00
	Large crabs	0.01	2.00
	Small crabs	0.01	2.00
	Giant triton	< 0.01	2.00
	Epifaunal det. inverts.	0.08	2.00
	Epifaunal carn. inverts	0.07	2.00
	Infaunal inverts.	0.20	2.00
	Jellyfish and hydroids	0.16	2.00
	Carn. zooplankton	10.23	2.00
	Large herb. zooplankton	9.16	2.00
	Small herb. zooplankton	20.87	2.00
	Phytoplankton	52.21	1.00
Ad. large reef assoc.	Ad. groupers	< 0.01	1.00
	Sub. groupers	< 0.01	1.00
	Juv. groupers	< 0.01	1.00
	Ad. snappers	< 0.01	1.00
	Sub. snappers	0.01	1.00

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Juv. snappers	0.01	1.00
	Ad. Napoleon wrasse	< 0.01	1.00
	Sub. Napoleon wrasse	0.01	1.00
	Juv. Napoleon wrasse	< 0.01	1.00
	Skipjack tuna	0.05	1.00
	Other tuna	0.05	1.00
	Mackerel	0.05	1.00
	Billfish	0.05	1.00
	Ad. coral trout	0.02	2.00
	Juv. coral trout	< 0.01	1.00
	Ad. large sharks	0.01	1.00
	Juv. large sharks	< 0.01	2.00
	Ad. small sharks	< 0.01	1.00
	Adult rays	0.30	1.00
	Juv. rays	0.02	1.00
	Ad. butterflyfish	0.10	1.00
	Juv. butterflyfish	< 0.01	1.00
	Cleaner wrasse	< 0.01	1.00
	Ad. large pelagic	< 0.01	1.00
	Juv. large pelagic	0.01	1.00
	Ad. medium pelagic	< 0.01	1.00
	Ad. small pelagic	< 0.01	1.00
	Ad. large reef assoc.	4.10	1.00
	Juv. large reef assoc.	1.00	1.00
	Ad. medium reef assoc.	4.00	1.00
	Juv. medium reef assoc.	3.79	1.00
	Ad. small reef assoc.	0.60	1.00
	Juv. small reef assoc.	0.20	1.00
	Ad. large demersal	0.05	1.00
	Juv. large demersal	0.01	1.00
	Ad. small demersal	0.10	1.00
	Juv. small demersal	0.18	1.00
	Ad. large planktivore	1.60	1.00
	Juv. large planktivore	0.20	1.00
	Ad. small planktivore	0.10	1.00
	Juv. small planktivore	0.11	1.00
	Ad. anchovy	1.00	1.00
	Juv. anchovy	0.25	1.00
	Ad. deepwater fish	0.20	1.00
	Juv. deepwater fish	0.10	1.00
	Ad. macro algal browsing	0.08	1.00
	Juv. macro algal browsing	0.05	1.00
	Ad. eroding grazers	< 0.01	1.00
	Juv. eroding grazers	0.06	1.00
	Ad. scraping grazers	0.20	1.00
	Juv. scraping grazers	0.32	1.00
	Detritivore fish	< 0.01	1.00
	Azooxanthellate corals	< 0.01	1.00
	Hermatypic corals	< 0.01	1.00
	Non reef building corals	< 0.01	1.00
	Soft corals	< 0.01	1.00
	Anemonies	0.01	1.00
	Shrimps and prawns	3.00	1.00
	Squid	0.35	1.00
	Octopus	1.37	1.00
	Sea cucumbers	0.45	1.00
	Lobsters	0.02	1.00
	Large crabs	0.20	1.00
	Small crabs	0.20	1.00
	Crown of thorns	0.35	1.00
	Giant triton	< 0.01	1.00
	Herbivorous echinoids	0.15	1.00
	Bivalves	2.30	1.00
	Sessile filter feeders	4.00	1.00
	Epifaunal det. inverts.	0.50	1.00
	Epifaunal carn. inverts	8.48	1.00
	Infaunal inverts.	20.88	1.00
	Jellyfish and hydroids	0.06	1.00
	Carn. zooplankton	1.37	1.00
	Large herb. zooplankton	2.00	1.00
	Small herb. zooplankton	8.18	1.00
	Macro algae	9.47	1.00
	Sea grass	9.10	1.00
	Fishery discards	< 0.01	1.00
	Detritus	8.52	1.00
Juv. large reef assoc.	Ad. groupers	< 0.01	1.00
	Sub. groupers	< 0.01	1.00
	Juv. groupers	< 0.01	1.00
	Ad. snappers	< 0.01	1.00
	Sub. snappers	< 0.01	1.00
	Juv. snappers	< 0.01	1.00
	Ad. Napoleon wrasse	< 0.01	1.00
	Sub. Napoleon wrasse	< 0.01	1.00
	Juv. Napoleon wrasse	< 0.01	1.00
	Juv. coral trout	< 0.01	1.00
	Juv. small sharks	0.02	1.00
	Juv. rays	< 0.01	1.00
	Ad. butterflyfish	< 0.01	1.00
	Juv. butterflyfish	0.02	1.00
	Cleaner wrasse	< 0.01	1.00
	Juv. small pelagic	< 0.01	1.00
	Ad. large reef assoc.	0.02	2.00
	Juv. large reef assoc.	1.00	1.00
	Ad. medium reef assoc.	< 0.01	1.00
	Juv. medium reef assoc.	2.00	1.00
	Ad. small reef assoc.	0.01	1.00
	Juv. small reef assoc.	0.10	1.00
	Ad. large demersal	< 0.01	1.00
	Juv. large demersal	0.01	1.00
	Ad. small demersal	0.20	1.00
	Juv. small demersal	0.20	1.00
	Ad. large planktivore	< 0.01	1.00
	Juv. large planktivore	1.75	1.00
	Ad. small planktivore	< 0.01	1.00
	Juv. small planktivore	0.30	1.00
	Ad. anchovy	0.10	1.00
	Juv. anchovy	0.10	1.00
	Ad. deepwater fish	< 0.01	1.00
	Juv. deepwater fish	0.10	2.00
	Ad. macro algal browsing	< 0.01	1.00
	Juv. macro algal browsing	0.10	1.00
	Ad. eroding grazers	< 0.01	1.00
	Juv. eroding grazers	< 0.01	1.00
	Ad. scraping grazers	< 0.01	1.00
	Juv. scraping grazers	0.38	1.00
	Detritivore fish	< 0.01	1.00
	Azooxanthellate corals	< 0.01	1.00
	Hermatypic corals	< 0.01	1.00
	Non reef building corals	< 0.01	1.00
	Soft corals	< 0.01	1.00
	Anemonies	< 0.01	1.00
	Shrimps and prawns	0.10	1.00
	Squid	0.50	1.00
	Octopus	0.31	1.00
	Sea cucumbers	0.08	1.00
	Lobsters	0.01	1.00
	Large crabs	< 0.01	1.00
	Small crabs	0.08	1.00
	Crown of thorns	0.01	1.00
	Giant triton	< 0.01	1.00
	Herbivorous echinoids	0.01	1.00
	Bivalves	2.31	1.00
	Sessile filter feeders	0.82	1.00
	Epifaunal det. inverts.	0.20	1.00
	Epifaunal carn. inverts	6.24	1.00
	Infaunal inverts.	30.02	1.00
	Jellyfish and hydroids	0.09	1.00
	Carn. zooplankton	13.53	1.00
	Large herb. zooplankton	7.24	1.00
	Small herb. zooplankton	12.71	1.00

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Phytoplankton	0.83	1.00
	Macro algae	9.50	1.00
	Sea grass	8.97	1.00
Ad. medium reef assoc.	Ad. groupers	< 0.01	1.00
	Sub. groupers	0.01	1.00
	Juv. groupers	0.01	1.00
	Ad. snappers	0.02	1.00
	Sub. snappers	0.02	1.00
	Juv. snappers	0.08	1.00
	Ad. Napoleon wrasse	< 0.01	1.00
	Sub. Napoleon wrasse	< 0.01	1.00
	Juv. Napoleon wrasse	< 0.01	1.00
	Skipjack tuna	0.01	1.00
	Other tuna	0.01	1.00
	Mackerel	0.01	1.00
	Billfish	0.01	1.00
	Juv. coral trout	< 0.01	1.00
	Ad. large sharks	< 0.01	1.00
	Ad. small sharks	0.01	1.00
	Adult rays	0.01	1.00
	Juv. rays	0.15	1.00
	Ad. butterflyfish	0.20	1.00
	Juv. butterflyfish	0.05	1.00
	Cleaner wrasse	0.01	1.00
	Ad. large pelagic	< 0.01	1.00
	Juv. large pelagic	< 0.01	1.00
	Ad. medium pelagic	< 0.01	1.00
	Ad. small pelagic	< 0.01	1.00
	Ad. large reef assoc.	0.12	1.00
	Juv. large reef assoc.	0.35	1.00
	Ad. medium reef assoc.	1.29	1.00
	Juv. medium reef assoc.	2.00	1.00
	Ad. small reef assoc.	1.00	1.00
	Juv. small reef assoc.	0.10	1.00
	Ad. large demersal	0.01	1.00
	Juv. large demersal	0.10	1.00
	Ad. small demersal	0.10	1.00
	Ad. large planktivore	0.06	1.00
	Juv. large planktivore	0.38	1.00
	Ad. small planktivore	0.15	1.00
	Juv. small planktivore	0.35	1.00
	Ad. anchovy	1.00	1.00
	Juv. anchovy	0.06	1.00
	Ad. deepwater fish	0.01	1.00
	Juv. deepwater fish	0.10	1.00
	Ad. macro algal browsing	< 0.01	1.00
	Juv. macro algal browsing	0.23	1.00
	Ad. eroding grazers	< 0.01	1.00
	Juv. eroding grazers	< 0.01	1.00
	Ad. scraping grazers	0.70	1.00
	Juv. scraping grazers	0.35	1.00
	Detritivore fish	0.02	1.00
	Azooxanthellate corals	0.50	1.00
	Hermatypic corals	0.03	1.00
	Non reef building corals	0.61	1.00
	Soft corals	0.69	1.00
	Anemonies	0.01	1.00
	Shrimps and prawns	5.00	1.00
	Squid	0.50	1.00
	Octopus	0.35	1.00
	Sea cucumbers	0.23	1.00
	Lobsters	0.01	1.00
	Large crabs	0.23	1.00
	Small crabs	1.15	1.00
	Crown of thorns	0.19	1.00
	Giant triton	< 0.01	1.00
	Herbivorous echinoids	0.20	1.00
	Bivalves	3.99	1.00
	Sessile filter feeders	8.07	1.00
	Epifaunal det. inverts.	1.11	1.00
	Epifaunal carn. inverts	14.34	1.00
	Infaunal inverts.	11.40	1.00
	Jellyfish and hydroids	0.50	1.00
	Carn. zooplankton	9.49	1.00
	Large herb. zooplankton	2.70	1.00
	Small herb. zooplankton	4.88	1.00
	Phytoplankton	2.00	1.00
	Macro algae	8.59	1.00
	Sea grass	9.40	1.00
	Fishery discards	0.06	0.00
	Detritus	4.53	1.00
Juv. medium reef assoc.	Ad. groupers	< 0.01	6.06
	Sub. groupers	< 0.01	6.06
	Juv. groupers	< 0.01	6.06
	Juv. snappers	0.01	6.06
	Juv. Napoleon wrasse	< 0.01	6.06
	Juv. coral trout	< 0.01	6.06
	Juv. rays	0.01	6.06
	Juv. butterflyfish	0.01	6.06
	Juv. large reef assoc.	0.20	6.06
	Ad. medium reef assoc.	1.17	1.0E+05
	Juv. medium reef assoc.	1.20	6.06
	Ad. small reef assoc.	0.10	6.06
	Juv. small reef assoc.	0.10	6.06
	Juv. large demersal	0.05	6.06
	Ad. small demersal	< 0.01	2.00
	Ad. large planktivore	< 0.01	6.06
	Juv. large planktivore	0.28	6.06
	Ad. small planktivore	0.02	6.06
	Juv. small planktivore	0.20	6.06
	Ad. anchovy	0.02	6.06
	Ad. deepwater fish	< 0.01	6.06
	Juv. macro algal browsing	0.10	6.06
	Juv. scraping grazers	0.57	6.06
	Detritivore fish	< 0.01	6.06
	Azooxanthellate corals	0.11	6.06
	Hermatypic corals	< 0.01	6.06
	Non reef building corals	0.17	6.06
	Soft corals	0.34	6.06
	Anemonies	0.01	6.06
	Shrimps and prawns	0.09	6.06
	Squid	< 0.01	6.06
	Octopus	0.46	6.06
	Sea cucumbers	0.11	6.06
	Lobsters	< 0.01	6.06
	Large crabs	0.01	6.06
	Small crabs	0.04	6.06
	Crown of thorns	< 0.01	6.06
	Giant triton	< 0.01	6.06
	Herbivorous echinoids	0.20	6.06
	Bivalves	0.46	6.06
	Sessile filter feeders	0.57	6.06
	Epifaunal det. inverts.	0.10	6.06
	Epifaunal carn. inverts	1.89	6.06
	Infaunal inverts.	5.22	6.06
	Jellyfish and hydroids	0.39	6.06
	Carn. zooplankton	5.61	6.06
	Large herb. zooplankton	1.94	6.06
	Small herb. zooplankton	3.72	6.06
	Phytoplankton	0.05	6.06
	Macro algae	33.58	6.06
	Sea grass	35.77	6.06
	Fishery discards	0.06	6.06
	Detritus	5.00	6.06
Ad. small reef assoc.	Juv. groupers	0.06	1.70
	Juv. snappers	0.20	1.70
	Juv. Napoleon wrasse	< 0.01	1.70
	Juv. coral trout	< 0.01	1.70
	Juv. rays	0.34	1.70
	Juv. butterflyfish	0.10	1.70

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Juv. large reef assoc.	0.34	1.70
	Juv. medium reef assoc.	0.03	1.70
	Juv. small reef assoc.	0.65	1.70
	Juv. large demersal	0.34	1.70
	Juv. small demersal	0.34	1.70
	Juv. large planktivore	0.34	1.70
	Juv. small planktivore	0.34	1.70
	Juv. macro algal browsing	0.34	1.70
	Juv. eroding grazers	< 0.01	1.70
	Juv. scraping grazers	1.57	1.70
	Azooxanthellate corals	2.01	1.70
	Hermatypic corals	0.07	1.70
	Non reef building corals	1.62	1.70
	Soft corals	0.02	1.70
	Anemonies	0.10	1.70
	Shrimps and prawns	2.57	1.70
	Squid	0.11	1.70
	Octopus	0.03	1.70
	Sea cucumbers	0.03	1.70
	Lobsters	0.10	1.70
	Large crabs	0.18	1.70
	Small crabs	0.17	1.70
	Crown of thorns	0.03	1.70
	Giant triton	0.05	1.70
	Herbivorous echinoids	0.02	1.70
	Bivalves	0.56	1.70
	Sessile filter feeders	2.68	1.70
	Epifaunal det. inverts.	1.41	1.70
	Epifaunal carn. inverts	12.06	1.70
	Infaunal inverts.	9.95	1.70
	Jellyfish and hydroids	0.09	1.70
	Carn. zooplankton	4.62	1.70
	Large herb. zooplankton	2.75	1.70
	Small herb. zooplankton	8.78	1.70
	Phytoplankton	7.97	1.70
	Macro algae	16.79	1.70
	Sea grass	17.85	1.70
	Fishery discards	0.03	1.70
	Detritus	2.34	1.70
Juv. small reef assoc.	Juv. groupers	< 0.01	8.7E+05
	Juv. snappers	< 0.01	8.7E+05
	Juv. Napoleon wrasse	< 0.01	8.7E+05
	Juv. rays	0.01	8.7E+05
	Juv. butterflyfish	0.01	8.7E+05
	Juv. large reef assoc.	0.33	8.7E+05
	Ad. medium reef assoc.	< 0.01	8.7E+05
	Juv. medium reef assoc.	0.04	8.7E+05
	Ad. small reef assoc.	< 0.01	8.7E+05
	Juv. small reef assoc.	0.02	8.7E+05
	Juv. large demersal	0.01	8.7E+05
	Ad. small demersal	0.01	8.7E+05
	Juv. small demersal	0.11	8.7E+05
	Juv. large planktivore	2.56	8.7E+05
	Ad. small planktivore	0.04	8.7E+05
	Juv. small planktivore	0.48	8.7E+05
	Ad. anchovy	2.00	8.7E+05
	Juv. anchovy	1.00	8.7E+05
	Ad. deepwater fish	< 0.01	8.7E+05
	Juv. macro algal browsing	0.10	8.7E+05
	Juv. eroding grazers	< 0.01	8.7E+05
	Juv. scraping grazers	0.01	8.7E+05
	Azooxanthellate corals	0.06	8.7E+05
	Hermatypic corals	< 0.01	8.7E+05
	Non reef building corals	0.06	8.7E+05
	Soft corals	0.11	8.7E+05
	Shrimps and prawns	0.09	8.7E+05
	Squid	0.01	8.7E+05
	Lobsters	< 0.01	8.7E+05
	Large crabs	< 0.01	8.7E+05
	Small crabs	0.01	8.7E+05
	Giant triton	< 0.01	8.7E+05
	Sessile filter feeders	0.70	8.7E+05
	Epifaunal det. inverts.	0.16	8.7E+05
	Epifaunal carn. inverts	1.91	8.7E+05
	Infaunal inverts.	17.06	8.7E+05
	Jellyfish and hydroids	< 0.01	8.7E+05
	Carn. zooplankton	9.40	8.7E+05
	Large herb. zooplankton	5.00	8.7E+05
	Small herb. zooplankton	7.63	8.7E+05
	Macro algae	21.69	8.7E+05
	Sea grass	14.34	8.7E+05
	Fishery discards	0.01	8.7E+05
	Detritus	15.01	8.7E+05
Ad. large demersal	Ad. groupers	0.02	25.70
	Sub. groupers	0.10	25.70
	Ad. snappers	0.39	25.70
	Sub. snappers	0.39	25.70
	Ad. butterflyfish	1.06	25.70
	Juv. butterflyfish	1.06	25.70
	Cleaner wrasse	0.09	25.70
	Ad. large reef assoc.	2.70	25.70
	Juv. large reef assoc.	2.12	25.70
	Ad. medium reef assoc.	< 0.01	25.70
	Ad. small reef assoc.	1.81	25.70
	Juv. small reef assoc.	1.00	25.70
	Ad. large demersal	0.08	25.70
	Ad. small demersal	0.87	25.70
	Ad. large planktivore	0.87	25.70
	Ad. small planktivore	1.56	25.70
	Ad. anchovy	0.39	25.70
	Juv. anchovy	0.87	25.70
	Ad. deepwater fish	0.77	25.70
	Juv. deepwater fish	0.77	25.70
	Ad. macro algal browsing	0.01	25.70
	Ad. scraping grazers	1.89	25.70
	Detritivore fish	0.16	25.70
	Shrimps and prawns	73.70	1.0E+05
	Lobsters	0.04	25.70
	Large crabs	0.32	25.70
	Small crabs	1.01	25.70
	Giant triton	0.04	25.70
	Epifaunal det. inverts.	0.39	25.70
	Epifaunal carn. inverts	0.39	25.70
	Infaunal inverts.	5.15	25.70
Juv. large demersal	Ad. groupers	< 0.01	8.6E+02
	Sub. groupers	0.01	8.6E+02
	Ad. butterflyfish	0.05	8.6E+02
	Juv. butterflyfish	0.05	8.6E+02
	Ad. large reef assoc.	0.61	8.6E+02
	Juv. large reef assoc.	3.10	8.6E+02
	Ad. medium reef assoc.	< 0.01	8.6E+02
	Juv. medium reef assoc.	1.00	8.6E+02
	Ad. small reef assoc.	0.23	8.6E+02
	Juv. small reef assoc.	1.76	8.6E+02
	Ad. large demersal	< 0.01	8.6E+02
	Ad. small demersal	0.40	8.6E+02
	Ad. large planktivore	0.47	8.6E+02
	Ad. small planktivore	0.33	8.6E+02
	Ad. anchovy	0.81	8.6E+02
	Juv. anchovy	0.47	8.6E+02
	Ad. deepwater fish	0.61	8.6E+02
	Juv. deepwater fish	1.08	8.6E+02
	Ad. scraping grazers	0.55	8.6E+02
	Detritivore fish	0.05	8.6E+02
	Shrimps and prawns	1.37	8.6E+02
	Lobsters	0.04	8.6E+02
	Large crabs	0.01	8.6E+02
	Small crabs	0.05	8.6E+02
	Giant triton	< 0.01	8.6E+02
	Bivalves	0.27	8.6E+02

