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Back to the Future: Reconstructing the Hecate Strait Ecosystem

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Preface and Acknowledgements

This report continues a series of ecosystem reconstructions begun only recently at the Fisheries Centre. The Strait of Georgia reconstruction was a large project involving many participants from diverse backgrounds, both academic and non-academic. On the other hand, this report is unique in that the majority of the participants were not from an academic background, but were primarily local people with lifelong ties to the ecosystem.

Three papers were contributed to this volume, two of which are long overdue in the literature: the Haida and Tsimshian annotated dictionaries of fish and marine related words. These works are not complete; there may never be fully complete documentaries of traditional First Nation interaction with their environments. These dictionaries may, nonetheless, provide invaluable clues of how the ecosystem may have been, even if it is only that a word for something existed. It is interesting to note, for example that the Tsimshian people have a word for Hammerhead shark, presently very rare along the BC coast. The third contributed papers, on lingcod, presents a more traditional stock assessment and serves to underscore how little is known, even in scientific circles about this fairly remote region. We hope that the contents of this report will be seen as contributing to overcoming this situation.

We gratefully acknowledge financial contributions of $7,000 from the Canadian Ocean Frontiers Initiative (COFRI), $10,000 from the Science Branch of the Department of Fisheries and Oceans and $20,000 from UBC Research. We thank the Haida Fisheries Program for contributing travel and expenses for Haida Elders. We acknowledge the Tsimshian Nation for their support for the concept and the warm welcome from Tsimshian Tribal Council President Bob Hill. We also acknowledge Dr. Jo-ann Archibald, Director of the UBC First Nations House of Learning for her role in developing and supporting the BACK TO THE FUTURE concept and attending the opening session. Particular thanks are due to George Hayes, Director of the Northwest Maritime Institute for help in organizing the participation of retired commercial fishers and experts in local history and archaeology. Thanks are also due to DFO for the participation of Dr. Glen Jamieson of the Pacific Biological Station. Above all, we thank all the workshop participants for the time, thought and energy they put into re-creating the Hecate Strait system as it might have been 100 years ago.

Director's Foreword

We humans like to define where we are going by where we have been. The problem with present day fisheries is that we have entered uncharted territory of stock collapses, species shifts and unprecedented alterations in the nature of marine ecosystems.

'Back to the Future' (BTF) is the model reconstruction of past marine ecosystems that, by comparison with the present day, may inform and shape fisheries policy and decisions. Specifically, it encourages the rebuilding of marine resources and makes explicit the trade-offs that must be faced to maintain and restore biodiversity, and ultimately, the nature and value of fishery products. The technique is in its infancy but has attracted a curious, but encouraging mixture of enthusiastic support and deep criticism. At the Fisheries Centre, we continue to develop the methodology and its scope.

This report is the second in a series of Fisheries Centre research reports on the (BTF) process. The first, on the Strait of Georgia, (Pauly *et al.* 1999) reported the work of sixteen researchers over about a year, but was able to present only a preliminary analysis. The work reported here is less extensive than that on the Strait of Georgia, but attempts to examine the fisheries of the Hecate Strait ecosystem in northern British Columbia as they are today and as they were 100 years ago. It derives from a workshop held in Prince Rupert, BC in May 1998 supplemented by additional research following that event.

BTF is an exciting new approach that challenges our science by requiring all kinds of ecological scientists to work together. The method prompts us to harness the work of economists, historians, archaeologists and linguists. Back to the Future has a direct use for the traditional environmental knowledge of indigenous peoples and experienced coastal fishing communities.

Fisheries Centre Research Reports publishes results of research work carried out, or workshops held, at the UBC Fisheries Centre. The series focuses on multidisciplinary problems in fisheries management, and aims to provide a synoptic overview of the foundations, themes and prospects of current research. Fisheries Centre Research Reports are distributed to appropriate workshop participants or project partners, and are recorded in Aquatic Sciences and Fisheries Abstracts. A full list appears on the Fisheries Centre's Web site, http://www.fisheries.com. Copies are available on request for a modest cost-recovery charge.

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Pauly, D., T.J. Pitcher and D. Preikshot (Editors). 1999. Back to the Future: Reconstructing the Strait of Georgia Ecosystem. Fisheries Centre Research Reports 6(5): 99 p.

Preface

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Three papers were contributed to this volume, two of which are long overdue in the literature: the Haida and Tsimshian annotated dictionaries of fish and marine related words. These works are not complete; there may never be fully complete documentaries of traditional First Nation interaction with their environments. These dictionaries may, nonetheless, provide invaluable clues of how the ecosystem may have been, even if it is only that a word for something existed. It is interesting to note, for example that the Tsimshian people have a word for Hammerhead shark, presently very rare along the BC coast. The third contributed paper, on lingcod, presents a more traditional stock assessment and serves to underscore how little is known, even in scientific circles about this fairly remote region. We hope that the contents of this report will be seen as contributing to overcoming this situation.

Report of the BTF Workshop on Reconstruction of the Hecate Strait Ecosystem

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Abstract

Participants gathered at a workshop held in Prince Rupert, May 20 and 21 1998, to discuss changes to the Hecate Strait ecosystem (see Appendix I for list of participants). Hecate Strait is defined here as DFO statistical areas 5C and 5D and includes Dixon Entrance. A preliminary mass-balance model of Hecate Strait in the early 1900s was constructed from information provided by participants, and a preliminary mass-balance model representing the same area during the early 1990s. Changes in biomass from the previous model were based on input from workshop participants. Thus, it presents a test of whether ECOPATH can be used to develop a picture of how the ecosystem looked based almost entirely on local knowledge. Unless otherwise noted, biomass values were adjusted according to the consensus of the workshop participants. Most changes in biomass ranged from a 25% to a 100% increase, back through time. Where information was lacking, ECOPATH was allowed to calculate new biomass values. The results indicate that a coherent mass-balance model can be developed, based on the experience gained from long histories of personal association with an ecosystem.

Introduction

First Nations, fishers, scientists, managers, conservationists and the general public are concerned about the depletion and possible disappearance of entire fish populations. This was brought forcibly to the attention of Canadians by the closure of the East Coast cod fishery. Coincident with the opening day of the workshop, the Minister of Fisheries announced the most severe salmon fishery closures in BC history to preserve depleted coho salmon (*Oncorynchus kisutch*) populations. Introductory comments reflected a deep sense of loss and fear for the future. One hoped that we had not just gathered to write an epitaph. The Aboriginal and commercial fishers present represented several hundred years of experience of the Hecate Strait ecosystem and its fisheries for salmon, herring, halibut, lingcod, dogfish, rockfish, trawl, crab, and other fish and invertebrate species. The degree of overlap and exchange of information not only on 'commercial' species, but also on the rise and fall of seal, seal lion, whale and seabird populations was particularly striking.

Some participants had over 50 years personal experience - lifetimes spent on the water, some could draw on generations of experience. Aboriginal participants drew equally from their personal and family experience of commercial fishing, subsistence fishing for many species and a rich oral history (Jones, this vol.; Watkinson this vol.). Others drew on history and archaeology for insights into past abundance and previous occurrences of the shift, now apparently under way, between herring vs. sardines and anchovies as the dominant pelagic species.

The volume and diversity of information was impossible to fully absorb in the time available. This is because it reflects the complexity and diversity of the ecosystem itself. It also contains information about the processes of change, not only over the last 100 years, but reaching back through archaeological evidence to a time when Hecate Strait was a grassy plain (Fedje *et al.* 1996; Fedje and Josenhans 1998).

Box 1. The 'Back to the Future' approach

The BTF approach (BTF) is based on two beliefs. First, understanding ecosystems as they were before modern industrial fishing is a good first step to setting goals for rebuilding. Second, that all concerned have important contributions to make to reaching a broader and deeper understanding of how ecosystems work. BTF workshops use recent advances in ecosystem modelling to bring the knowledge of commercial fishers, First Nations, government scientists and managers, historians, archaeologists and others together. For additional information on BTF please see (Haggan *In press*; Pauly *et al.* 1998; Pitcher *in press*; Pitcher *et al.* 1999; Pitcher 1998a,b,c).

The greatest strength of BTF is that it enables many different actors to capture the interplay between ecological, economic, social and cultural forces in the ecosystems upon which they rely. For this reason, it has a ceremonial aspect of coming to terms with the depletion of the marine environment. With recognition that all sectors have knowledge that can contribute to good management, balanced by an acknowledgement that aquatic ecosystems are severely compromised and that all concerned – government, First Nations, fishers, scientists, managers, processors and policy-makers – share responsibility, an agreement can be forged to treat different knowledge systems with respect and work towards sharing knowledge in the interest of improved understanding (Haggan *in press*; Haggan *et al.* 1998; Haig-Brown and Archibald, 1996; Salas *et al.* 1998).

Ecosystems are still far too complex for us to grasp completely. Thus, ECOPATH (Christensen and Pauly 1992 and 1993) simplifies an ecosystem by combining species in up to 50 groups or 'boxes.' Groupings are usually made up of fish or other animals that eat, and are eaten by, the same things. For example, we have grouped lemon, rock, petrale, rex, and dover soles together in a box called 'Flatfish'. Done with care, the boxes will implicitly include all the animals and plants making up the system. This approach represents a significant advance over previous models of food webs, for instance multispecies virtual population analysis (MSVPA). The application of MSVPA is hampered by the high degree of expertise required by modellers, data needed are both difficult and expensive to obtain and the overall lack of transparency in the estimation procedure (for a more detailed citique, see Walters *et al.* 1997). Perhaps most importantly, MSVPA only includes harvested fish. In contrast, the relative ease of the application of ECOPATH has resulted in its increasing use to model aquatic ecosystems. A recent cooperative project between the UBC Fisheries Centre and University of Tennessee constructed a 47 group model of Prince William Sound for the period after the *Exxon Valdez* oil spill (Okey and Pauly, 1998). In addition, more than 100 ECOPATH models have been published world-wide describing upwelling systems, shelves, lakes, rivers, open oceans and terrestrial farming systems (http:\\www.ECOPATH.org).

ECOPATH is designed to help understand the ecological process of eating and being eaten. ECOPATH works like an accounting system. Each ECOPATH box gains or loses capital as the creatures in it feed, or are fed upon. ECOPATH tracks the flow of capital between boxes, ensuring the amount eaten does not exceed what is available. Furthermore, there must be a balance between all levels within the 'food chain'. A food chain consists of many links, each one of which represents a species, or a group of species. Each chain has a 'bottom' and a 'top'. At the base are the primary producers (plankton and kelp), which produce their food directly from sunlight. At the top are the predators, such as killer whales and of course, humans. At each level in the food chain animals are either eating prey, or are being eaten by predators.

The food chain is a very simple way of thinking about an ecosystem. In fact, ecosystems consist of many different food chains linked together like a spiderweb – a food 'web'. The figure in Appendix II shows the boxes and connections in the Hecate Strait model, giving some idea of how complex systems can be. ECOPATH requires five main types of information in order to model these food webs:

- The average weight of each group for the period covered by the model;
- The amount each group grows during a year;
- The amount each group eats during a year;
- How much of each group is caught during a year;
- The kind of food each of the groups eat.

If all of the above information is available, you have more than enough to proceed with the building of an ECOPATH model. Most often, not all of the above is available. In those cases, as long as you have any four of the above, ECOPATH can calculate the missing one.

Summary of Participant Input and Biomass Values

The following summary of the main parts of the Hecate Strait ecosystem 100 years ago is based on information provided by participants and research by graduate students at the UBC Fisheries centre. Where information is lacking, the ECOPATH software treated the value as an unknown, to be estimated from the balance of the various inputs.

Initially, it was planned that the model would reconstruct the ecosystem of 50 years ago. During discussion, however, participants pointed out that there had been fairly extensive steam trawl fisheries in the early 1900s. It was therefore agreed that reconstructing the system of 100 years ago would give a better sense of what the system was like prior to modern industrial fishing. Note that all references to the 'present day model' refer to Beattie (this vol.). As well, a detailed account and map of the study area may be found in Beattie (this vol.)

Transient killer whales, dolphins and porpoises (Odontocetae)

Information from Aboriginal and commercial fishers indicated a reduction in killer whales since their early days, but their numbers are now on the increase. There was some discussion about transient killer whales including an account of Orcas apparently trying to drown two Grey whales (*Eschrictius robustus*) by 'jumping' on top of them, thus preventing them to surface and breathe. It was agreed that a modest recovery in the population of both resident and transient killer whales is attributable to higher numbers of salmon and seals over the last 20 years. Porpoises (*Phocoenoides dalli*) were harpooned during the war as oil from a sack in the nose has a high freezing point and was valued for use on rifles and equipment in the Arctic. The meat was also used. Porpoises were previously "thick" in Juan Perez and Skincuttle inlets. Porpoises also followed eulachons (*Thaleichthys pacificus*) to the Nass. An association was made between dolphins and tuna, both being associated with warmer water. A recent coastwide increase in Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) was also noted.

Despite the recent recovery in killer whales, it was agreed their present biomass is still low. The 100-year biomass was increased by 20% based on a rationale that there was "more of everything" before industrial fishing started. More food allows for more top predators.