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Epifaunal det. inverts.	1.07	8.6E+02
	Epifaunal carn. inverts	13.97	8.6E+02
	Infaunal inverts.	13.97	8.6E+02
	Carn. zooplankton	15.71	8.6E+02
	Large herb. zooplankton	15.71	8.6E+02
	Small herb. zooplankton	15.75	8.6E+02
Ad. small demersal	Juv. groupers	0.07	47.30
	Juv. snappers	0.37	47.30
	Juv. Napoleon wrasse	0.03	47.30
	Juv. coral trout	0.01	47.30
	Juv. rays	0.43	47.30
	Juv. butterflyfish	0.20	47.30
	Ad. large reef assoc.	0.72	47.30
	Juv. large reef assoc.	2.16	47.30
	Ad. medium reef assoc.	< 0.01	47.30
	Juv. medium reef assoc.	2.32	47.30
	Ad. small reef assoc.	0.79	47.30
	Juv. small reef assoc.	0.40	47.30
	Ad. large demersal	< 0.01	47.30
	Juv. large demersal	1.00	47.30
	Ad. small demersal	2.00	47.30
	Juv. small demersal	2.00	47.30
	Ad. large planktivore	3.72	47.30
	Juv. large planktivore	1.44	47.30
	Ad. small planktivore	1.19	47.30
	Juv. small planktivore	3.00	47.30
	Ad. anchovy	17.06	1.00
	Juv. anchovy	0.72	47.30
	Ad. deepwater fish	2.30	47.30
	Juv. deepwater fish	2.50	47.30
	Juv. macro algal browsing	2.00	47.30
	Juv. eroding grazers	0.10	47.30
	Juv. scraping grazers	0.43	47.30
	Detritivore fish	0.12	47.30
	Shrimps and prawns	7.34	47.30
	Squid	1.52	47.30
	Octopus	2.45	47.30
	Sea cucumbers	7.34	47.30
	Lobsters	0.11	47.30
	Large crabs	0.10	47.30
	Small crabs	2.20	47.30
	Crown of thorns	0.53	47.30
	Giant triton	< 0.01	47.30
	Herbivorous echinoids	2.21	47.30
	Bivalves	1.45	47.30
	Sessile filter feeders	1.45	47.30
	Epifaunal det. inverts.	1.45	47.30
	Epifaunal carn. inverts	4.85	47.30
	Infaunal inverts.	14.79	47.30
	Detritus	5.13	2.00
Juv. small demersal	Juv. groupers	< 0.01	1.00
	Juv. snappers	0.02	1.00
	Juv. Napoleon wrasse	< 0.01	1.00
	Juv. coral trout	< 0.01	1.00
	Juv. rays	0.40	1.00
	Juv. butterflyfish	0.10	1.00
	Juv. large reef assoc.	1.98	1.00
	Ad. medium reef assoc.	0.13	1.00
	Juv. medium reef assoc.	6.65	1.00
	Ad. small reef assoc.	1.20	1.00
	Juv. small reef assoc.	0.20	1.00
	Juv. large demersal	0.30	1.00
	Ad. small demersal	0.02	1.00
	Juv. small demersal	0.20	1.00
	Juv. large planktivore	2.76	1.00
	Ad. small planktivore	0.31	1.00
	Juv. small planktivore	1.00	1.00
	Ad. anchovy	9.65	1.00
	Juv. anchovy	2.26	1.00
	Ad. deepwater fish	1.83	1.00
	Juv. deepwater fish	2.43	1.00
	Juv. macro algal browsing	0.10	1.00
	Juv. eroding grazers	< 0.01	1.00
	Juv. scraping grazers	1.07	1.00
	Detritivore fish	0.04	1.00
	Shrimps and prawns	0.97	1.00
	Squid	0.15	1.00
	Octopus	1.52	1.00
	Sea cucumbers	1.59	1.00
	Lobsters	0.04	1.00
	Large crabs	0.04	1.00
	Small crabs	0.73	1.00
	Crown of thorns	0.16	1.00
	Giant triton	< 0.01	1.00
	Herbivorous echinoids	1.00	1.00
	Bivalves	3.85	1.00
	Sessile filter feeders	3.05	1.00
	Epifaunal det. inverts.	1.00	1.00
	Epifaunal carn. inverts	12.00	1.00
	Infaunal inverts.	17.93	2.00
	Macro algae	23.31	1.00
Ad. large planktivore	Ad. groupers	< 0.01	8.95
	Sub. groupers	0.01	8.95
	Juv. groupers	0.01	8.95
	Ad. snappers	< 0.01	8.95
	Sub. snappers	0.01	8.95
	Juv. snappers	0.01	8.95
	Juv. Napoleon wrasse	0.01	8.95
	Skipjack tuna	0.08	8.95
	Other tuna	0.91	8.95
	Mackerel	0.69	8.95
	Billfish	0.34	8.95
	Juv. coral trout	< 0.01	8.95
	Juv. large sharks	< 0.01	8.95
	Juv. small sharks	0.02	8.95
	Juv. rays	0.02	8.95
	Ad. butterflyfish	0.40	8.95
	Juv. butterflyfish	0.10	8.95
	Cleaner wrasse	0.03	8.95
	Ad. large pelagic	0.03	8.95
	Juv. large pelagic	0.02	8.95
	Ad. medium pelagic	< 0.01	8.95
	Juv. medium pelagic	< 0.01	8.95
	Ad. small pelagic	0.05	8.95
	Juv. small pelagic	< 0.01	8.95
	Ad. large reef assoc.	0.10	8.95
	Juv. large reef assoc.	2.29	8.95
	Ad. medium reef assoc.	0.20	8.95
	Juv. medium reef assoc.	< 0.01	8.95
	Ad. small reef assoc.	0.34	8.95
	Juv. small reef assoc.	0.50	8.95
	Ad. large demersal	< 0.01	8.95
	Juv. large demersal	0.01	8.95
	Ad. small demersal	0.11	8.95
	Juv. small demersal	0.01	8.95
	Ad. large planktivore	0.50	8.95
	Juv. large planktivore	< 0.01	8.95
	Ad. small planktivore	0.47	8.95
	Juv. small planktivore	< 0.01	8.95
	Ad. anchovy	0.34	8.95
	Juv. anchovy	0.02	8.95
	Ad. deepwater fish	1.37	8.95
	Juv. deepwater fish	0.10	8.95
	Ad. macro algal browsing	0.01	8.95
	Juv. macro algal browsing	0.01	8.95
	Ad. eroding grazers	< 0.01	8.95
	Juv. eroding grazers	< 0.01	8.95
	Ad. scraping grazers	1.00	8.95
	Juv. scraping grazers	0.01	8.95
	Detritivore fish	0.03	8.95

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Shrimps and prawns	8.00	8.95
	Squid	1.50	8.95
	Octopus	0.01	8.95
	Sea cucumbers	< 0.01	8.95
	Lobsters	0.05	8.95
	Large crabs	0.43	8.95
	Small crabs	0.05	8.95
	Crown of thorns	< 0.01	8.95
	Giant triton	0.12	8.95
	Herbivorous echinoids	< 0.01	2.00
	Bivalves	0.69	8.95
	Sessile filter feeders	3.15	8.95
	Epifaunal det. inverts.	0.56	8.95
	Epifaunal carn. inverts	4.11	0.00
	Infaunal inverts.	3.77	8.95
	Jellyfish and hydroids	2.50	8.95
	Carn. zooplankton	23.08	8.95
	Large herb. zooplankton	12.36	8.95
	Small herb. zooplankton	18.34	8.95
	Phytoplankton	3.50	8.95
	Macro algae	3.09	8.95
	Sea grass	3.36	8.95
	Fishery discards	0.02	8.95
	Detritus	0.91	8.95
Juv. large planktivore	Juv. groupers	< 0.01	1.00
	Juv. snappers	< 0.01	1.00
	Juv. Napoleon wrasse	< 0.01	1.00
	Juv. coral trout	< 0.01	1.00
	Juv. large sharks	0.03	1.00
	Juv. small sharks	0.03	1.00
	Juv. rays	0.01	1.00
	Juv. butterflyfish	0.01	1.00
	Cleaner wrasse	< 0.01	1.00
	Juv. large pelagic	< 0.01	1.00
	Juv. medium pelagic	0.01	1.00
	Juv. small pelagic	0.09	1.00
	Juv. large reef assoc.	1.26	1.00
	Ad. medium reef assoc.	< 0.01	1.00
	Juv. medium reef assoc.	1.61	1.00
	Juv. small reef assoc.	0.12	1.00
	Juv. large demersal	0.01	1.00
	Juv. small demersal	0.09	1.00
	Juv. large planktivore	4.00	1.00
	Juv. small planktivore	0.01	1.00
	Ad. anchovy	2.00	2.00
	Juv. anchovy	1.00	1.00
	Ad. deepwater fish	0.50	2.00
	Juv. deepwater fish	0.50	1.00
	Juv. macro algal browsing	0.13	1.00
	Juv. eroding grazers	< 0.01	1.00
	Juv. scraping grazers	0.86	1.00
	Shrimps and prawns	1.06	1.00
	Squid	< 0.01	1.00
	Lobsters	< 0.01	1.00
	Large crabs	< 0.01	1.00
	Small crabs	< 0.01	1.00
	Giant triton	< 0.01	1.00
	Bivalves	3.66	1.00
	Epifaunal det. inverts.	0.48	1.00
	Epifaunal carn. inverts	1.18	1.00
	Infaunal inverts.	10.59	1.00
	Jellyfish and hydroids	0.38	1.00
	Carn. zooplankton	28.00	1.00
	Large herb. zooplankton	13.33	1.00
	Small herb. zooplankton	29.00	1.00
	Phytoplankton	0.02	2.00
Ad. small planktivore	Juv. groupers	0.01	2.00
	Juv. snappers	< 0.01	2.00
	Juv. Napoleon wrasse	< 0.01	2.00
	Mackerel	< 0.01	2.00
	Juv. coral trout	0.01	2.00
	Juv. large sharks	0.42	2.00
	Juv. small sharks	0.30	2.00
	Juv. rays	0.15	2.00
	Juv. butterflyfish	0.21	2.00
	Juv. large pelagic	0.18	2.00
	Ad. medium pelagic	< 0.01	2.00
	Juv. medium pelagic	0.05	2.00
	Ad. small pelagic	< 0.01	2.00
	Juv. small pelagic	0.08	2.00
	Juv. large reef assoc.	0.21	2.00
	Juv. medium reef assoc.	0.02	2.00
	Juv. small reef assoc.	0.09	2.00
	Juv. large demersal	0.21	2.00
	Juv. small demersal	0.21	2.00
	Ad. large planktivore	< 0.01	2.00
	Juv. large planktivore	0.32	2.00
	Juv. small planktivore	0.21	2.00
	Ad. anchovy	< 0.01	2.00
	Juv. anchovy	0.42	2.00
	Ad. deepwater fish	< 0.01	2.00
	Juv. deepwater fish	0.42	2.00
	Juv. macro algal browsing	0.21	2.00
	Juv. eroding grazers	< 0.01	2.00
	Juv. scraping grazers	0.76	2.00
	Anemonies	0.02	2.00
	Shrimps and prawns	0.21	2.00
	Squid	0.11	2.00
	Octopus	0.02	2.00
	Sea cucumbers	0.02	2.00
	Lobsters	0.05	2.00
	Large crabs	0.05	2.00
	Small crabs	0.11	2.00
	Crown of thorns	0.02	2.00
	Giant triton	< 0.01	2.00
	Herbivorous echinoids	0.01	2.00
	Bivalves	0.02	2.00
	Sessile filter feeders	1.07	2.00
	Epifaunal det. inverts.	0.90	2.00
	Epifaunal carn. inverts	6.66	2.00
	Infaunal inverts.	6.66	2.00
	Jellyfish and hydroids	0.09	2.00
	Carn. zooplankton	28.68	2.00
	Large herb. zooplankton	0.90	2.00
	Small herb. zooplankton	28.75	2.00
	Macro algae	10.56	2.00
	Sea grass	10.56	2.00
Juv. small planktivore	Juv. groupers	< 0.01	1.04
	Juv. snappers	< 0.01	1.04
	Juv. Napoleon wrasse	< 0.01	1.04
	Juv. coral trout	< 0.01	1.04
	Juv. large sharks	0.11	1.04
	Juv. small sharks	0.11	1.04
	Juv. rays	< 0.01	1.04
	Juv. butterflyfish	0.05	1.04
	Juv. large pelagic	0.03	1.04
	Juv. medium pelagic	0.01	1.04
	Juv. small pelagic	0.02	1.04
	Juv. large reef assoc.	0.10	1.04
	Juv. medium reef assoc.	< 0.01	1.04
	Juv. small reef assoc.	0.02	1.04
	Juv. large demersal	0.01	1.04
	Juv. small demersal	0.10	1.04
	Juv. large planktivore	0.07	1.04
	Juv. small planktivore	0.03	1.04
	Juv. anchovy	0.11	1.04
	Juv. deepwater fish	0.11	1.04
	Juv. macro algal browsing	0.10	1.04
	Juv. eroding grazers	< 0.01	1.04
	Juv. scraping grazers	0.10	1.04