Seals and Sea Lions

Seals are an emotive topic these days. There was concern about the effect of Harbour seals (*Phoca vitulina*) on salmon populations, particularly the presence of large numbers of seals in river systems when juvenile salmon are out-migrating. Examples included the Skeenan River and Oweekeno Lake/Rivers Inlet. This was tempered by comments that human impacts such as fishing, pollution and habitat loss were also to blame and a realization that ecosystems are complex. Seals are highly visible taking salmon from gillnets, lying in wait in rivers for in-migrating adult salmon or hatchery releases, but seals also eat hake (*Merluccius productus*), a major predator of juvenile salmon. Some recalled the Department of Fisheries and Oceans bounty on seals in the 1970s, but no one expressed any real desire to return to those days. One Haida participant recalled a stack of fur seal (*Callorhinus ursinus*) bones on the beach at Tow Hill, near Masset and said that fur seals used to be "like the buffalo on the prairies." Steller sea lions (*Eumetopias jubatus*) were said to be up since the 1950s when they were shot for mink feed and the skins used as anti-chafe material on beam trawls. More recently, Steller sea lions have decreased sharply, but have been largely replaced by California sea lions (*Zalophus califonianus*).

For the model, Seals and Sea Lions were left the same on the assumption that any decline of the Steller sea lion population has been offset by the increase in the California sea lion and Harbour seal populations

Baleen whales (Mysticetae)

It was noted that the Haida hunted whales (Jones, this vol.). Grey whales in particular have increased over the last 15 years and cause some problems for the spawn-on-kelp fishery on Haida Gwaii due to silt stirred up by their feeding habits. Grey, Humpback and Minke whales are believed to have recovered from past industrial whaling operations. Blue and Fin whales have not. Since the former group comprises the main bulk of the biomass, the 100-year biomass was assumed to be the same as at present.

Seabirds

General comments reflected the conceptual split between how fishers and fisheries scientists regard birds. All who make their living from fisheries pay close attention to the presence, absence and behaviour of birds. Negative impacts on Ancient Murrelets (*Synthliboramphus antiquus*), Auklets (*Ptychoramphus aleuticus*) and other bird populations include logging, the introduction of rats and raccoons (*Procyon lotor*) that prey on eggs and young and overall reduction in food availability due to intensive fishing. Discards from the trawl fishery, on the other hand, provide a new food source for some species.

Participants provided a wealth of information on this area that, up to now, has not had a formal place in fisheries science. This is not to say that there is a lack of good research, just that there has been no tradition of fisheries scientists and ornithologists working together. It is thus a rich area for ecosystem research and one place where ECOPATH provides a new opportunity to link seabirds to the marine ecosystem (Bishop and Okey 1998; Esler 1998; Kelson *et al.* 1996; Okey and Pauly 1998; Ostrand and Irons 1998; Wada and Kelson 1996). Perry and Waddell (1994) also address plankton availability to seabirds in Queen Charlotte Island waters. Areas for further research therefore include correlation of past and present studies, Audubon Society Christmas counts on Haida Gwaii and Prince Rupert, interviews with birdwatchers, fishers and other observers and archaeological research now under way at pre-contact village sites around Hecate Strait. Incorporating the impact of rats and raccoons on seabirds and their prey will be a challenge.

In view of the overall negative impacts, the 100-year biomass is tentatively increased by 100%.

Spiny dogfish (*Squalus acanthias*)

There was a general impression that dogfish had recovered well from an intensive WWII era fishery. The 100-year biomass is tentatively left unchanged, on the assumption that the population has recovered from the directed fishery. More research and follow-up interviews are needed to correlate observations on the relative abundance of dogfish in halibut and other fisheries over time.

Ratfish/skates

There was a small fishery for ratfish (*Hydrolagus collei*) in order to process them for oil used for guns and on slipways, though primarily it was a bycatch species in the dogfish fishery. Skates (*Raja* sp.) were only recently the target of a directed fishery. Tentatively the 100-year biomass will be left the same as for the present day model.

Pacific halibut (*Hippoglossus stenolepsis*)

Halibut have always been very important to BC First Nations, indeed, for the Haida, halibut may have been more important than salmon. Input included 6,000 years evidence of halibut in middens and a pre-contact catch estimate of close to 1,400t per year north of Cape Caution. In fact, Tsimshian elders were unable to attend the workshop primarily because they were at camp drying halibut and picking seaweed (*Porphyra* spp.). First Nations fished from canoes, with lines made of variously twisted cedar, animal sinew/intestine, or kelp (*Macrocystis* spp.), and wooden hooks with boned barbs (Jones, this vol.). By the turn of the century, gasoline and diesel engines were used, and in 1907 the commercial halibut catch reached more than 20,000 t. After 1915 catches were declining, and the International Fisheries Commission (IFC), later renamed the International Pacific halibut Commission (IPHC) was formed in 1923 to ensure proper management.

The discarding of bycatch is a major concern; several participants referred to the number of red snapper discarded in the halibut fishery before a market developed. One comment was that the sea looked "like a pumpkin patch." Bycatch in the trawl and blackcod fisheries is an ongoing concern. There is also a belief that small 'homesteader' populations of halibut may have been depleted or fished out in a similar manner to small herring stocks. This should be the default assumption in the absence of unequivocal scientific evidence to the contrary. There was also concern that although the sport fishery catch is a fraction of the commercial take, sport fishers have a tendency to fish out the corners where commercial vessels do not necessarily go. This has a dual role of eroding populations of resident species and impacting the Aboriginal subsistence fishery that depends on the ready availability of stocks that are nearby and can be easily accessed using small boats.

Overall, the recovery of the stock appears to be a rare fishery management success. The consensus of the workshop was that there were more halibut today than before, perhaps twice as many. The available data suggest, however, that there is perhaps only as many as there were 100 years ago. For the purpose of this model, halibut are tentatively left the same as for the present day model.

Pacific cod (*Gadus macrocephalus*)

Between 1918 and the late 1950s, Pacific cod landings increased from about 400 to 8000 t. There is a spawning ground at the north end of Banks Island. Substantial amounts were landed at Bellingham. Data may be available through the University of Western Washington.

The consensus of the participants is that cod have only 10% of their historical abundance, and the 100-year biomass is tentatively set at that figure.

Walleye pollock (*Theragra chalcogramma*)

Despite mention of a winter midwater fishery at the top end of Two Peaks, the consensus was that pollock were never very common. The 100-year biomass was tentatively left as in the present day model.

Juvenile and Adult blackcod (*Anoplopoma fimbria*)

Blackcod were considered to be reduced in numbers, by as much as 33-50%. The BC blackcod fishery began sometime in the 1890s as a setline fishery, but landings were minor until 1913. The current blackcod fishery is by trap. The 100-year biomass for juveniles and adults was tentatively increased by 33%.