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Azooxanthellate corals	0.05	1.04
	Hermatypic corals	< 0.01	1.04
	Non reef building corals	0.03	1.04
	Soft corals	0.05	1.04
	Shrimps and prawns	0.09	1.04
	Lobsters	0.02	1.04
	Large crabs	< 0.01	1.04
	Small crabs	0.02	1.04
	Giant triton	< 0.01	1.04
	Sessile filter feeders	1.45	1.04
	Epifaunal det. inverts.	0.34	1.04
	Epifaunal carn. inverts	0.37	1.04
	Infaunal inverts.	5.85	1.04
	Carn. zooplankton	11.53	1.04
	Large herb. zooplankton	0.61	1.04
	Small herb. zooplankton	14.65	1.04
	Phytoplankton	15.81	1.04
	Macro algae	28.03	1.04
	Sea grass	20.00	1.04
Ad. anchovy	Penaeid shrimps	2.11	2.5E+07
	Shrimps and prawns	0.20	2.5E+07
	Jellyfish and hydroids	0.80	2.5E+07
	Carn. zooplankton	40.00	2.5E+07
	Large herb. zooplankton	3.59	2.5E+07
	Small herb. zooplankton	35.23	2.5E+07
	Phytoplankton	18.07	2.5E+07
Juv. anchovy	Shrimps and prawns	0.01	2.0E+02
	Jellyfish and hydroids	< 0.01	2.0E+02
	Carn. zooplankton	1.24	2.0E+02
	Large herb. zooplankton	0.90	2.0E+02
	Small herb. zooplankton	10.00	2.0E+02
	Phytoplankton	87.84	2.0E+02
Ad. deepwater fish	Ad. groupers	< 0.01	5.2E+21
	Sub. groupers	0.02	5.2E+21
	Ad. snappers	0.02	5.2E+21
	Sub. snappers	0.11	5.2E+21
	Ad. Napoleon wrasse	0.02	5.2E+21
	Sub. Napoleon wrasse	0.02	5.2E+21
	Skipjack tuna	2.83	5.2E+21
	Other tuna	2.83	5.2E+21
	Mackerel	3.06	5.2E+21
	Billfish	2.83	1.01
	Ad. small sharks	0.07	5.2E+21
	Juv. small sharks	0.30	2.00
	Adult rays	2.60	5.2E+21
	Ad. butterflyfish	0.01	5.2E+21
	Juv. butterflyfish	0.30	5.2E+21
	Cleaner wrasse	0.40	5.2E+21
	Ad. large pelagic	0.03	5.2E+21
	Juv. large pelagic	0.11	5.2E+21
	Ad. medium pelagic	< 0.01	5.2E+21
	Ad. small pelagic	0.20	1.01
	Juv. small pelagic	0.33	5.2E+21
	Ad. large reef assoc.	2.01	5.2E+21
	Juv. large reef assoc.	2.38	5.2E+21
	Ad. medium reef assoc.	0.52	5.2E+21
	Juv. medium reef assoc.	1.00	5.2E+21
	Ad. small reef assoc.	0.71	5.2E+21
	Juv. small reef assoc.	1.00	5.2E+21
	Ad. large demersal	0.01	5.2E+21
	Ad. small demersal	2.00	5.2E+21
	Juv. small demersal	0.20	5.2E+21
	Ad. large planktivore	0.45	1.01
	Ad. small planktivore	1.02	5.2E+21
	Juv. small planktivore	1.00	5.2E+21
	Ad. anchovy	2.53	5.2E+21
	Juv. anchovy	0.39	5.2E+21
	Ad. deepwater fish	1.00	5.2E+21
	Juv. deepwater fish	2.00	5.2E+21
	Ad. macro algal browsing	0.37	5.2E+21
	Juv. macro algal browsing	1.00	5.2E+21
	Ad. eroding grazers	< 0.01	5.2E+21
	Ad. scraping grazers	0.26	5.2E+21
	Detritivore fish	0.11	5.2E+21
	Shrimps and prawns	5.72	5.2E+21
	Squid	2.78	5.2E+21
	Lobsters	0.10	5.2E+21
	Large crabs	0.09	5.2E+21
	Small crabs	3.08	5.2E+21
	Giant triton	< 0.01	5.2E+21
	Sessile filter feeders	3.13	2.00
	Epifaunal det. inverts.	2.94	5.2E+21
	Epifaunal carn. inverts	11.32	5.2E+21
	Infaunal inverts.	15.80	5.2E+21
	Jellyfish and hydroids	11.00	5.2E+21
	Carn. zooplankton	8.00	5.2E+21
Juv. deepwater fish	Juv. small reef assoc.	0.10	2.00
	Juv. small planktivore	0.10	2.00
	Juv. anchovy	0.50	2.00
	Juv. deepwater fish	1.00	2.00
	Juv. macro algal browsing	0.05	2.00
	Shrimps and prawns	0.14	2.00
	Squid	0.06	2.00
	Lobsters	< 0.01	2.00
	Large crabs	< 0.01	2.00
	Small crabs	0.30	2.00
	Giant triton	< 0.01	2.00
	Sessile filter feeders	0.48	2.00
	Epifaunal det. inverts.	0.14	2.00
	Epifaunal carn. inverts	9.97	2.00
	Infaunal inverts.	12.42	2.00
	Jellyfish and hydroids	0.01	2.00
	Carn. zooplankton	24.00	5.0E+02
	Large herb. zooplankton	15.00	2.00
	Small herb. zooplankton	30.00	2.00
	Macro algae	3.46	2.00
Ad. macro algal browsing	Juv. butterflyfish	0.22	2.00
	Ad. large pelagic	0.02	2.00
	Juv. large pelagic	0.14	2.00
	Ad. medium pelagic	< 0.01	2.00
	Ad. small pelagic	0.42	2.00
	Ad. large reef assoc.	0.54	2.00
	Juv. large reef assoc.	0.54	2.00
	Ad. medium reef assoc.	< 0.01	2.00
	Ad. small reef assoc.	0.57	2.00
	Juv. small reef assoc.	0.36	2.00
	Ad. large demersal	0.02	2.00
	Ad. small demersal	1.08	2.00
	Ad. large planktivore	0.54	2.00
	Ad. small planktivore	1.38	2.00
	Juv. small planktivore	2.05	2.00
	Ad. anchovy	1.08	2.00
	Juv. anchovy	0.54	2.00
	Epifaunal det. inverts.	0.87	2.00
	Epifaunal carn. inverts	2.16	2.00
	Infaunal inverts.	1.08	2.00
	Carn. zooplankton	5.40	2.00
	Large herb. zooplankton	5.40	2.00
	Small herb. zooplankton	5.40	2.00
	Phytoplankton	5.45	2.00
	Macro algae	53.96	2.00
	Sea grass	10.79	2.00
Juv. macro algal browsing	Ad. small pelagic	< 0.01	2.00
	Ad. small reef assoc.	0.01	2.00
	Juv. small reef assoc.	0.19	2.00
	Ad. small demersal	0.01	2.00
	Juv. small demersal	0.01	2.00
	Ad. small planktivore	< 0.01	2.00
	Juv. small planktivore	0.25	2.00
	Ad. anchovy	< 0.01	2.00

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Juv. anchovy	0.13	2.00
	Epifaunal det. inverts.	0.10	2.00
	Epifaunal carn. inverts	0.08	2.00
	Infaunal inverts.	< 0.01	2.00
	Carn. zooplankton	3.19	2.00
	Large herb. zooplankton	1.71	2.00
	Small herb. zooplankton	6.10	2.00
	Phytoplankton	17.01	2.00
	Macro algae	53.51	2.00
	Sea grass	17.10	2.00
	Mangroves	0.59	2.00
Ad. eroding grazers	Azooxanthellate corals	15.46	2.00
	Hermatypic corals	9.51	2.00
	Non reef building corals	15.24	2.00
	Soft corals	17.80	2.00
	Calcareous algae	1.10	2.00
	Epifaunal det. inverts.	1.76	2.00
	Epifaunal carn. inverts	2.20	2.00
	Infaunal inverts.	0.55	2.00
	Macro algae	35.28	2.00
	Mangroves	1.10	2.00
Juv. eroding grazers	Azooxanthellate corals	18.49	2.00
	Hermatypic corals	11.10	2.00
	Non reef building corals	18.49	2.00
	Soft corals	18.49	2.00
	Calcareous algae	0.92	2.00
	Epifaunal det. inverts.	2.95	2.00
	Epifaunal carn. inverts	3.70	2.00
	Infaunal inverts.	1.83	2.00
	Macro algae	24.04	2.00
Ad. scraping grazers	Azooxanthellate corals	3.00	2.00
	Hermatypic corals	0.10	2.00
	Non reef building corals	2.38	2.00
	Soft corals	0.55	2.00
	Anemonies	0.11	2.00
	Shrimps and prawns	0.10	2.00
	Squid	0.55	2.00
	Octopus	0.33	2.00
	Sea cucumbers	0.11	2.00
	Lobsters	0.11	2.00
	Large crabs	0.02	2.00
	Small crabs	0.02	2.00
	Crown of thorns	0.09	2.00
	Giant triton	0.23	2.00
	Herbivorous echinoids	0.11	2.00
	Bivalves	1.07	2.00
	Sessile filter feeders	0.22	2.00
	Epifaunal det. inverts.	0.22	2.00
	Epifaunal carn. inverts	0.55	2.00
	Infaunal inverts.	0.55	2.00
	Jellyfish and hydroids	0.26	2.00
	Carn. zooplankton	0.66	2.00
	Large herb. zooplankton	0.32	2.00
	Small herb. zooplankton	0.66	2.00
	Phytoplankton	4.77	2.00
	Macro algae	39.59	2.00
	Sea grass	32.74	2.00
	Fishery discards	0.05	2.00
	Detritus	10.56	2.00
Juv. scraping grazers	Juv. groupers	< 0.01	2.00
	Juv. snappers	< 0.01	2.00
	Juv. Napoleon wrasse	< 0.01	2.00
	Juv. coral trout	< 0.01	2.00
	Juv. rays	0.01	2.00
	Juv. butterflyfish	0.01	2.00
	Juv. large reef assoc.	0.34	2.00
	Juv. medium reef assoc.	0.03	2.00
	Juv. small reef assoc.	0.07	2.00
	Juv. large demersal	0.05	2.00
	Juv. small demersal	0.11	2.00
	Juv. large planktivore	0.34	2.00
	Juv. small planktivore	0.55	2.00
	Juv. macro algal browsing	0.10	2.00
	Juv. eroding grazers	< 0.01	2.00
	Juv. scraping grazers	0.34	2.00
	Azooxanthellate corals	0.11	2.00
	Hermatypic corals	< 0.01	2.00
	Non reef building corals	0.06	2.00
	Soft corals	0.11	2.00
	Shrimps and prawns	0.16	2.00
	Squid	0.06	2.00
	Octopus	0.22	2.00
	Sea cucumbers	0.01	2.00
	Lobsters	0.01	2.00
	Large crabs	0.01	2.00
	Small crabs	0.02	2.00
	Crown of thorns	< 0.01	2.00
	Giant triton	< 0.01	2.00
	Herbivorous echinoids	< 0.01	2.00
	Bivalves	0.28	2.00
	Sessile filter feeders	1.47	2.00
	Epifaunal det. inverts.	0.07	2.00
	Epifaunal carn. inverts	0.15	2.00
	Infaunal inverts.	0.56	2.00
	Jellyfish and hydroids	< 0.01	2.00
	Carn. zooplankton	6.40	2.00
	Large herb. zooplankton	4.16	2.00
	Small herb. zooplankton	7.06	2.00
	Phytoplankton	7.23	2.00
	Macro algae	29.76	2.00
	Sea grass	24.45	2.00
	Fishery discards	0.05	2.00
	Detritus	15.60	2.00
Detritivore fish	Octopus	1.30	2.00
	Sea cucumbers	2.60	2.00
	Lobsters	0.98	2.00
	Large crabs	0.36	2.00
	Small crabs	0.34	2.00
	Herbivorous echinoids	4.33	2.00
	Bivalves	1.43	2.00
	Sessile filter feeders	1.30	2.00
	Epifaunal det. inverts.	1.47	2.00
	Epifaunal carn. inverts	1.78	2.00
	Infaunal inverts.	1.78	2.00
	Fishery discards	0.05	2.00
	Detritus	82.28	2.00
Azooxanthellate corals	Carn. zooplankton	9.50	2.00
	Large herb. zooplankton	5.13	2.00
	Small herb. zooplankton	24.39	2.00
	Phytoplankton	48.78	2.00
	Detritus	12.20	2.00
Hermatypic corals	Carn. zooplankton	9.50	2.00
	Large herb. zooplankton	5.13	2.00
	Small herb. zooplankton	24.39	2.00
	Phytoplankton	48.78	2.00
	Detritus	12.20	2.00
Non reef building corals	Carn. zooplankton	9.50	2.00
	Large herb. zooplankton	5.13	2.00
	Small herb. zooplankton	24.39	2.00
	Phytoplankton	48.78	2.00
	Detritus	12.20	2.00
Soft corals	Carn. zooplankton	9.50	2.00
	Large herb. zooplankton	5.13	2.00
	Small herb. zooplankton	24.39	2.00
	Phytoplankton	48.78	2.00
	Detritus	12.20	2.00
Anemonies	Juv. large reef assoc.	6.42	2.00
	Juv. medium reef assoc.	0.56	2.00
	Ad. small reef assoc.	2.66	2.00
	Juv. small reef assoc.	3.07	2.00

Table A3.6 - (cont.)

Predator	Prey	Diet %	Vulnerability
	Small crabs	0.61	2.00
	Epifaunal det. inverts.	3.22	2.00
	Epifaunal carn. inverts	6.42	2.00
	Carn. zooplankton	19.26	2.00
	Large herb. zooplankton	19.26	2.00
	Small herb. zooplankton	12.84	2.00
	Phytoplankton	12.84	2.00
	Detritus	12.84	2.00
Penaeid shrimps	Penaeid shrimps	1.84	2.00
	Shrimps and prawns	1.00	2.00
	Large crabs	0.10	2.00
	Small crabs	0.05	2.00
	Bivalves	6.66	2.00
	Sessile filter feeders	0.40	2.00
	Epifaunal det. inverts.	0.05	2.00
	Epifaunal carn. inverts	1.79	2.00
	Infaunal inverts.	33.19	2.00
	Carn. zooplankton	0.92	2.00
	Macro algae	10.39	2.00
	Sea grass	4.17	2.00
	Detritus	39.44	2.00
Shrimps and prawns	Sessile filter feeders	0.80	1.00
	Epifaunal det. inverts.	0.10	1.00
	Epifaunal carn. inverts	0.14	1.00
	Infaunal inverts.	0.18	1.00
	Macro algae	21.18	1.00
	Sea grass	21.18	1.00
	Detritus	56.42	1.00
Squid	Juv. medium pelagic	0.02	2.00
	Juv. small pelagic	0.40	2.00
	Juv. large reef assoc.	8.10	2.00
	Juv. small planktivore	1.00	2.00
	Juv. anchovy	5.00	2.00
	Penaeid shrimps	12.15	2.00
	Shrimps and prawns	1.31	2.00
	Squid	0.50	2.00
	Carn. zooplankton	35.01	2.00
	Large herb. zooplankton	32.39	2.00
	Detritus	4.12	2.00
Octopus	Juv. large reef assoc.	1.48	2.00
	Juv. deepwater fish	0.30	2.00
	Juv. macro algal browsing	0.28	2.00
	Juv. scraping grazers	0.85	2.00
	Detritivore fish	0.02	2.00
	Penaeid shrimps	15.00	2.00
	Shrimps and prawns	0.35	2.00
	Squid	1.37	2.00
	Octopus	8.00	2.00
	Sea cucumbers	0.05	2.00
	Lobsters	0.02	2.00
	Large crabs	< 0.01	2.00
	Small crabs	0.10	2.00
	Herbivorous echinoids	0.20	2.00
	Bivalves	30.71	2.00
	Sessile filter feeders	6.40	2.00
	Epifaunal det. inverts.	0.50	2.00
	Epifaunal carn. inverts	13.57	2.00
	Infaunal inverts.	13.48	2.00
	Carn. zooplankton	2.25	2.00
	Detritus	5.08	2.00
Sea cucumbers	Macro algae	40.00	2.00
	Detritus	60.00	2.00
Lobsters	Herbivorous echinoids	1.45	1.00
	Bivalves	18.86	1.00
	Sessile filter feeders	3.00	1.00
	Epifaunal det. inverts.	1.24	1.00
	Epifaunal carn. inverts	37.73	1.00
	Infaunal inverts.	37.72	1.00
Large crabs	Penaeid shrimps	26.41	2.00
	Shrimps and prawns	1.24	2.00
	Small crabs	0.10	2.00
	Bivalves	39.62	2.00
	Epifaunal det. inverts.	0.69	2.00
	Epifaunal carn. inverts	0.25	2.00
	Infaunal inverts.	5.28	2.00
	Macro algae	13.21	2.00
	Detritus	13.21	2.00
Small crabs	Epifaunal det. inverts.	0.82	2.00
	Epifaunal carn. inverts	0.38	2.00
	Infaunal inverts.	49.40	2.00
	Macro algae	6.17	2.00
	Sea grass	37.05	2.00
	Detritus	6.17	2.00
Crown of thorns	Azooxanthellate corals	10.00	2.00
	Hermatypic corals	80.92	2.00
	Non reef building corals	7.55	2.00
	Calcareous algae	1.53	2.00
Giant triton	Crown of thorns	8.40	2.00
	Bivalves	9.72	2.00
	Epifaunal det. inverts.	30.70	2.00
	Epifaunal carn. inverts	30.70	2.00
	Infaunal inverts.	20.47	2.00
Herbivorous echinoids	Infaunal inverts.	0.04	2.00
	Macro algae	55.53	2.00
	Sea grass	44.43	2.00
Bivalves	Small herb. zooplankton	20.00	2.00
	Phytoplankton	50.90	2.00
	Detritus	29.10	2.00
Sessile filter feeders	Carn. zooplankton	4.58	2.00
	Large herb. zooplankton	1.99	2.00
	Small herb. zooplankton	20.29	2.00
	Phytoplankton	59.23	2.00
	Detritus	13.91	2.00
Epifaunal det. inverts.	Infaunal inverts.	0.09	2.00
	Macro algae	14.83	2.00
	Sea grass	14.83	2.00
	Detritus	70.25	2.00
Epifaunal carn. inverts	Juv. large reef assoc.	0.10	1.00
	Juv. small demersal	0.05	1.00
	Juv. deepwater fish	0.10	1.00
	Ad. macro algal browsing	0.10	1.00
	Juv. macro algal browsing	< 0.01	1.00
	Ad. eroding grazers	0.30	1.00
	Juv. eroding grazers	0.33	1.00
	Juv. scraping grazers	0.80	1.00
	Detritivore fish	< 0.01	1.00
	Hermatypic corals	< 0.01	1.00
	Non reef building corals	0.16	1.00
	Shrimps and prawns	0.08	1.00
	Octopus	0.13	1.00
	Sea cucumbers	0.13	1.00
	Lobsters	< 0.01	1.00
	Large crabs	< 0.01	1.00
	Small crabs	< 0.01	1.00
	Herbivorous echinoids	0.06	1.00
	Bivalves	8.34	1.00
	Sessile filter feeders	1.38	1.00
	Epifaunal det. inverts.	0.20	1.00
	Epifaunal carn. inverts	0.35	1.00
	Infaunal inverts.	75.52	1.00
	Detritus	11.84	2.00
Infaunal inverts.	Juv. large demersal	< 0.01	6.1E+06
	Juv. small demersal	0.01	6.1E+06
	Ad. macro algal browsing	< 0.01	6.1E+06
	Juv. macro algal browsing	< 0.01	6.1E+06
	Ad. eroding grazers	< 0.01	6.1E+06
	Juv. eroding grazers	< 0.01	6.1E+06
	Juv. scraping grazers	0.11	6.1E+06
	Penaeid shrimps	0.01	6.1E+06
	Shrimps and prawns	< 0.01	6.1E+06

Table A3.6- (cont.)

Predator	Prey	Diet %	Vulnerability
	Sea cucumbers	0.03	6.1E+06
	Bivalves	0.60	6.1E+06
	Epifaunal det. inverts.	< 0.01	6.1E+06
	Epifaunal carn. inverts	0.01	6.1E+06
	Infaunal inverts.	0.10	6.1E+06
	Macro algae	16.31	6.1E+06
	Sea grass	33.64	6.1E+06
	Detritus	49.16	6.1E+06
Jellyfish and hydroids	Juv. groupers	0.01	2.00
	Juv. snappers	0.01	2.00
	Juv. Napoleon wrasse	0.01	2.00
	Juv. butterflyfish	0.10	2.00
	Juv. large pelagic	0.04	2.00
	Juv. medium pelagic	0.07	2.00
	Juv. small pelagic	0.46	2.00
	Juv. large reef assoc.	0.11	2.00
	Juv. medium reef assoc.	< 0.01	2.00
	Juv. small reef assoc.	0.06	2.00
	Juv. large demersal	0.10	2.00
	Juv. small demersal	0.33	2.00
	Juv. large planktivore	0.55	2.00
	Juv. small planktivore	0.10	2.00
	Juv. anchovy	3.74	2.00
	Juv. deepwater fish	1.18	2.00
	Juv. macro algal browsing	0.10	2.00
	Juv. eroding grazers	0.04	2.00
	Juv. scraping grazers	0.22	2.00
	Jellyfish and hydroids	1.80	2.00
	Carn. zooplankton	22.05	2.00
	Large herb. zooplankton	24.70	2.00
	Small herb. zooplankton	22.10	2.00
	Phytoplankton	22.10	2.00
Carn. zooplankton	Carn. zooplankton	15.00	5.2E+21
	Large herb. zooplankton	2.50	1.50
	Small herb. zooplankton	82.50	5.2E+21
Large herb. zooplankton	Phytoplankton	100.00	7.14
Small herb. zooplankton	Phytoplankton	100.00	1.00

Appendix A4 - Ecopath parameters: 1990 RA model

Table A4.1 - 1990 RA model parameters., Biomass in t·km^{-2}. CPUE change is $CPUE_{2006}/CPUE_{1990}$. For multistanza groups, the biomass assumption refers to the combined biomass of all life history stanzas. Group biomasses estimated by Ecopath assume EE = 0.99.

#	Functional group	2006 biomass	CPUE change	Biomass assumption	1990 biomass	2006 catch	Catch assumption	1990 catch
1	Mysticetae	0.033		No change	0.033	0	No catch	0
2	Pisc. odontocetae	0.052		No change	0.052	0	No catch	0
3	Deep. odontocetae	0.091		No change	0.091	0	No catch	0
4	Dugongs	0.054		No change	0.054	0	No catch	0
5	Birds	0.366		No change	0.366	0	No catch	0
6	Reef assoc. turtles	0.043		No change	0.043	0	No catch	0
7	Green turtles	0.082		No change	0.082	0	No catch	0
8	Oceanic turtles	0.087		No change	0.087	0	No catch	0
9	Crocodiles	0.001		No change	0.001	0	No catch	0
10	Ad. groupers	0.184	1.16	Custom	0.435	0.017	Time series	0.007
11	Sub. groupers	0.057	1.16	Custom	0.062	0.009	Time series	0.003
12	Juv. groupers	0.016	1.16	Custom	0.016	0.002	Time series	7.7E-04
13	Ad. snappers	0.081	0.81	Custom	0.164	0.014	Time series	0.004
14	Sub. snappers	0.042	0.81	Custom	0.079	0.014	Time series	0.004
15	Juv. snappers	0.030	0.81	Custom	0.061	0.003	Time series	9.6E-04
16	Ad. Napoleon wrasse	0.011	0.22	CPUE	0.060	9.3E-04	10%	9.3E-05
17	Sub. Napoleon wrasse	0.020	-	CPUE	0.084	9.3E-04	10%	9.3E-05
18	Juv. Napoleon wrasse	0.004	-	CPUE	0.016	2.1E-04	10%	2.1E-05
19	Skipjack tuna	0.693	0.21	CPUE	3.188	0.348	Time series	0.335
20	Other tuna	0.541	0.21	CPUE	2.517	0.047	Time series	0.045
21	Mackerel	0.086	0.87	CPUE	0.098	0.064	Time series	0.022
22	Billfish	0.825		No change	0.825	0.050	50%	0.025
23	Ad. coral trout	0.033		No change	0.036	0.002	50%	8.2E-04
24	Juv. coral trout	0.007		No change	0.005	1.6E-04	50%	8.2E-05
25	Ad. large sharks	0.061	1.09	CPUE	0.020	0.025	Time series	0.017
26	Juv. large sharks	0.053	-	CPUE	0.084	0.003	as 2006	0.003
27	Ad. small sharks	0.041	1.09	CPUE	0.007	0.006	Time series	0.004
28	Juv. small sharks	0.017	-	CPUE	0.046	6.2E-04	50%	3.1E-04
29	Whale shark	0.003		No change	0.003	0	No catch	0
30	Manta ray	0.003		No change	0.003	0	No catch	0
31	Adult rays	0.177		No change	0.185	0.019	50%	0.010
32	Juv. rays	0.068		No change	0.060	0.002	50%	9.5E-04
33	Ad. butterflyfish	0.243		No change	0.249	0.016	50%	0.008
34	Juv. butterflyfish	0.081		No change	0.076	0.002	50%	7.8E-04
35	Cleaner wrasse	0.009		No change	0.009	8.2E-04	50%	4.1E-04
36	Ad. large pelagic	0.054	0.64	CPUE	0.091	0.031	Time series	0.009
37	Juv. large pelagic	0.032	-	CPUE	0.043	0.004	50%	0.002
38	Ad. medium pelagic	0.011	0.53	CPUE	0.031	0.007	Time series	0.003
39	Juv. medium pelagic	0.017	-	CPUE	0.021	0.003	50%	0.002
40	Ad. small pelagic	0.071	0.88	CPUE	0.104	0.034	Time series	0.008
41	Juv. small pelagic	0.108	-	CPUE	0.102	0.004	50%	0.002
42	Ad. large reef assoc.	7.128	1.08	CPUE	6.778	0.577	Time series	0.093
43	Juv. large reef assoc.	4.512	-	CPUE	4.043	0.112	50%	0.056
44	Ad. medium reef assoc.	2.853	0.18	CPUE	13.892	0.350	Time series	0.332
45	Juv. medium reef assoc.	2.355	-	CPUE	14.426	0.035	50%	0.018
46	Ad. small reef assoc.	0.259	0.11	CPUE	1.313	0.150	Time series	0.173
47	Juv. small reef assoc.	0.135	-	CPUE	2.137	0.015	50%	0.008
48	Ad. large demersal	0.127	0.32	CPUE	0.238	0.024	Time series	0.010
49	Juv. large demersal	0.135	-	CPUE	0.589	0.005	50%	0.002

Table A4.1 – ocnt.

#	Functional group	2006 biomass	CPUE change	Biomass assumption[1]	1990 biomass	2006 catch	Catch assumption	1990 catch
50	Ad. small demersal	0.192	0.20	CPUE	0.977	0.028	Time series	0.019
51	Juv. small demersal	0.135	-	CPUE	0.688	0.003	50%	0.002
52	Ad. large planktivore	1.000	0.71	CPUE	1.496	0.300	Time series	0.115
53	Juv. large planktivore	0.887		No change	1.168	0.030	50%	0.015
54	Ad. small planktivore	0.414		No change	0.300	0.013	50%	0.006
55	Juv. small planktivore	0.614		No change	0.728	0.001	50%	7.1E-04
56	Ad. anchovy	1.500	0.30	CPUE	4.518	0.509	Time series	0.442
57	Juv. anchovy	2.237	-	CPUE	7.840	0.051	50%	0.025
58	Ad. deepwater fish	0.600	0.48	CPUE	0.675	0.008	Time series	0.004
59	Juv. deepwater fish	0.794		No change	0.719	9.2E-04	50%	4.6E-04
60	Ad. macro algal browsing	0.250		No change	0.164	8.2E-04	50%	4.1E-04
61	Juv. macro algal browsing	0.500		No change	0.585	8.2E-05	50%	4.1E-05
62	Ad. eroding grazers	0.526		No change	0.525	2.7E-04	50%	1.4E-04
63	Juv. eroding grazers	0.256		No change	0.255	2.7E-05	50%	1.4E-05
64	Ad. scraping grazers	0.348		No change	0.239	0.022	50%	0.011
65	Juv. scraping grazers	1.656		No change	1.137	0.002	50%	1.1E-03
66	Detritivore fish	0.016		No change	0.016	0.002	50%	9.6E-04
67	Azooxanthellate corals	0.600		No change	0.600	0	No catch	0
68	Hermatypic corals	0.875		No change	0.875	1.0E-03	as 2006	1.0E-03
69	Non reef building corals	0.600		No change	0.600	0	No catch	0
70	Soft corals	0.600		No change	0.600	0	No catch	0
71	Calcareous algae	0.100		No change	0.100	0	No catch	0
72	Anemonies	0.500		No change	0.500	0	No catch	0
73	Penaeid shrimps	2.000	1.40	CPUE	1.426	0.145	Time series	0.064
74	Shrimps and prawns	2.000	1.40	CPUE	1.426	0.017	Time series	0.007
75	Squid	0.237	1.03	CPUE	0.231	0.006	Time series	0.005
76	Octopus	1.000	0.92	CPUE	1.086	1.2E-05	Time series	0.000
77	Sea cucumbers	0.971	0.85	CPUE	1.138	0.006	Time series	0.004
78	Lobsters	0.219	1.14	CPUE	0.192	0.044	Time series	0.012
79	Large crabs	0.255	0.89	CPUE	0.286	0.003	Time series	0.002
80	Small crabs	0.255	0.89	CPUE	0.286	0.003	Time series	0.002
81	Crown of thorns	0.219		No change	0.219	0	no catch	0
82	Giant triton	0.050		No change	0.050	0.003	50%	0.002
83	Herbivorous echinoids	0.722		No change	0.722	0.003	50%	1.4E-03
84	Bivalves	9.189	1.54	CPUE	5.973	0.006	Time series	0.003
85	Sessile filter feeders	4.580		No change	4.580	1.0E-03	50%	5.0E-04
86	Epifaunal det. inverts.	1.400		No change	1.400	0.003	50%	0.002
87	Epifaunal carn. inverts	5.600	1.49	Ecopath	4.861	0.004	Time series	0.002
88	Infaunal inverts.	27.422		No change	27.422	0	No catch	0
89	Jellyfish and hydroids	0.100		No change	0.220	0	No catch	0
90	Carn. zooplankton	1.000		Ecopath	1.548	0	No catch	0
91	Large herb. zooplankton	0.560		Ecopath	1.086	0	No catch	0
92	Small herb. zooplankton	2.430		No change	2.430	0	No catch	0
93	Phytoplankton	26.100		No change	26.100	0	No catch	0
94	Macro algae	39.389		No change	39.389	0	No catch	0
95	Sea grass	20.157		No change	20.157	0	No catch	0
96	Mangroves	19.136		No change	6.147	0	No catch	0
97	Fishery discards	20.000		No change	20.000	0	No catch	0
98	Detritus	100.000		No change	100.000	0	No catch	0

Appendix A5 - Ecosim parameters: 1990-2006 RA model

Table A5.1 - Feeding rate parameters.

Group	Max relative feeding time	Feeding time adjustment
Mysticetae	2	0.5
Pisc. odontocetae	2	0.5
Deep. odontocetae	2	0.5
Dugongs	2	0.5
Birds	2	0.5
Reef assoc. turtles	2	0.5
Green turtles	2	0.5
Oceanic turtles	2	0.5
Crocodiles	2	0.5
Ad. groupers	2	0.5
Sub. groupers	2	0.5
Juv. groupers	2	0.5
Ad. snappers	2	0.5
Sub. snappers	2	0.5
Juv. snappers	2	0.4
Ad. Napoleon wrasse	2	0.5
Sub. Napoleon wrasse	2	0.5
Juv. Napoleon wrasse	2	0.5
Skipjack tuna	2	0.5
Other tuna	2	0.5
Mackerel	2	0.5
Billfish	2	0
Ad. coral trout	2	0.5
Juv. coral trout	2	0.5
Ad. large sharks	2	0.5
Juv. large sharks	2	0.5
Ad. small sharks	2	0.5
Juv. small sharks	2	0.5
Whale shark	2	0.5
Manta ray	2	0.5
Adult rays	2	0.1
Juv. rays	2	0.1
Ad. butterflyfish	2	0.5
Juv. butterflyfish	2	0.5
Cleaner wrasse	2	0.5
Ad. large pelagic	2	0.5
Juv. large pelagic	2	0.5
Ad. medium pelagic	2	0.5
Juv. medium pelagic	2	0.5
Ad. small pelagic	2	0.5
Juv. small pelagic	2	0.5
Ad. large reef assoc.	2	0
Juv. large reef assoc.	2	0.5
Ad. medium reef assoc.	2	0.05
Juv. medium reef assoc.	2	0.5
Ad. small reef assoc.	2	0.5
Juv. small reef assoc.	2	0.5
Ad. large demersal	2	0.5
Juv. large demersal	2	0.5
Ad. small demersal	2	0.5
Juv. small demersal	2	0.5
Ad. large planktivore	2	0.5
Juv. large planktivore	2	0.5
Ad. small planktivore	2	0.5
Juv. small planktivore	2	0.5
Ad. anchovy	2	0.5
Juv. anchovy	2	0.5
Ad. deepwater fish	2	0.5
Juv. deepwater fish	2	0.5
Ad. macro algal browsing	2	0.5
Juv. macro algal browsing	2	0.5
Ad. eroding grazers	2	0.5
Juv. eroding grazers	2	0.5
Ad. scraping grazers	2	0.5
Juv. scraping grazers	2	0.5
Detritivore fish	2	0.5
Azooxanthellate corals	2	0.5
Hermatypic corals	2	0.5
Non reef building corals	2	0.5
Soft corals	2	0.5
Calcareous algae	-	-
Anemonies	2	0.5
Penaeid shrimps	2	0.5
Shrimps and prawns	2	0.5
Squid	2	0.5
Octopus	2	0.5
Sea cucumbers	2	0.5
Lobsters	2	0.5
Large crabs	2	0.5
Small crabs	2	0.5
Crown of thorns	2	0.5
Giant triton	2	0.5
Herbivorous echinoids	2	0.5
Bivalves	2	0.5
Sessile filter feeders	2	0.5
Epifaunal det. inverts.	2	0.5
Epifaunal carn. inverts	2	0.5
Infaunal inverts.	2	0.5
Jellyfish and hydroids	2	0.5
Carn. zooplankton	2	0.5
Large herb. zooplankton	2	0.5
Small herb. zooplankton	2	0.5

Appendix A6 - Time series data

Figure A6.1 - Estimated fisheries catch in Raja Ampat. Source: DKP and Trade and Industry Office. Life history stanzas and body size categories may be aggregated.