Herring (*Clupea harengus pallasi*), small pelagic fish

The herring reduction fishery was cited as an example of how little is known about unfished levels and the importance of herring to other ecosystem components (Jones *in press*; Newell 1993). Fishers, the Union and First Nations concerns were disregarded by DFO biologists until a crash forced a six-year closure. There was a consensus on the crucial ecosystem role of herring. Fishers also believe that the Hecate Strait area is (or was) home to a very large number of small discrete stocks as well as one (or more) large stocks of bigger herring. Skidegate Inlet, Prince Rupert Harbour and Chismore Pass were cited as areas where stocks had been virtually eradicated. Chismore Pass was also given as an example of how sport fisheries can target small stocks for bait. Concern was also felt about inconsistencies in the way herring spawn is measured and reduction in effort in this program.

Based on the critical role of herring, it was agreed that a precautionary approach that considers the ecosystem role of herring is essential (Jones *in press*). Recent examples were given of Haida and Tsimshian (Kitkatla) fishers opposing DFO openings. In the absence of information to the contrary, the default assumption should be that stocks are discrete, fishing strategies should also be very conservative. The idea of 'sanctuaries' (marine protected areas) to protect small local herring stocks as well as other species was discussed and well received.

The relative abundance of herring compared with sardines/pilchards, anchovies and mackerel was a recurrent topic. Observations tallied that the 1990s have seen a significant rise in pilchards. There was also a fishery for sardines/pilchards in the 1960s and other species

The consensus of the workshop was that herring biomass was in general down, with some areas showing more of a reduction than others. For eulachons, the general feeling was the biomass is down 25-30%. The average reduction for the entire study area for herring was estimated to be 75%. The 100-year biomass was be tentatively increased 75% above present day model levels.

Juvenile salmon (*Oncorhynchus* spp.)

Loss of spawning and nursery habitat, coupled with decades of heavy fishing has forced a decrease in the amount of salmon spawning in BC waters, and therefore the number of juvenile salmon in the Strait. Possible negative impacts include increase in seal populations and more mackerel due to El Niño. However, little information has been found on how much of a reduction has taken place. For the want of better data, the biomass will be left the same as for the present day model.

Pacific Ocean perch (POP, *Sebastes alutus*)

The general feeling was that POP were down, although no overall percentage was obtained. Until the 1950s, POP were not an important species to the BC fisheries, comprising less than a 1/4 of Pacific cod landings and about the same for total flatfish landings (Figure 1). In the 1960s and 1970s, POP were heavily targeted by foreign fisheries, including Japanese and U.S. fleets (Westrheim 1987). Little is known about actual quantities of fish removed, or how well the population has recovered. For this model, the biomass was thus left for ECOPATH to estimate.

Flatfish

Information provided indicated a reduction in Dover sole, lemon sole and Arrowtooth flounder, previously taken in large amounts and used for mink feed. The overall impression was a reduction in flatfish numbers of about 1/3. The 100-year biomass will therefore be set 1/3 higher.

Rockfish and small bottom dwelling fish

The consensus was that rockfish are at 10% of their historical abundance. In particular, it was felt that Yelloweye rockfish or red snapper, (*Sebastes ruberrimus*) were significantly reduced (see above on bycatch in the halibut fishery). Within this model, however, they are grouped with a variety of small bottom-dwelling species. It is not known whether the biomass of these has decreased, increased, or remained the same; indeed, this box was problematic for the present day model. The biomass was therefore left for ECOPATH to estimate, as was done for the present day model.

Turbot (*Atheresthes stomias*)

Although turbot has only recently been the target of directed fisheries, it was used in the past for mink food, although apparently retained principally as by-catch. Turbot is very common in the trawl catches today. For

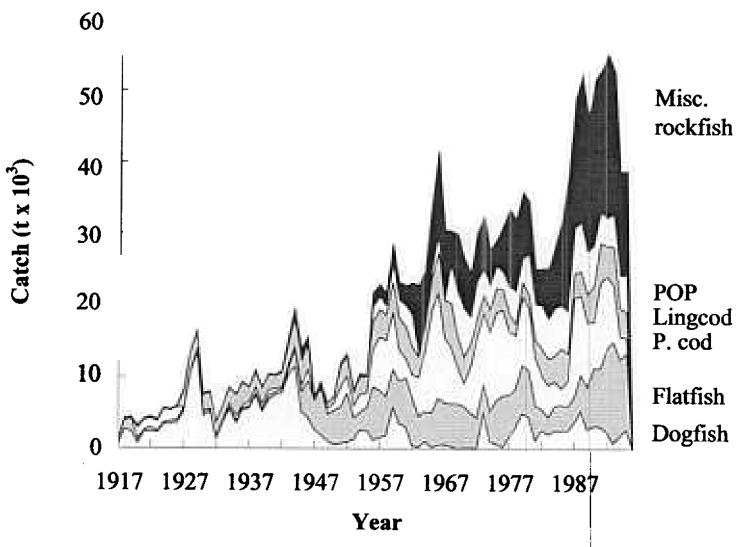

Figure 1. Catches by species for the Canadian trawl fleet for the years 1917-1994. Data from Forrester *et al.* (1978), Forrester *et al.* (1983), Westrheim *et al.* (1986) and Pauly *et al.* (*In press*).

this model, the biomass is tentatively left as for the present day model.

Lingcod (*Ophiodon elongatus*)

lingcod provoked a great deal of discussion. Input included a belief that male lingcod migrate across Hecate Strait to Haida Gwaii returning in February to spawn and guard eggs. This is based on large seasonal catchers by bottom trawlers ('draggers'). Longtime participants in the fishery spoke of severe reduction in numbers and size attributed to the introduction of longlines (including ghost fishing by lost gear), catch by draggers and cleanup of the corners by charterboat (sportfishing) operations. One longtime participant recalled that landings for a good day trolling would be 450 kg with 110 kg on a poor day. Average size jigging was 14 kg., 3.5 kg. trolling. Average weight in the sport fishery is now 3.5 kg.

Overall, lingcod are considered to be severely reduced in abundance (Martell, this vol.). Biomass for the 100-year model is tentatively set for a 95% increase, based on Martell and Wallace (1998), who estimated a 95% reduction in Georgia Strait lingcod.

Jellyfish, Zooplankton, Phytoplankton and Detritus

No consensus was reached during the workshop. For phytoplankton and zooplankton, any large increase or reduction seems unlikely as climatic conditions seem to be constant over the period. The 100-year biomasses are tentatively left the same as for the present day model.