A.) Catch

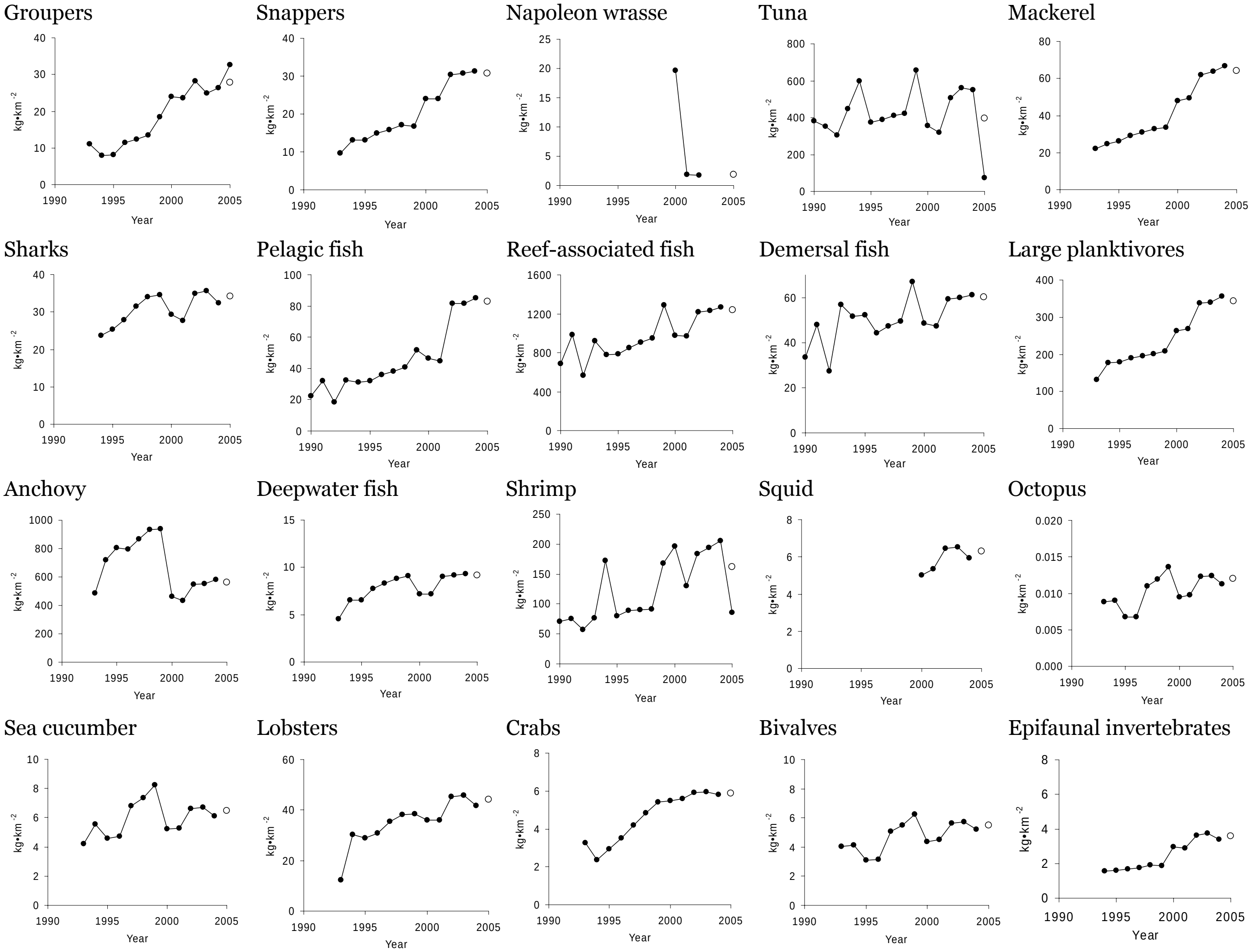
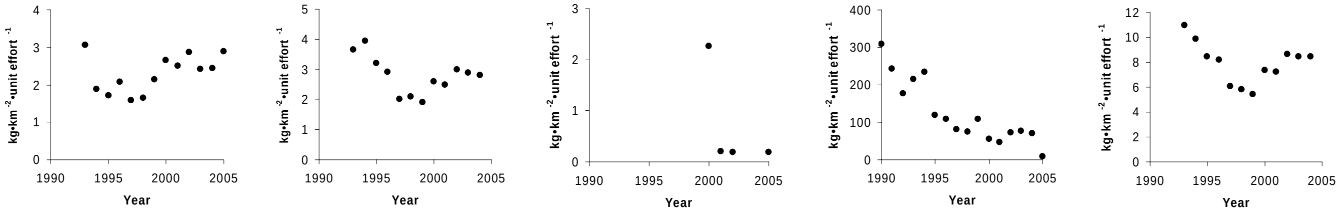


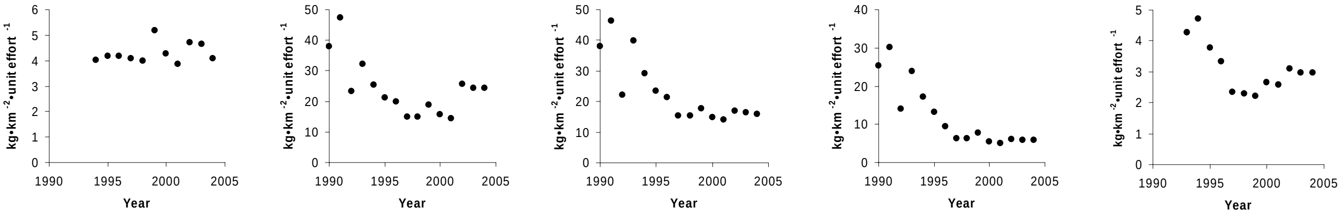
Figure A6.2 - Estimated catch per unit effort in Raja Ampat. Source: DKP and Trade and Industry Office. Life history stanzas and body size categories may be aggregated.

B.) Catch per unit effort

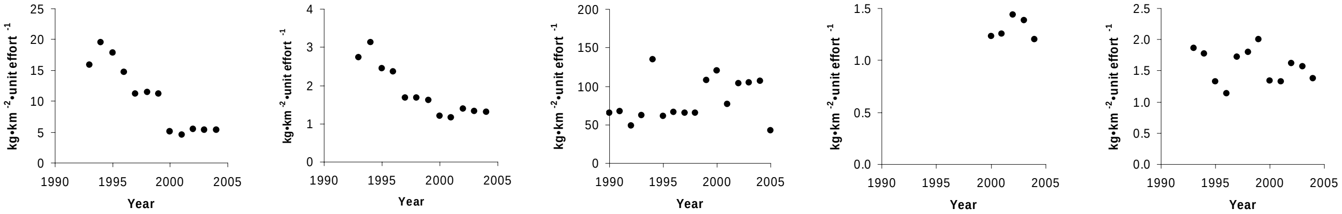
Groupers Snappers Napoleon wrasse Tuna Mackerel



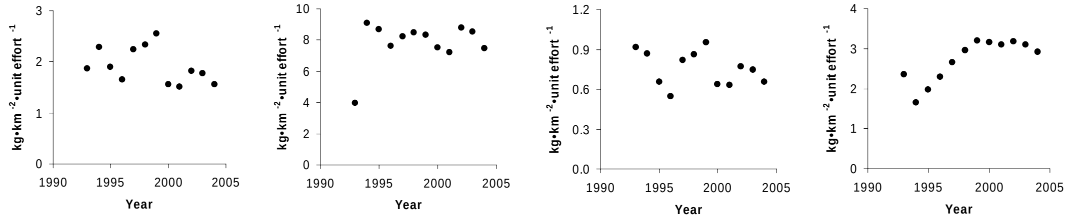
Sharks Pelagic fish Reef-associated fish Large demersal fish Large planktivores



Anchovy Deepwater fish Shrimp Squid Octopus



Sea cucumber Lobsters Crabs Bivalves



APPENDIX B - EWE RESULTS

Appendix B1 - Ecopath results

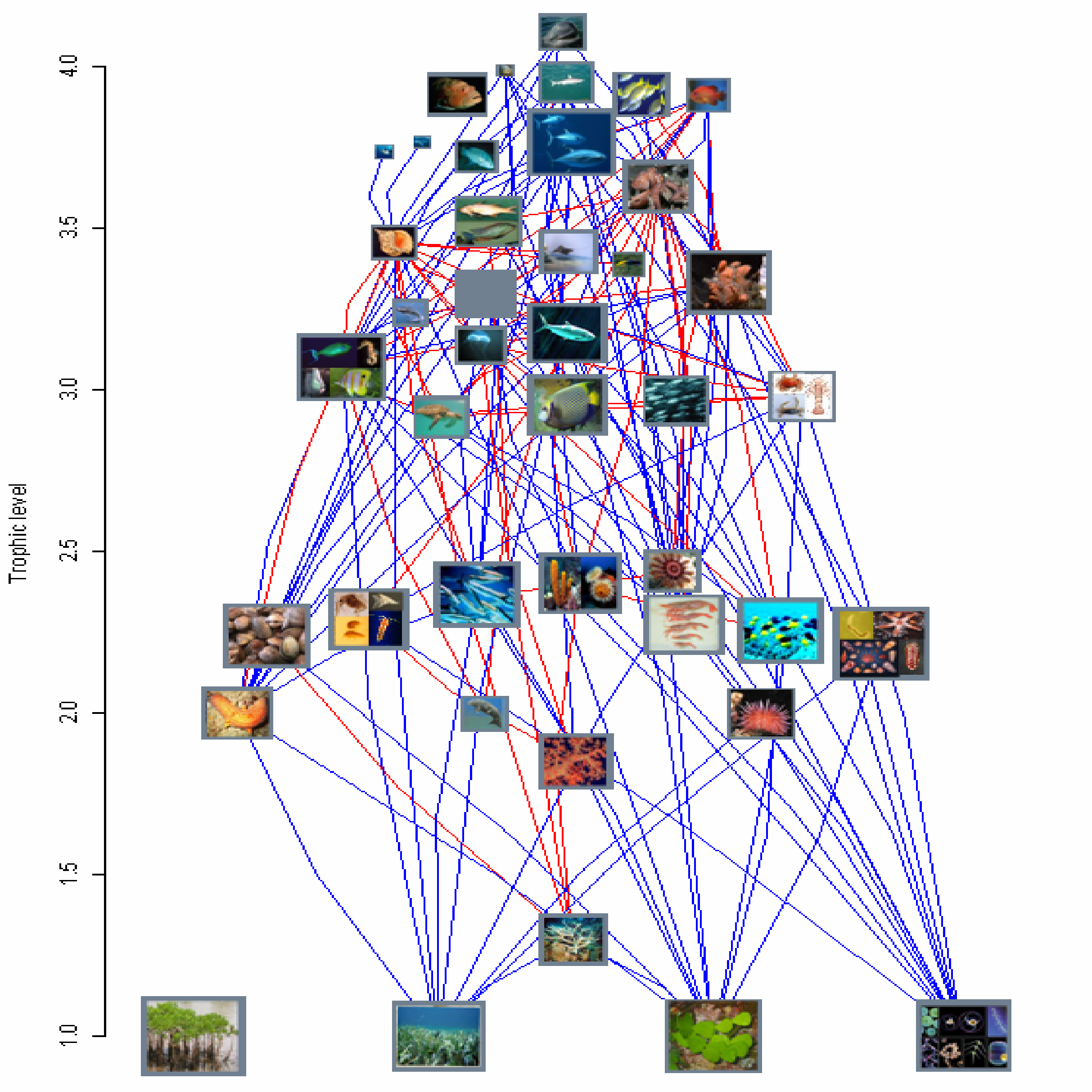


Figure B1.1 - Food web diagram. Trophic flows in the Raja Ampat marine ecosystem. Y-axis indicates functional group trophic level (TL); apex predators appear at the top, basal species are at the bottom. Boxes show model functional groups (simplified); box size is scaled logarithmically to represent relative group biomass. Lines show diet matrix connectances of 20% or greater. Coloured lines indicate direction of trophic flow (blue lines: predator is higher TL; red lines: predator is lower TL).

Appendix B2 - Ecosim results

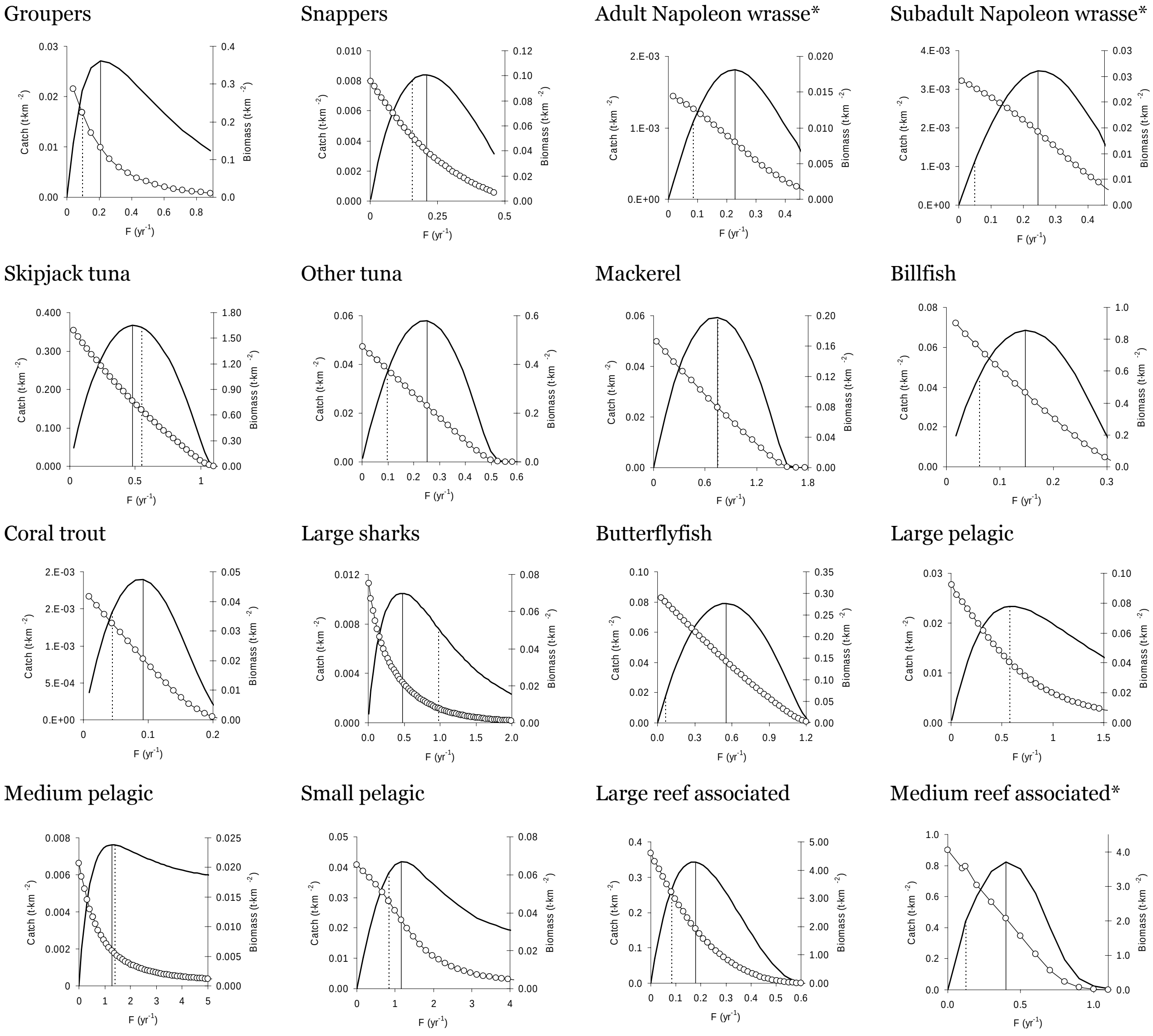
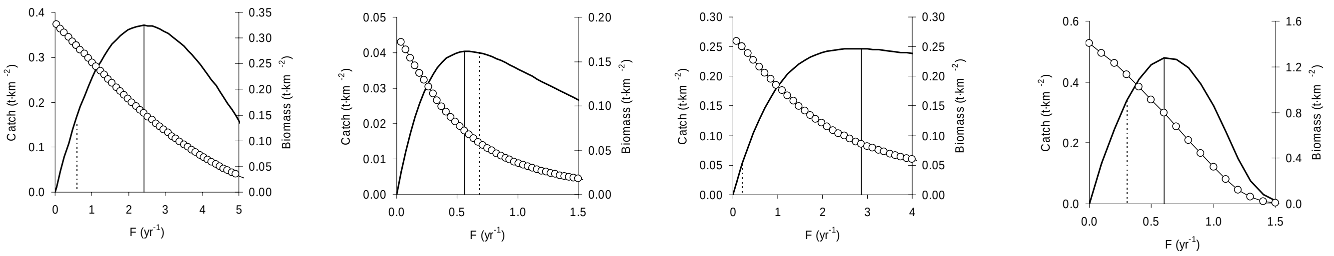


Figure B2.1 - Equilibrium analysis of commercial groups. Curved line shows surplus yield; vertical solid line shows F_{msy}; broken vertical line shows fishing mortality in 2006 (F_{2006}) (baseline); open circles show equilibrium biomass. Adult stanzas shown for multi-stanza groups unless otherwise specified. Asterix indicates equilibriums were determined manually; F was incremented for all life history stanzas.

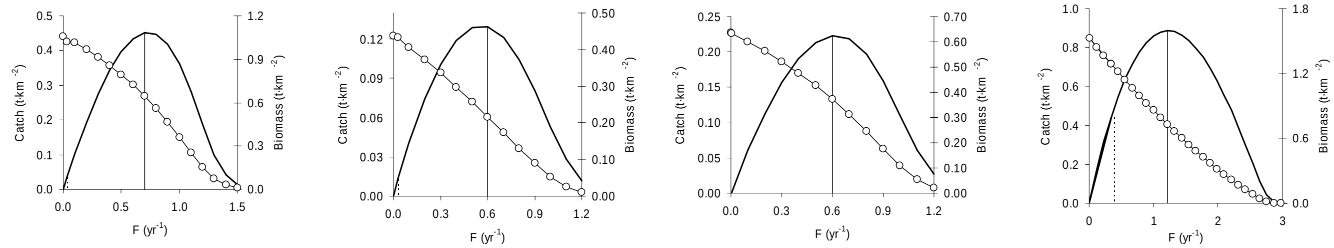
Figure B2.1 - (cont.)


Small reef associated

Large demersal

Small demersal

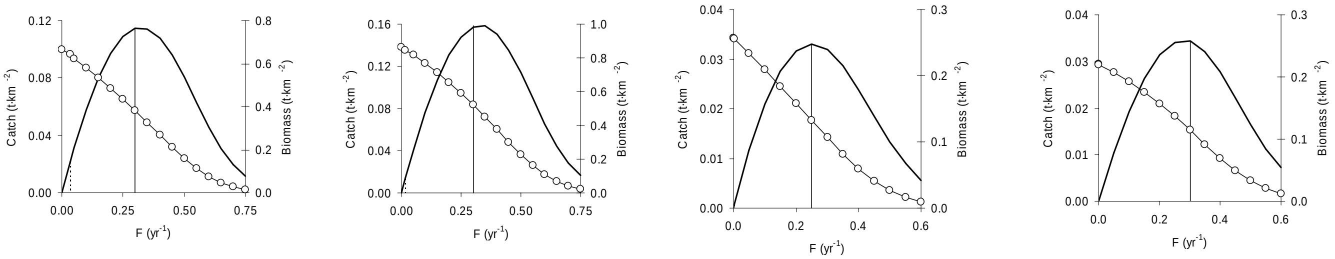
Adult large planktivores*


Juvenile large planktivores*

Adult small planktivores*

Juvenile small planktivores*

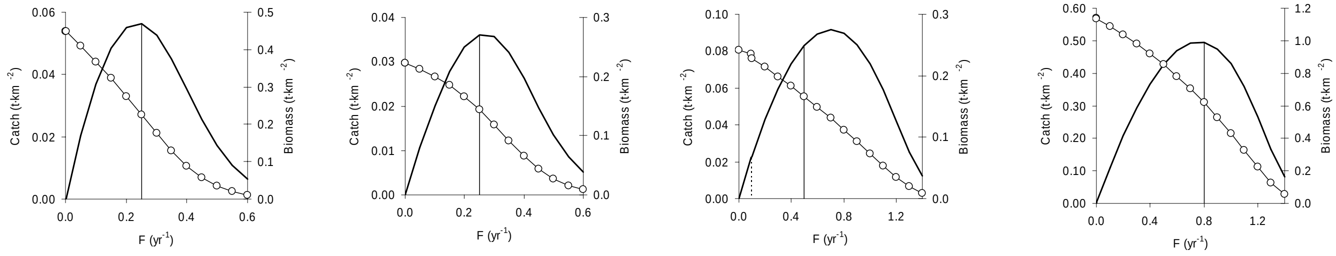
Anchovy


Adult deepwater fish*

Juvenile deepwater fish*

Adult macro algal browsing*

Juvenile macro algal browsing*

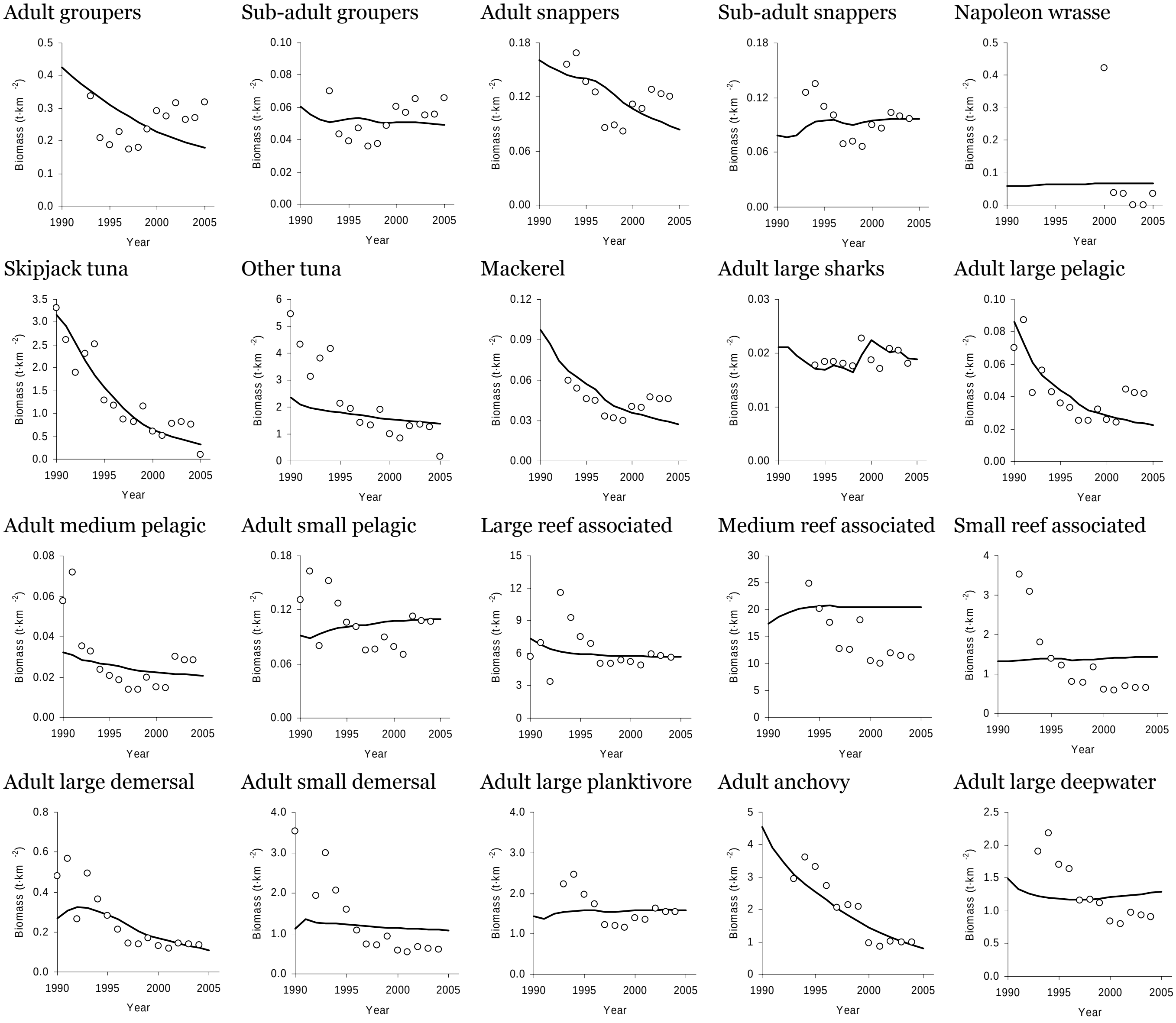

Adult eroding grazers*

Juvenile eroding grazers*

Adult scraping grazers*

Juvenile scraping grazers*

* Equilibrium was determined manually; fishing mortality was incremented for all life history stanzas.



Adult groupers

Sub-adult groupers

Adult snappers

Sub-adult snappers

Napoleon wrasse

Skipjack tuna

Other tuna

Mackerel

Adult large sharks

Adult large pelagic

Adult medium pelagic

Adult small pelagic

Large reef associated

Medium reef associated

Small reef associated

Adult large demersal

Adult small demersal

Adult large planktivore

Adult anchovy

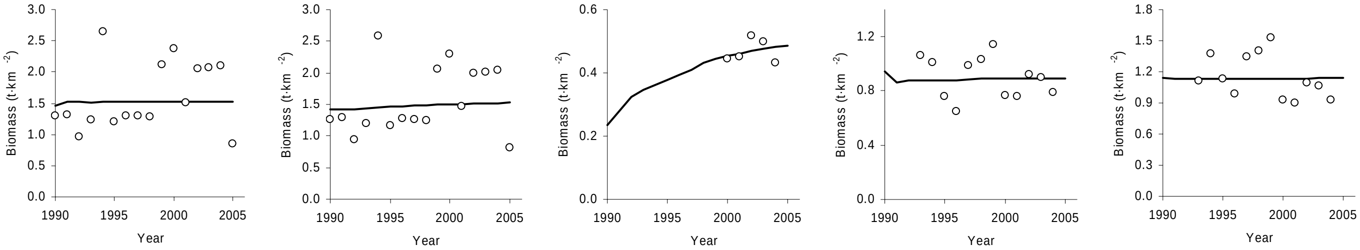
Adult large deepwater

Figure B2.2 - Predicted and observed biomass time series 1990-2006 for Raja Ampat. Time series fits are based on DKP and Trade and Industry Office catch per unit effort (CPUE). Black lines indicate biomass predictions, open circles represent CPUE scaled to minimize residuals versus predicted biomass.

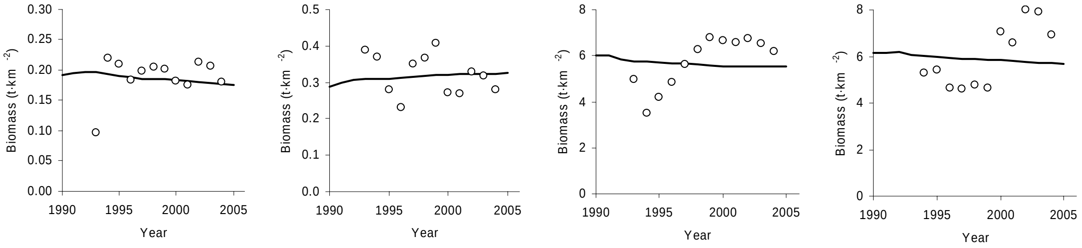
Figure B2.2 - (cont.)

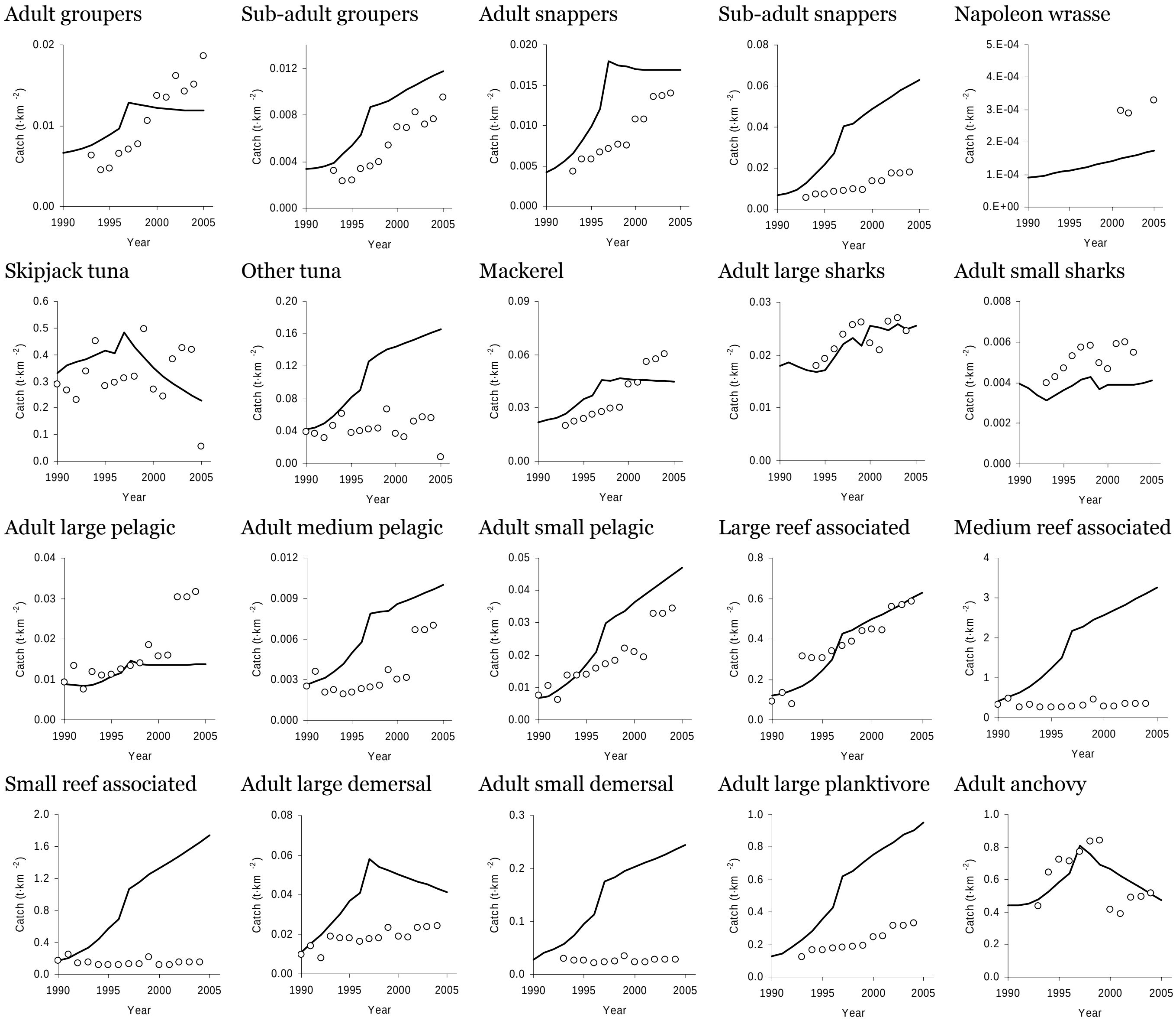
A.) Biomass

Penaeid shrimps | Shrimps and prawns | Squid | Octopus | Sea cucumbers



Lobsters | Large crabs | Bivalves | Epifaunal carnivorous inv.





Adult groupers

Sub-adult groupers

Adult snappers

Sub-adult snappers

Napoleon wrasse

Skipjack tuna

Other tuna

Mackerel

Adult large sharks

Adult small sharks

Adult large pelagic

Adult medium pelagic

Adult small pelagic

Large reef associated

Medium reef associated

Small reef associated

Adult large demersal

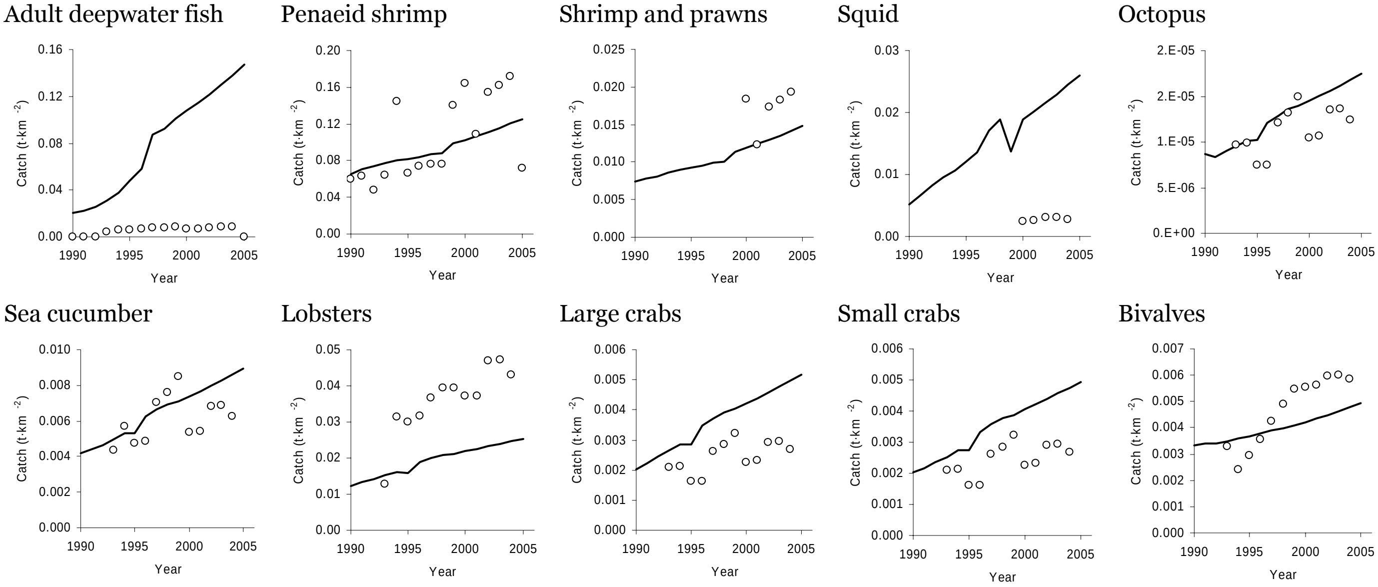
Adult small demersal

Adult large planktivore

Adult anchovy

Figure B2.3 - Predicted and observed catch time series 1990-2006 for Raja Ampat. Time series fits are based on DKP and Trade and Industry Office landings. Black lines indicate catch predictions including unreported catch, open circles represent absolute reported landings. Models are driven by an independant effort series.