Crustaceans, Shellfish and Echinoderms

It was felt that biomass of clams and prawns were in general down. Other groups such as sea urchins were thought to have increased. Haida participants expressed great concern about the number of traps in the crab fishery as well as ghost fishing, i.e., killing of fish by lost or discarded gear. Concern was also expressed about the depletion of abalone (*Haliotis kamtschatkana*), including an interesting observation about the role of raccoons in depleting abalone in Naden Harbour. The biomass 100 years ago was tentatively left unchanged from the present day model.

Fishery harvests

Modern commercial fishery harvest in the Hecate Strait region apparently did not begin in earnest until 1910. Thus, commercial harvest was left at zero. The Aboriginal harvest figure calculated in the Strait of Georgia BTF project was used in the absence of better information (Pauly *et al.* 1998). This is probably low as a verbal report on archaeological information by David Archer indicates that the study area had one of the highest Aboriginal population densities in North America. Boyd (1990) gives figures of approximately 14,500 for both the Haida and Tsimshian, but allows that these are probably low.

Results

Figure 2 shows the results of the trophic flows estimated by ECOPATH. Note that the diagram is virtually identical to the one obtained for the present day model, as also confirmed by the similar or identical trophic levels of the various groups (Table 1, also see Table B, Appendix II for more details).

Both models are preliminary in nature, and as such we will not attempt a detailed analysis of their structure. It is worth noting, however, that the perceptions of the people involved in the workshop as to the state of the Hecate Strait ecosystem as it was 100 years ago were found to be entirely plausible under the ECOPATH mass-balance assumption. Thus, with more study, such results (subject to further verification) may provide a solution to, or at the very least mitigate the effects of the 'shifting baseline syndrome of fisheries' (Pauly 1995).

Table 1. Comparison of the trophic levels calucualted for the present day and 100-year models. Differences are highlighted.

Group name	Trophic level	
	Present	100-year
Adult sablefish	**3.6**	**3.7**
Carnivorous jellyfish	**3.0**	**3.1**
Crustaceans	2.2	2.2
Flatfish	**3.1**	**3.5**
herring, small pelagic fish	3.1	3.1
Juvenile sablefish	**3.8**	**3.7**
Juvenile salmon	3.1	3.1
lingcod	4.0	4.0
Macrobenthos	2.1	2.1
Mysticetae	3.1	3.1
Odontocetae	4.1	4.1
P.O. perch	3.1	3.1
P. Cod	3.4	3.4
P. halibut	3.9	3.9
Pinnipeds	4.1	4.1
ratfish, skates	**3.4**	**3.5**
rockfish, small benthic fish	3.2	3.2
Seabirds	3.6	3.6
Spiny dogfish	3.2	3.2
Transient orcas	**5.0**	**5.1**
turbot	3.7	3.7
Walleye pollock	3.3	3.3
Zooplankton	2.1	2.1

Unanswered questions

There are two kinds of unanswered question. The first relates to an absence of data on individual species or groups. Earlier discussion pointed to significant uncertainty about present and past numbers of a range of species, particularly rockfish, ratfish, skate, bottom dwelling species, even adult and juvenile salmon. Mention was made of the disappearance of tomcod *Microgadus proximus* from both Prince Harbour and Skidegate Inlet. Other information requirements include:

- Pre-contact and early fisheries harvests;
- biomass of adult salmon, and changes in abundance from 100 years ago;
- the abundance or presence of squid in the ecosystem; and,
- Information on types, abundance and harvest of sharks.

The second type of question relates to the ecosystem interactions between say herring, seals, sea lions, seabird, salmon, lingcod and commercial fisheries. This bears directly on the ability of commercial species to sustain fisheries or indeed recover from previous overfishing; the slow rate of recovery of Atlantic cod, despite 7 years of closure is a case in point. Jones (*In press*) discusses the impacts of commercial herring fisheries on Haida Gwaii stocks. Bycatch is another complex area that calls for ecosystem modelling.

Another area pertains to large changes in ecosystem structure. For example, in his introductory remarks, Tsimshian President Bob Hill mentioned a kelp forest that used to stretch from Kitamaat to Dundas. It is generally believed that the disappearance of kelp is related to the rise in sea urchin populations after the demise of the sea otter (*Enhydra lutris;* Paine 1980). However, this