Figure B2.3 - (cont.)


Adult deepwater fish

Penaeid shrimp

Shrimp and prawns

Squid

Octopus

Sea cucumber

Lobsters

Large crabs

Small crabs

Bivalves

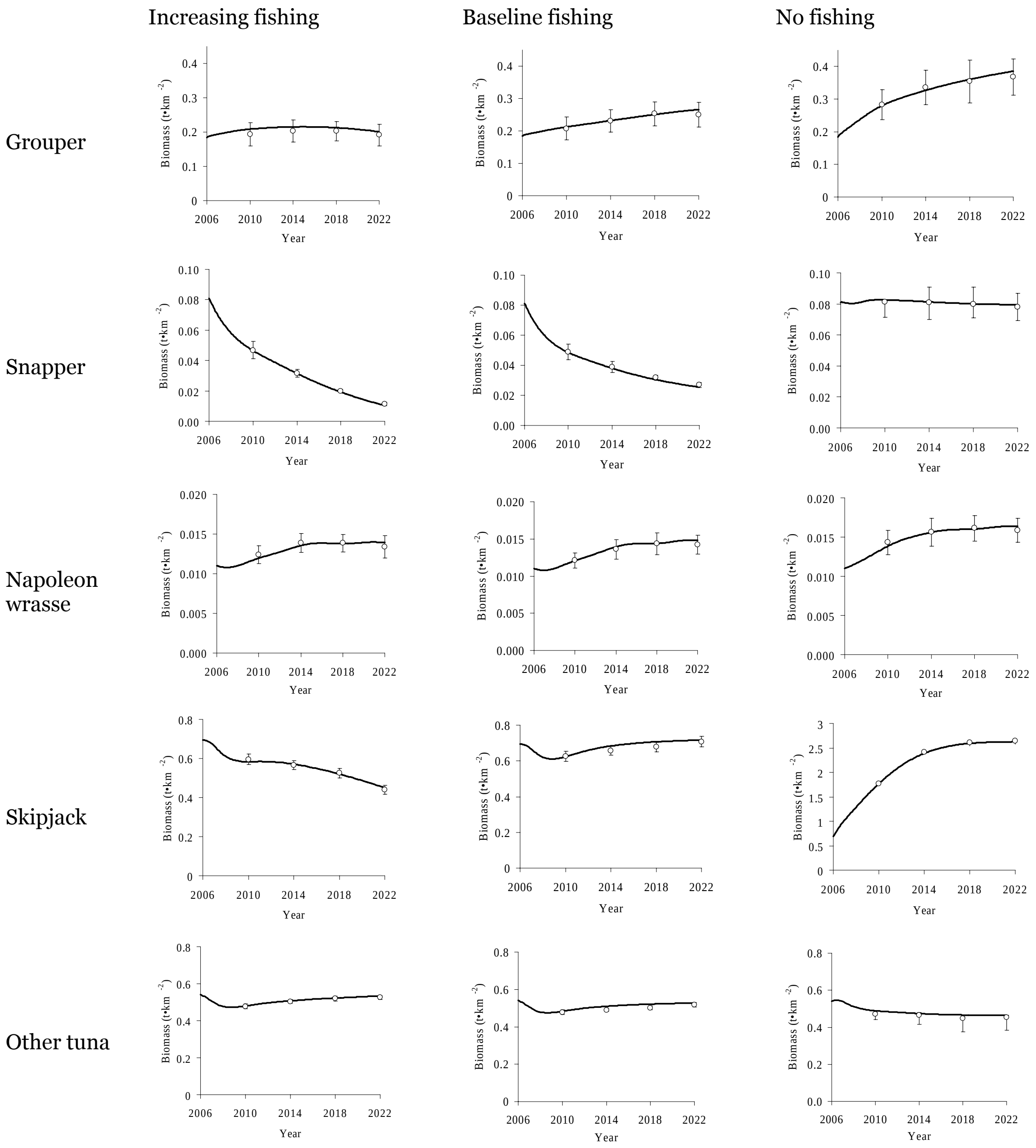
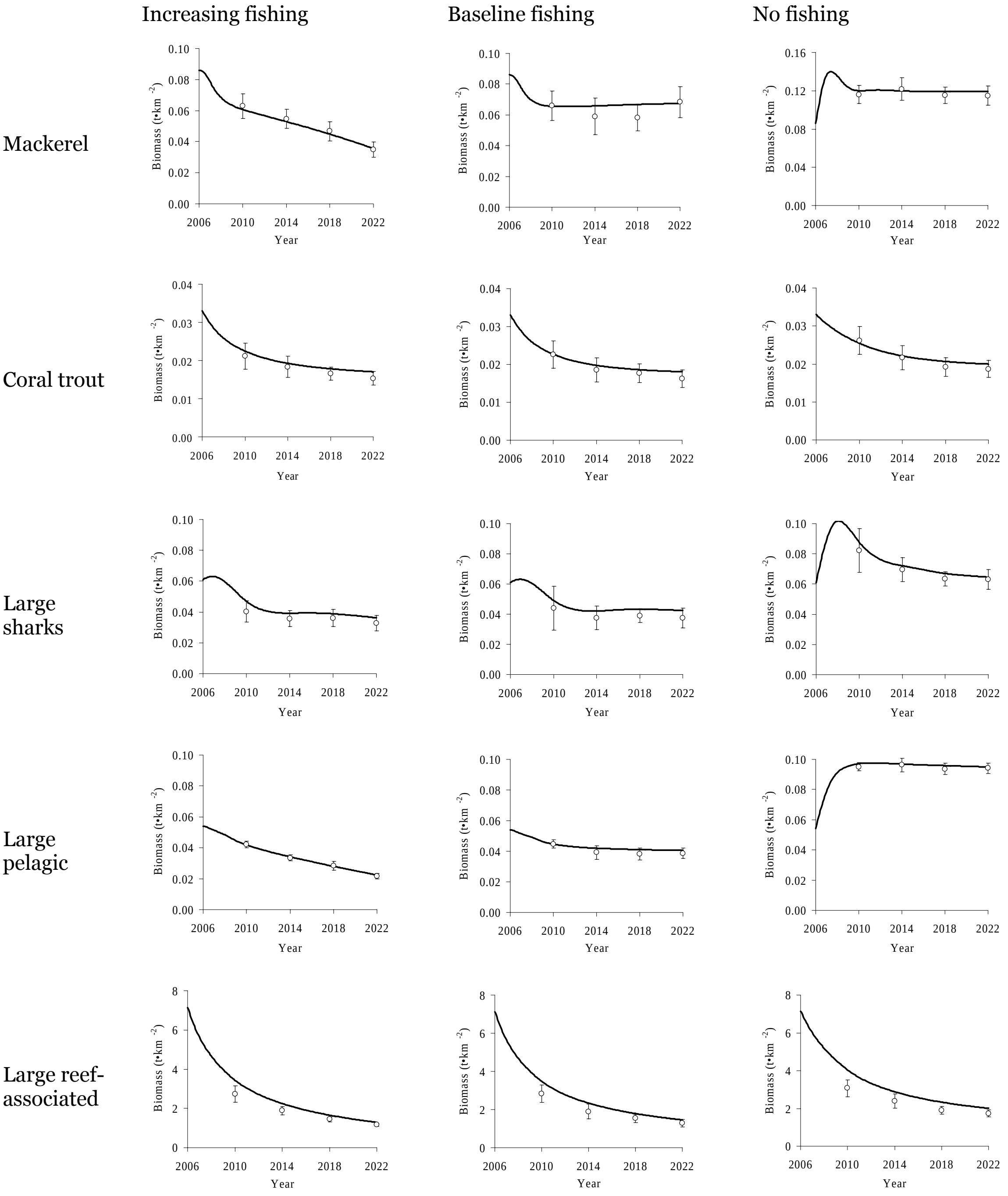


Figure B2.4 - Challenges to RA Ecosim model (2006-2022). Three fishing scenarios challenge Ecosim. The 'increased fishing' scenario increments fishing mortality on all exploited groups by 3.2% per year; the 'baseline fishing' scenario extends current (2006) fishing mortalities forward; the 'no fishing' scenario reduces F to zero for all groups. We expect exploited functional groups to increase relative to baseline when fishing is reduced, and decrease when fishing is increased. Error bars show the error range predicted by a Monte Carlo analysis that varies initial biomass parameters in Ecopath for commercial groups +/- 20%. Error bars show 1 SD around the mean (white circle). Black line shows the baseline model run (i.e., applying the described group biomass values).

Figure B2.4 - (cont.)



THE MIGRANT ANCHOVY FISHERY IN KABUI BAY, RAJA AMPAT, INDONESIA: CATCH, PROFITABILITY AND INCOME DISTRIBUTION

Megan Bailey[a], Christovel Rotinsulu[b] and U. Rashid Sumaila[a]
[a]*Fisheries Economics Research Unit, Fisheries Centre,*
University of British Columbia, 2202 Main Mall, Vancouver, BC, Canada, V6T 1Z4
[b]*Conservation International Indonesia, Sorong 98413, West Irian Jaya, Indonesia.*

Abstract

The Raja Ampat regency government in Papua, Indonesia, is a newly created political unit seeking to increase development sustainably for the 31,000 people living there. Increases in fisheries production is one suggested development plan. This paper analyzes the economics of the Kabui Bay migrant anchovy fishery, and estimates unreported annual catch, in hopes of providing necessary information to assist the regency in future fisheries management decisions. Catch, costs and revenues of the fishery were estimated using data based on interviews with migrant fishers conducted in April and November of 2006, and running Monte Carlo simulations across the ranges of all parameters. The mean annual catch estimate for the entire fleet is 3,384 t, and ranged between 2,463 t and 4,452 t. Estimated annual revenue of the fishery ranged from about US $1 to $2 million, with a mean of US$ 1.6 million. Per capita fisher income ranged from US$ 1,440 and US$ 2,254, with a mean of US $1,835 per year. The anchovy fishers interviewed appear to be making almost twice as much as the average fisher in Raja Ampat. The economic content in this paper is simple, and thus whatever value it has lies in its contribution in spite of the scant literature and available data pertaining to fisheries in Raja Ampat. The catch estimates from Kabui Bay can be extended to the other anchovy fisheries to estimate total annual unreported anchovy catch in Raja Ampat, and perhaps elsewhere in Indonesia. The profitability of the fishery suggests that the Raja Ampat Fisheries Bureau could begin capturing some of the economic rent from the fishery to help fund a monitoring and management program of the anchovy fishery, and indeed fund management of other fisheries within Raja Ampat.

INTRODUCTION

As a country composed of over 17,000 islands, differing marine resource management needs are felt throughout Indonesia. Historically, the capital city of Jakarta, on the island of Java, has been the center of resource control. But like many other countries, Indonesia has seen destruction of its coral reefs, and the serial depletion of fish stocks, mainly sharks, tunas, and reef associated fishes (Tomascik *et al.*, 1997). In 1999, the Indonesian government instituted a decentralization plan throughout the country, giving more power to regency level authorities (Usman, 2001). One of the main reasons for this shift is the assumption that local authorities will have a more accurate idea of the needs of their communities (Usman, 2001; Satria and Matsuda, 2004, Sachs, 2005).

Despite decreasing fish stocks and habitat degradation in other areas of the country, the ecosystem on the western most side of the province of Papua is quite pristine. A new political unit called the Raja Ampat regency has been created in this area, and recent ecological surveys suggest that the region boasts the highest coral reef biodiversity in the world (Mckenna *et al.*, 2002; TNC, 2003). This biodiversity, however, is threatened by increasing fishing activity, both

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legal and illegal, in Raja Ampat (TNC, 2003, 2004a) Neighbouring provinces (Komodo, Sulawesi) and countries (Philippines, Palau) can no longer catch sufficient fish from their own depleted waters, and thus fishers from these areas are fishing in the waters of Raja Ampat (Mckenna *et al.* 2002, TNC 2003, 2004a). Not much is known in terms of how much fish is being caught by migrant fishers, or how much revenue these fisheries generate. Such unregulated catches can negatively affect fish stock sizes and undermine management goals (Pitcher *et al.*, 2002). Thus there is a need to quantify the migrant fishery catch to help ensure that fish stocks in Raja Ampat are being fished sustainably.

This paper provides a description of the Raja Ampat area, as well as an overview of one of the major migrant-dominated fisheries: the anchovy lantern fishery. Annual anchovy catch is estimated and economics of the fishery analyzed. Annual gross revenue is calculated and costs are discussed, to produce an estimated annual profit for 2006, from the fishery's point of view (i.e., private costs and benefits). The Fisheries Bureau in Sorong, the closest landings port adjacent to Raja Ampat, has no official catch statistics for migrant anchovy fisheries, and thus this paper can hopefully be used by the Raja Ampat regency as they attempt to develop their marine resource management plan in the coming years.

AREA DESCRIPTION

The province of Papua is the most easterly of Indonesia's 33 provinces, and shares its island with the country of Papua New Guinea to the east. Raja Ampat was designated a regency in 2002, and includes the four main islands of Waigeo, Batanta, Salawati, and Misool, where the majority of the population resides, and consists of about 600 other islands (Figure 1) (Mckenna *et al.*, 2002; TNC, 2003, 2004b). There are about 31,000 people dispersed throughout the 4 million hectare area that makes up Raja Ampat (TNC, 2003; Dohar and Anggraeni, 2006).

Approximately 1,200 species of fish are present in Raja Ampat (TNC, 2003, Ainsworth *et al.*, 2006). Fish caught in the area include wrasse, grouper, snapper, parrotfish, tuna, surgeonfish, squid, and small pelagics like sardine and anchovy (Mckenna *et al.*, 2002; TNC, 2003, 2004a)**.**

In this regency, marine resources are paramount. Throughout the year most regency inhabitants are involved in subsistence fishing, even though they may be employed in other industries as their main economic source (farming, construction, pearl farming, etc.; TNC, 2003, 2004a). A recent valuation report conducted by Conservation International Indonesia estimates that seventy percent of the population engages in fishing (Dohar and Anggraeni, 2006). Small-scale commercial sale of fish, often just within a village, occurs throughout the year. When weather permits (during calm seas), the amount of commercial fishing for export in Raja Ampat increases, and catch is often sold at the Sorong fish market on mainland Papua (TNC, 2003, 2004a).

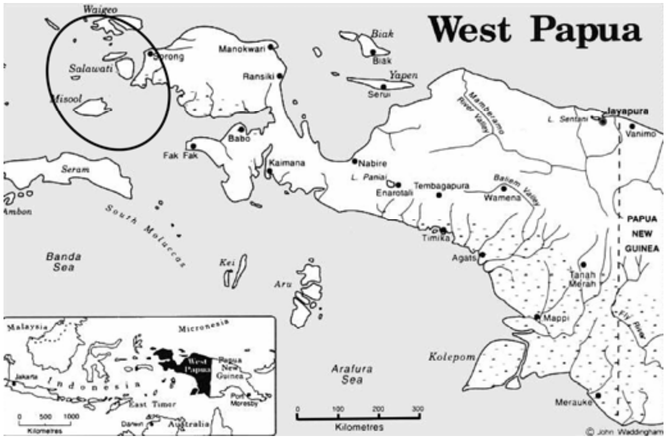

Figure 1. Map of Raja Ampat, a newly created regency (circled) in West Papua, Indonesia (inset), available from www.cs.utexas.ued/users/cling/papua/map.jpg

The dispersed population and large regency area means that fisheries management in Raja Ampat has historically been limited, or non-existent. But with a new regency government in place, Raja Ampat officials are seeking to increase development in the area, with increases in the fisheries sector highlighted as a probable development path (Wanma, 2000; TNC, 2003). This will mean that members of the Raja Ampat Fisheries Bureau (DKP) will need to implement effective monitoring, control, and enforcement for development to proceed sustainably. Both native and migrant fishing activity will need to be managed.

THE MIGRANT ANCHOVY FISHERY

Migrant fishers (fishers who travel from one area to another in search of work, engaging in employment away from their permanent residence) can often enter Raja Ampat waters, drop their lines or nets, and fish uninterrupted. This type of migrant fishing activity is rarely regulated. Illegal, unreported, and unregulated (IUU) fisheries in Indonesia, and the world over, make fisheries management difficult (Sumaila *et al.*, 2006). Fisheries stock assessment work depends on accurate records of catch and effort, both of which are underestimated with IUU fishing (Pitcher *et al.*, 2002). For future development of fisheries resources, the DKP will need to invest adequate resources to identify the types of unregulated migrant fishing activity in the area, and to estimate the catch and profitability of such fisheries. Regulating migrant fisheries can increase fisheries revenue to the regency, and can help the DKP monitor destructive fishing practices, a major problem in Indonesia (Pet-Soede and Erdmann, 1998).

The anchovy fishery in Kabui Bay is an unregulated migrant fishery. The fishers operate in an area where there are no catch limits set by the DKP, and no requirements for reporting that catch. In 1999, 20 men from the Indonesian province of South East (SE) Sulawesi came to Papua for fishing access in Kabui Bay, on the southwest side of Waigeo Island. At that time, Raja Ampat was under the authority of the Sorong regency, based on mainland Papua. The migrant fishers paid a one-time access fee of 1 million Rupiahs (IDR) (=US$111) to the Sorong Fisheries Department, and have been fishing in the bay ever since. The fishers set up a temporary settlement camp, but this has become a second home for the men. Today, about 250 migrant fishers live in Kabui Bay fishing anchovy. Although they no longer pay money to regency level authorities, the anchovy fishers do owe monthly access fees to two villages in order to live on the land, and fish in the bay's waters.

Fresh anchovy is fished at dusk by dropping nets attached between two wooden boats manned by 5 fishers. The nets are lowered about 13 meters down, and the fishers turn on a kerosene lantern. The light attracts the anchovy, and a few hours later the nets are pulled up with manual winches. Anchovy are then set on dozens of racks for one and a half days to dry out. This fish is called *puri* or *ikan teri* by Indonesians. Vendors in Sorong will sell bags of puri at the local market, but the fish from Kabui Bay is virtually 100% exported to the province of Java, in western Indonesia.

Fishers remain at the settlement camp for 4 or 5 months, at which time they go back to their homes in Buton, SE Sulawesi. It is in the province of SE Sulawesi that most of the income generated from the fishery will be spent. Other than rice, the men farm or fish everything they consume, including cassava, tomatoes, chili peppers, bananas and coconut. Similar anchovy fisheries are set up elsewhere in Raja Ampat, namely Aljui Bay and the area north of Misool. However, like Kabui Bay, there are limited catch data from these fisheries. As far as the Kabui Bay anchovy fishers can recall, the DKP has never asked them what, or how much, they are fishing. Furthermore, because the majority of the anchovy catch is exported, it is never officially landed anywhere in Papua, and therefore Papua has incomplete catch statistics.

This paper presents annual catch and fisher profitability estimates for 2006. A static analysis was chosen to simplify the issue of changes in annual group composition (i.e., number of vessels fishing), changes in costs and revenues of fishing, as well as inter-annual catch variations.

Figure 2. Photographs of Kabui Bay anchovy fishery. Clockwise from top left: A, authors Bailey and Rotinsulu interview fishers in April 2006; B, fishers stand beside 80 kg bags of dried anchovy; C, a fisher dries the days' catch on racks; D, anchovy fishery boats. *Photo credits*: A, A.Dohar; B, C, M.Bailey; D, C.Rotinsulu.

INTERVIEWS

Official anchovy fishery data from Raja Ampat does not exist and thus could not be acquired from the Sorong Fisheries Bureau database. Therefore, quantitative data were obtained from interviewing the migrant anchovy fishers in Kabui Bay. Interviews took place at the temporary settlement camp in Kabui Bay, Raja Ampat, on April 19th, 2006, and November 28, 2006. These times coincide with the dry and wet seasons, respectively. We came with a prepared list of questions, and had anticipated speaking with individuals one at a time. However, our April visit sparked the camp's interest, bringing around 100 men to join the first interview. Ultimately, this led to only one set of questions being asked, with one primary respondent giving answers, and other respondents occasionally pitching in. Our timing was off in November, as most of the people in the camp had traveled back to SE Sulawesi for Ramadan, and had yet to return to the settlement. In November, only two fishers were interviewed. Answers to questions pertaining to prices were given in Indonesian Rupiah (IDR) values, but are reported in this paper in US dollars by using the rounded current exchange rate of 9,000 IDR to 1 US$. The authors recognize that due to the interview limitations (small sample size) this analysis serves only as a rough snapshot estimating the catch and profitability of the fishery. A more rigorous interview process would serve to better estimate catch, effort, revenues and costs.

COMPUTATIONS

Catch and profitability distributions were generated using the Monte Carlo simulation method. Answers to most interview questions were given as ranges, (for example, the weight of anchovy in the baskets used to collect fish from the nets ranged from 5.5 to 6.5 kg) and all variables were assumed to be distributed uniformly over the range. Ten thousand random draws were sampled from within the variable ranges to produce a frequency distribution of all possible catch and revenue estimates. See Appendix C for the full list of variables and their ranges.

Catch

The amount of fish caught annually per boat was estimated from a number of responses from the fishers, and varies with season (Table 1). The Kabui Bay fishers do not weigh their fish directly, but know that each basket of fish they catch is equal to about 6 kg of fish. Effort for this fishery is represented by number of days fished per month and per season. Seasonal catch (h_s) was calculated by the following:

$$h_s = n_s w d_s m_s \tag{1}$$

where n_s is the number of baskets caught on a given night in season *s*, either dry or wet, *w* is the weight of fish per basket (does not vary with season), d_s is the number of days fished per month in season *s*, and m_s is the number of months fished in season *s*.

The total annual catch is the sum of these two seasonal estimates:

$$h = h_d + h_w \tag{2}$$

where h_d and h_w are the total catches in the dry and wet season, respectively. To estimate catch for the entire fleet, the estimate per boat was multiplied by all possible number of boats operating during a period, which ranged from 50-60.

Table 1. Catch variable ranges used for Monte Carlo simulations, all variables assumed to be uniformly distributed.

Variable	**Min**	**Max**
Number of baskets caught per night (dry season)	35	45
Number of baskets caught per night (wet season)	45	55
Weight of fish in basket (kg)	5.5	6.5
Number of nights fished per month (dry season)	24	24
Number of nights fished per month (wet season)	21	25
Number of months fished (dry season)	6	6
Number of months fished (wet season)	4	4
Number of boats operating in the fleet	50	60

Revenue

To obtain revenue, the seasonal catch estimates were first divided by 2. For the anchovy fishery, it is generally assumed that the weight of the catch once dried is about one half of the fresh weight harvested (A. Muljadi, personal communication)[1]. This dry catch is then multiplied by the price for landed, dried fish, in each season. That is, total revenue in 2006 is:

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[1] Andreas Muljadi, Field Researcher with The Nature Conservancy in Papua, Indonesia, pers. comm.. April 20, 2006

$$TR = p_d(h_d)/2 + p_w(h_w)/2 \tag{3}$$

Where p_d and p_w are the prices per kilogram of dried anchovy in the dry and wet season respectively.

The ex-vessel price of anchovy caught and dried during the dry season is fixed at about $1.30 per kilogram. Fish caught and dried during the wet season, however, fetch a lower and variable price due to unfavourable drying conditions leading to lesser quality fish. Therefore, a price range was used in the Monte Carlo simulations (Table 2).

Table 2. Revenue variable ranges used for Monte Carlo simulations, all variables assumed to be uniformly distributed.

Variable	**Min**	**Max**
Exchange rate (Indonesian Rupiah (IDR) per USD)	9,000	9,000
Price per kg of dried anchovy (dry season) (USD)	1.33	1.33
Price per kg of dried anchovy (wet season) (IDR)	0.39	0.56

Cost

The total cost (TC) of the fishery is composed of both fixed and variable costs:

$$TC = Fixed + Variable \tag{4}$$

The fixed costs in the anchovy fishery include the boat and net setup and the access fees paid to the villages (i.e. the boat owner owes money to the villages even if he chooses not to fish). Variable costs include gasoline for the boat engine and kerosene for the lanterns, as well as labour costs. The fishers said that their income depends on the revenue. Each fisher receives about 1/16th of the total revenue in the form of personal income. The boat owner, on the other hand, takes 3/16ths of the total revenue for his personal income. Therefore total labour-associated costs equal 8/16ths or one half of the total revenue.

Profit and gains from the fishery

Profit in this fishery is considered for two cases: boat owner profit and fisher profit. The owner's profit, π_o, is the difference between the total revenue and total cost of the fishery:

$$\pi_o = TR - TC \tag{5}$$

The fisher profit, π_f, is the difference between the personal income earned from the anchovy fishery, C_l, and that fisher's opportunity cost, OC, essentially the average annual income the fisher could make in another fishery in Raja Ampat.

$$\pi_f = C_l - OC \tag{6}$$

RESULTS

Catch

Annual per boat catch varied from 49 to 76 tonnes, with a mean of 62 tonnes (Figure 3). Annual catch for the entire fleet (50-60 boats) ranged from 2493 to 4468 tonnes, with a mean of 3389 tonnes (Figure 4). The 95% confidence intervals are indicated in both figures. Table 3 presents a summary of simulation ranges.

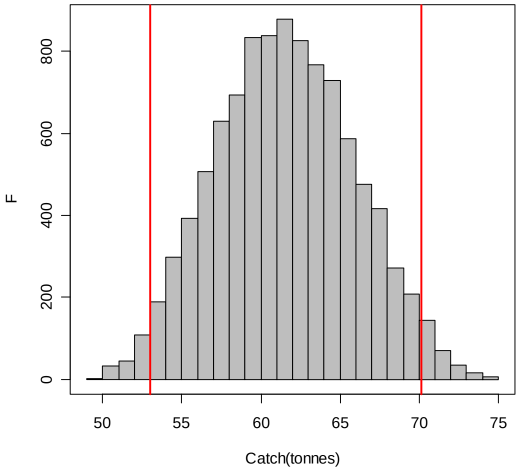

Figure 3. 2006 Catch per boat

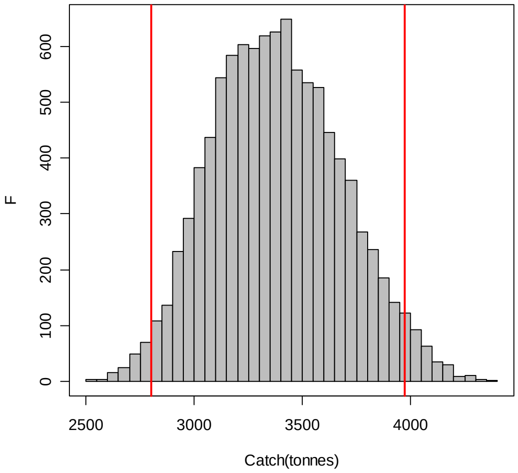

Figure 4. 2006 Fleet catch

Revenue

Estimated annual revenue per boat ranged from US$23,280 to $36,730, with a mean annual revenue of $29,380 (Figure 5). Annual revenue for the entire fleet ranged from an estimated $1.16 million to $2.1 million, with a mean of $1,62 million (Figure 6). The 95 % confidence intervals are shown in both figures. See Table 3 for a review of simulation ranges.

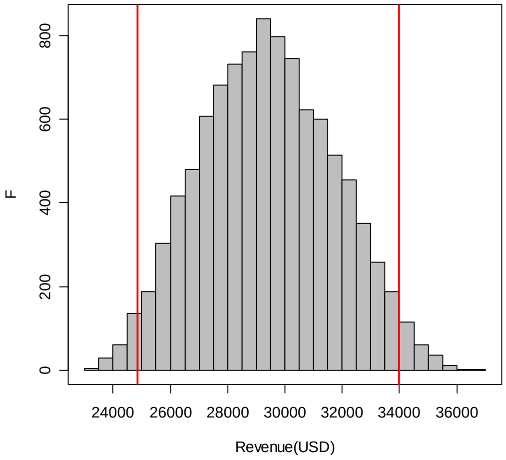

Figure 5. 2006 Revenue per boat

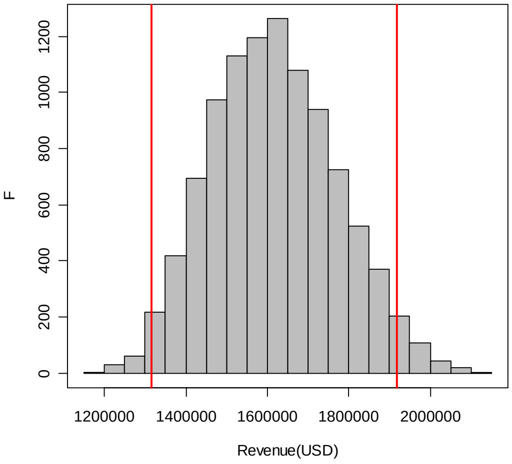

Figure 6. 2006 Fleet revenue

Costs

Discussions with the fishers gave the following cost estimates: annual access fees amount to \$267; annual capital investment (cost of boat and net setup multiplied by 0.2; fishers told us that the setup lasts 5 years, therefore 1/5 of the cost gets allocated to 2006) equals \$156; fuel costs average \$1,455 per year, and kerosene costs average \$468 per year. Thus the boat owner's cost (excluding labour) averages \$2,346 per boat per year (Table 3). As stated above, the revenue is split in half to pay labour costs. Each fisher receives 1/16th of the revenue, which averages about \$1,835 per year. Recall there are 5 fishers per boat, so total labour costs paid out to the fishers average \$9,189 annually. The boat owner takes 3/16ths for his labour, averaging about \$5,513 per year.

Profit and gains from the fishery

The estimated annual owner profit, the difference between the total revenue and total costs, is about \$10,870 (Table 3). This is quite substantial given that he average annual per capita income in the province of Papua was \$938 in 2002 (UNIPA, 2002). Furthermore, fishers told us that owners in fact take half of the revenue (averaging \$14,698 per boat per year) to pay back their "capital investments", even though those costs, as described by the fishers, are substantially lower (recall non-labour costs equal \$2,346). Thus it appears that the boat owners are capturing all rent from the fishery.

The estimated annual fisher profit is the difference between the fisher's personal income from the anchovy fishery and his opportunity cost. Unfortunately, direct statistics for average annual fishery income is not available for Raja Ampat. However, a valuation study conducted by Conservation International (CI) reported the average per capita Gross Regional Domestic Product (GRDP) in Raja Ampat in 2004 was \$824 (Bappeda, 2004 in Dohar and Anggraeni, 2006). The same CI study estimated the combined net value of artisanal and commercial fisheries in Raja Ampat at about \$9.22 million and suggested that about 24,693 people within the regency participate in the fisheries sector (Dohar and Anggraeni, 2006). By dividing the value of the fisheries by the number of fishers, we can roughly estimate that each fisher makes about \$1,024 per year. Note, however, that this is an average, and includes artisanal fishers and boat owners; groups that probably make very different income. If we do assume that the average fisher in Raja Ampat makes about \$1,024 per year, and using the estimate from the interviews with the Kabui Bay anchovy fishers yielding a mean annual income of \$1,835, it appears that the anchovy fishers are making about 1.8 times as much as other fishers in Raja Ampat.

Table 3. Monte Carlo simulation result ranges, means, and standard deviations for the 2006 season.

Simulation	**Min**	**Max**	**Mean**	**Standard Deviation**
Catch per boat (tonnes)	49	76	72	4.35
Catch per fleet (tonnes)	2,493	4,468	3,389	299
Gross revenue per boat (USD)	23,280	36,730	29,380	2,321
Gross revenue per fleet (USD)	1,160,000	2,100,000	1,620,000	154,000
Costs per boat (USD)	2,297	2,396	2,346	37
Costs per fleet (USD)	115,000	144,000	129,000	7,100
Fishery profit (USD)	401,000	837,000	596,000	71,100
Boat owner profit per boat (USD)	7,732	14,561	10,868	1,160
Fisher annual profit (USD)	410	1,240	811	146

CONCLUSION

The inequitable distribution of gains from the anchovy fishery seems quite apparent. Boat owners are capturing the majority of rent from the fishery, making about five times as much as the fishers. One possible consideration is that boat owners owe money to a broker that sets up the boat owners with the vendors who buy the fish, and that this cost is unknown to the fishers we interviewed and thus not included in this analysis. The anchovy fishers themselves are also making substantial profits in this fishery, as their annual income is almost twice as much as the average Raja Ampat fisher.

The majority of these profits will be spent in Buton, when the fishers return home. Therefore, there is no possible argument that the large incomes earned by migrant fishers would directly benefit the people of Raja Ampat, through increased personal expenditure.

As current access fees are paid only to villages, and not directly to the regency government, the government is not generating any revenue from the migrant anchovy fishery. Because the regency is a newly created political unit, the initial terms of the original access agreement in 1999 might be subject to change. Regency revenue somehow generated from the profitability of the fishery could help the DKP fund regency-wide fisheries management, such as effort monitoring, stock assessment work, research on illegal and destructive fishing practices, and modeling of economic development options for the area through marine resource use. All of these management programs have the potential of increasing fishers' incomes in the medium and long term.

Specific monitoring of the migrant anchovy fishery is an important consideration not currently part of the Bureau's management plan. The migrant respondents told us that the DKP had never come by their settlement to ask them what they are fishing or how much they are catching. As stated earlier, unreported catches have the potential to severely bias stock assessments and to undermine management objectives (Pitcher *et al.*, 2002; Clark, 2006). Furthermore, anchovy have been identified as a key prey item for higher level predators (Skewgar *et al.*, 2007). Within the Raja Ampat ecosystem, tuna, mackerel, billfish, as well as reef-associated and pelagic fishes feed on anchovy (Ainsworth *et al.*, 2006). The groups fishing in Kabui Bay have noticed a decrease in the population of anchovy close to shore, and this could mean reduced prey availability for other fish species. Beginning last year, the fishers expanded their range, and are now traveling twice as far offshore as past fishers did. The fishers told us that they would stop fishing in Kabui Bay if their catches decreased to about half of what they catch now. In light of this, the DKP should monitor and manage this fishery, and other anchovy fisheries in Raja Ampat. The profitability of the fishery, as reported here, should be incentive enough to manage it sustainably, to ensure the flow of benefits to the area through time.

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