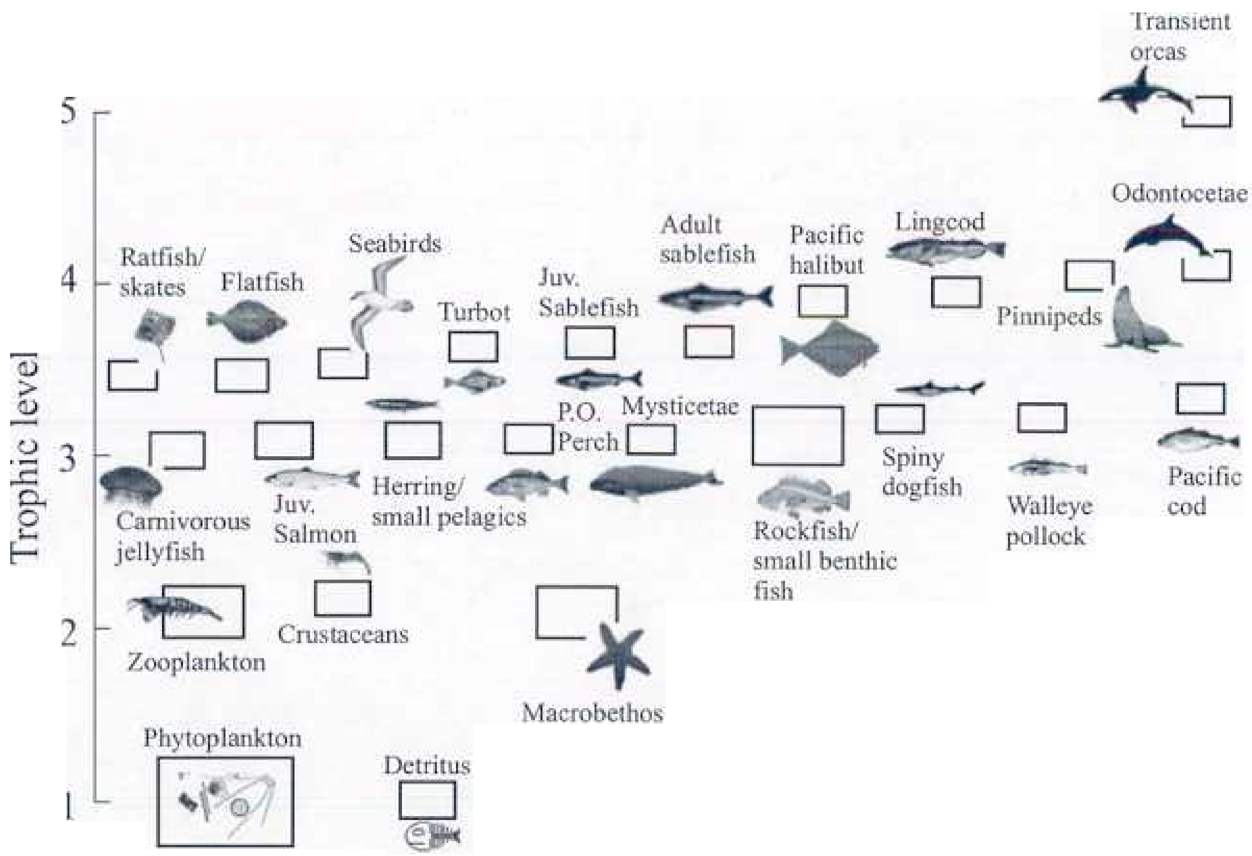

Figure 2. Pictorial representation of the elements of the Hecate Strait ecosystem, as it might have been 100 years ago. For comparison, this diagram and the diagram for the present day model are scaled to the same size, using the biomass of the phytoplankton box as reference.

large change in ecosystem structure will have profound implications for the presence, absence and relative abundance of species that depend on kelp forests for cover. Kelp is also important for herring spawn and the spawn on kelp fishery. The second example was of 'red tree' (gorgonians) in trawl fisheries. The effect of trawling on bottom structure is beginning to be documented (Auster 1998; Engel and Kvitek 1998; Watling and Norse 1998). On the credit side, ECOPATH can now accommodate the species that change actual ecosystem structure (C. Walters, UBC Fisheries Centre, pers. comm.), even if their impacts is due to effects other than predation. This should make it rewarding to revisit the models presented here.

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The Hecate Strait: a preliminary present-day model

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Abstract

A preliminary mass-balance model of the Hecate Strait region of British Columbia, Canada, for a period representing the early 1990s is presented. The model boundaries are defined by the fisheries statistical areas 5C and 5D. The model includes 25 functional groups, ranging from primary producers to top predators. Some problems, including over-aggregation of species within some of the functional groups and a lack of even general biological data for some groups may have biased the results.

The Study area

The Hecate Strait is defined here as the major statistical areas defined in the Canada Fishery Regulations as 5C and 5D. The southern boundary of region 5C is a straight line stretching East-West, from the southern tip of the Queen Charlotte islands to the mainland, along the longitude 52° 10" N. The northern boundary of area 5D is more complicated, extending from the northwestern-most tip of the Queen Charlottes, north to Canada/U.S.A. international boundary, and from there roughly due east to the mainland. The area thus defined includes the Hecate Strait and Dixon Entrance, and incorporates a surface area of ≈ 46,000 km^2 (see Fig. 1; and Tyler 1986). The area boundaries were determined in order to ease the calculation of the harvest rates and management strategies of the important fisheries in the region (including salmon, groundfish, halibut and sablefish), which are often reported by the major statistical areas.

This model is a modification of an earlier model created for the southern B.C. shelf region (see Pauly and Christensen 1996), that had a northern boundary in common with the southern boundary of this model. Other characteristics of the model are similar to the earlier model, including the difficulty of considering this a closed system. The area is not as well studied as other coastal regions within the province, however at least one earlier study attempted a multispecies research agenda, generating over 30 papers, many of which were useful for this study (see Tyler 1986; 1989). Some of the boxes incorporated in this preliminary model were obtained directly from the southern B.C. shelf model, due to a lack of relevant data for Hecate Strait.

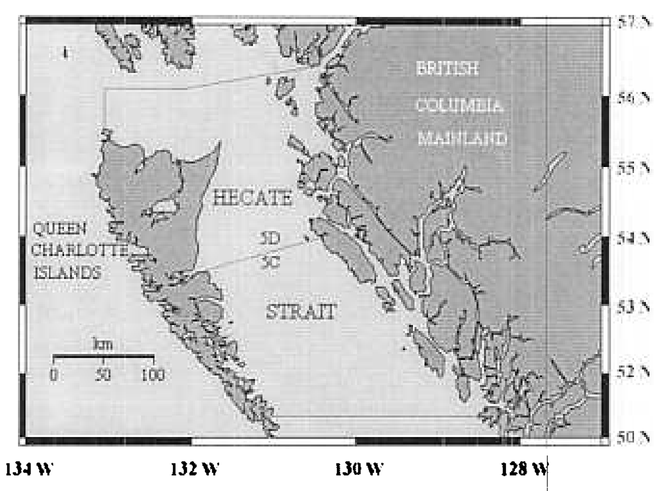

Figure 1. Map of the study area, showing the major statistical areas used as boundaries.

Modifications to the Southern B.C. Shelf Model

Several modifications to the southern B.C. Shelf model were made before beginning the building of the Hecate Strait model. These modifications were necessary for several reasons, including:

- the study area is considered oceanographically distinct from that of the previous model;
- the ranges of some species do not extend to the study area;
- and a lack of data for this study area.

First, imports and exports from the system were assumed to be zero (i.e., a closed system is assumed). This was done due to need for simplicity and lack of data.

Second, hake was deleted as element of the model. This was based on the assumption that the northern boundary of their range is generally south of the study area. This assumption was made because the fishery for hake takes place off the West Coast of Vancouver Island, and catches fall dramatically north of Cape Scott (author's pers. obs.).

Third, several boxes were aggregated into a reduced number of boxes, due to a lack of species-specific information for the study area. The aggregations were done using the manual aggregation utility incorporated in the ECOPATH software. The aggregations are as follows:

- The boxes for sea stars, brittle stars, bivalves and polychaetes were aggregated into a single box for 'Macrobenthos';
- The boxes for euphausiids, amphipods, copepodsx, chaetognaths and salps were aggregated into a single box for 'Zooplankton';
- The boxes for shrimp and decapods were aggregated into a single box for 'Crustaceans'.

Once the above steps were taken, no further modifications to the data in the model were performed (i.e., adjusting diet composition) until the new boxes were entered.

Model inputs

Primary productivity

Ware and McFarlane (1989) defined the study area as being within a "Coastal Downwelling Domain". This domain extends from Prince William Sound in Alaska, south to the northern tip of Vancouver Island, and extends offshore to 170°W. Thus, the region is considered distinct, in oceanographic terms, from the area covered by in the southern B.C. shelf model, although there is some overlap in the Queen Charlotte Sound area. The system is largely characterized by coastal waters; these differ from one area to another due to local variations in runoff, winds, heating and cooling, tides and currents. These differences are mediated, however, by the continuity and stability of the adjacent Alaska Current domain. The primary productivity for shelf waters of the domain ranges from 185-330 $gC{\cdot}m^{-2}{\cdot}year^{-1}$, and varies seasonally.

For the purposes of this model, which covers the time span of an average year, a mean of 257.5 $gC{\cdot}m^{-2}{\cdot}year^{-1}$, corresponding to 2,575 $t{\cdot}km^{-2}{\cdot}year^{-1}$ (wet weight), was used.

Zooplankton

The southern B.C shelf model incorporated boxes for several species of zooplankton. By contrast, little species specific information was found for the Hecate Strait region. Two estimates of zooplankton biomass were found. The first suggested a range of 30 – 50 $gC{\cdot}m^{-2}{\cdot}year^{-1}$, dominated by copepods, notably *Neocalanus* sp. (Ware and McFarlane 1989), although other studies have suggested that the zooplankton is in fact dominated by euphausiid species (Hay *et al.* 1986). The contradictory nature of the reports may be due to seasonal variation. As much as five times the annual secondary production may be advected shoreward from offshore production domains such as the Alaskan Gyre (Cooney 1984). Dunbrack and Ware (1986) found a value for all zooplankton to be 30 $gC{\cdot}m^{-2}{\cdot}year^{-1}$, based on plankton hauls from six stations in the Hecate Strait during the months of May, June and July over two years. This value compares favorably with Ware and McFarlane's (1989) estimate. The estimate used for this model was 40 $gC{\cdot}m^{-2}{\cdot}year^{-1}$, corresponding to 400 t·km-2·year-1 (wet weight).

Transient orca, Odontocetae, and Pinnipeds

No information specific to the study area could be found. The number of Steller sea lions, however, may range from 5-12,000 individuals (A. Trites, Fisheries Centre, UBC, pers. comm.). Based on an average weight of 198 kg (Trites and Heise 1996), this would result in a minimum biomass for pinnipeds of between 0.022 – 0.052 $t\cdot km^{-2}\cdot year^{-1}$. No changes were made to the biomass, or any of the inputs for these boxes, except the diet composition of pinnipeds was modified to include 17% pollock. This change reflects both the lack of hake in the study area and the increased availability of pollock relative to southern shelf areas.

Baleen whales (Mysticetae)

Inputs for this box remained the same as the southern B.C shelf model (Trites and Heise 1996), except for the biomass input. Here data from the IWC whaling base was used to calculate a probable number of animals in the area. The whaling operation was extensive, and here assumed to represent the removal of nearly the entire biomass for the region. This figure was inputted as an upper limit for the present day biomass, calculated by multiplying the total number of whales by an average biomass per whale. The value obtained was 0.31 $t\cdot km^{-2}\cdot year^{-1}$. All other parameters from the southern B.C shelf model remained the same.

Seabirds

Most parameters for seabirds remained the same as for the southern B.C shelf model (Wada and Kelson 1996). The biomass was changed, however, based on an estimate obtained from Vermeer and Rankin (1984). Their study of the total standing stock found that seabird numbers varied seasonally over several years, from a low of 75,000 in the winter months, to a high of greater than 5,000,000 in the early spring. The estimate used here is based on counts averaged over several years times an average body weight of seabirds. The value obtained was 0.016 $t\cdot km^{-2}\cdot year^{-1}$.

Spiny dogfish (*Squalus acanthias*)

The parameters for spiny dogfish remained the same as for the southern B.C shelf model (Polovina 1986), except for the biomass, and a shift in the diet composition of 2% to zooplankton, upon which dogfish are known to feed heavily, up to 70%, especially in winter (Hay *et al.* 1986, Simenstad *et al.* 1979), and reflecting the removal of hake from the system. Fargo *et al.* (1990) obtained a biomass estimate through a series of trawl surveys over the years 1984-1987. The values ranged from a low of 27,000 t to a high of 95,000 t. The value entered for this model was based on an average value, 1.25 t·km-2·year-1.

Ratfish/skates

This box is the first new box to be entered into this model. Though relatively little is known about these species, Brinkhurst *et al.* (1986) reported that in some areas of the Hecate Strait, ratfish (*Hydrolagus collei*) and skates combined may account for greater than 50% of the biomass in waters less than 100m deep, as estimated by trawl surveys. Furthermore, as fishery quotas on other species become increasingly smaller, vessels have begun targeting skate species, used in the production of false scallops. Ratfish are often caught in the groundfish trawl fishery, and may at times comprise the bulk of the biomass from individual sets. A biomass estimate for these two species was obtained in Fargo *et al.* (1990, Table 1).

No study was found of diet composition of skates in the study area; however studies on diet composition of skate species are available in the literature. For the purpose of this study, it was assumed that the diet composition of different species of skates would be similar due to constraints such as mouth shape. Based on this, a skate diet composition of 39% crabs, 28% invertebrates, 29% fish and 5% others were constructed (Robichaud *et al.* 1986; see also Table 2). This does not contradict Hart (1973), who indicated the diet of Big skate consisted of crustaceans and fish. Hart also indicated the diet of ratfish consisted of clams, crustaceans, and fishes.

A P/B ratio for skates was calculated using an empirical equation in Pauly *et al.* (1993),

Table 1. Biomass estimates for twelve major species based on trawl surveys in the Hecate Strait 1984-87[a].

Species	Standing Crop (t)		
	1984	1986	1987
Turbot	94229	21424	95444
Spiny dogfish	86003	27199	59441
English sole	37765	49261	15369
Ratfish	28644	54292	14157
Pacific halibut	25830	8073	8204
Dover sole	23497	361	34951
Rex sole	15600	17699	25900
Rock sole	12347	13458	8213
Sablefish	8134	1139	10852
Big Skate	5731	63058	5567
Pacific sanddab	3947	4375	1817
Petrale sole	2285	970	384

[a] from Fargo *et al.* 1990

also available in the 'Ecoempire' utility in ECOPATH, to calculate M (assuming P/B=Z=M, given F=0 and Z=F+M). Data for the equation came from Zeiner and Wolf (1993). No Q/B estimate was available, and thus a GE value of 0.25 was entered and Q/B calculated from GE = (P/B)/Q/B.

Pacific halibut (*Hippoglossus stenolepsis*)

All input parameters for this box were left as they were in the southern B.C shelf model (Venier 1996), except for biomass, which was taken from Fargo *et al.* (1990, Table 1). The value input was the average of the three values, 0.305 t·km-2·year-1.

Pacific cod (*Gadus macrocephalus*)

No data on cod for this area was found, and all input parameters remained as in the southern B.C shelf model (Livingston 1996), except for the diet composition, for which the predation on zooplankton was increased by 9%, to account for the lack of hake in the system. One study found a strong positive correlation between pacific cod recruitment and herring abundance, and *vice versa*, with herring figuring prominently in the diet of cod (Walters *et al.* 1986). However, physical oceanographic factors may be more important in the stock dynamics of the two species (Walters *et al.* 1986). Cod recruitment is subject to large fluctuations in from year to year and exhibits a strong inverse relationship with stock size, suggesting strong density dependence (Welch and Foucher 1986).

Walleye pollock (*Theragra chalcogramma*)

Walleye pollock were added to this model because of a reasonably large directed mid-water trawl fishery, which exists in the Hecate Strait and Queen Charlotte Sound, but not further south. Landings from the fishery have been increasing, and take place mainly in the first quarter of the year, when the stock is most abundant, although pollock are present year round (Saunders and Andrews 1994). It is likely that the stock is contiguous with the offshore stock, however, and that migration in and out of the system does occur (Saunders and Andrews 1994).

The biomass for pollock was reported to be 0.357 t·km-2·year-1 (Saunders and Andrews 1994); a P/B of 0.8, and a Q/B of 4.76 year-1 were taken from Venier and Kelson (1996). The diet composition was, as well, taken from Venier and Kelson (1996), but modified to reflect that the demersal fish box in that model consisted of a large group of dissimilar fish. Values for the diet composition entered into the model were: 15% herring and small pelagics, 60%

Table 2. Skate stomach contents from five samples from eastern Atlantic. Samples are from five tows[a].

	% wet weight (g)					
Prey	1	2	3	4	5	Mean
Crabs	0.65	0.35	0.30	0.35	0.30	0.39
Invertebrates	0.05	0.10	0.50	0.25	0.50	0.28
Fish	0.28	0.50	0.15	0.35	0.15	0.29
Others	0.02	0.05	0.05	0.05	0.05	0.04

[a] from Robichaud *et al.* 1986, (sp=*Raja radiata*)

macrobenthos, and 25% zooplankton.

Juvenile/adult sablefish (*Anoplopoma fimbria*)

All input parameters for this group remained as in the southern B.C shelf model (Livingston 1996), except for the diet composition, for which the predation on zooplankton was increased by 16% for juveniles and 5% for adults. This increase was done in order to reflect the absence of hake in the system.

Herring (*Clupea harengus pallasi*) and other small pelagics

The herring fishery in B.C. is second in commercial importance only to the salmon fishery, and indeed if one considers that it is a single species fishery, it becomes the most important by far (M.C. Healey, UBC, pers. comm.). There is a thriving fishery for herring in the Hecate Strait, where some year -round resident populations exist, and these may be separate stocks (Hay *et al.* 1986). The swelling of the gonads in the winter months may reduce feeding rates, due to gut volume constraints (Hay *et al.* 1986). herring may also exist in a predator-prey system with Pacific cod (Walters *et al.* 1986).

Biomass is estimated every year, although the methodology is dependent on back calculation of year strength, and rests upon the accuracy of an assumed fishing rate, which is generally set for a low risk option (M. C. Healey, UBC, pers. comm.). Research into other methods that would provide more reliable estimates of biomass, including hydroacoustic methods (Hay *et al.* 1986) and a particle-size spectrum estimation method (Dunbrack and Ware 1986) has been carried out. Results of these preliminary experimental models were unclear whether the estimates were more accurate or precise than the back calculation method, although the particle-size method provided similar results to the back calculation method (Dunbrack and Ware 1986). Estimate from the particle size spectrum analysis were 76,000 t, while Haist *et al.* (1985) estimated a value of 88,000 t for the same year using the traditional method.

Relatively little is known about other small pelagics in the region, other than that the group may include anchovies, eulachons, other smelts and sandlance. It is likely that these would be an important component in the diet of many other species, including Harbour porpoise (Trites and Heise 1996), Pacific halibut (Venier 1996), and some bird species (Wada and Kelson 1996); they and are therefore included in the 'herring' box.

Because this box includes other small pelagics for which there is little information, input parameters for this box were left the same as for the southern B.C shelf model, and the model was allowed to estimate the biomass. This allows for the estimates of the biomass of herring to act as a lower limit to the allowable biomass during the ECOPATH run.

Carnivorous jellies

No information was found for this group in the Hecate Strait region. All input parameters remained the same as for the southern B.C shelf model (Arai 1986).

Macrobenthos

This box is the result of an extreme aggregation, as noted above. Consequently, it has a high biomass and is subject to predation from a variety of other groups, including itself. Burd and Brinkhurst (1987) conducted a study on the macrobenthic infauna of the Hecate Strait. Their results (Table 3) indicated that polychaetes, bivalves and amphipods were the most abundant groups, in descending order, for all areas sampled. Individual areas differed significantly in species composition, due to differences in bottom type. Very deep stations sampled had very low biomass, possibly indicating limited water circulation.

The biomass of all taxa were averaged over the three areas, and averaged 3.94 g·m^{-2}. This is very similar to the 40 t·km-2·year-1; thus, no change was made to the biomass of this box. All other input parameters remained as in the southern B.C shelf model (Jarre-Teichmann and Guénette 1996), or as calculated by the manual aggregation performed by the ECOPATH software.

Table 3. Biomass estimates of fourteen macrobenthic infaunal species from the Hecate Strait.

Taxa	Cruise #			Mean
	1 (t·km^{-1})	2 (t·km^{-1})	3 (t·km^{-1})	(t·km^{-1})
Nemertea	15	683	7	235
Polychaeta	275	1222	814	770
Gastropoda	42	682	1849	858
Pelecypoda	878	70	95	348
Scaphopoda	12	1	10	8
Ostracoda	-	-	3	1
Cumacea	-	38	26	21
Isopoda	8	44	1	18
Amphipoda	13	1	1	5
Decapoda	8	4	80	30
Sipunculidae	7	10	3	7
Ophiuroidea	232	8	220	153
Echinoidea	2	41	568	203
Holothuroidea	125	-	3	43

Juvenile salmon (*Oncorhynchus* spp.)

Juvenile salmon make use of the Hecate Strait as a migratory pathway and as a nursery ground (Healey 1986). Depending on different assumptions about juvenile migratory behavior, the population would be dominated by pink salmon, followed by chum and sockeye (Healey 1986), with Coho and Chinook relatively minor or non-existent components of the system. The biomass of juveniles present in the Hecate Strait can thus vary widely (Table 4), as can the Q/B value required to support the population. For the purpose of this study, the biomass and Q/B were taken as the averages of the high and low model. A P/B/ estimate was obtained from Buckworth (1996), set at 0.75·year^{-1}.

Table 5 (Healey 1991) shows the diet composition for three species of juvenile salmon. In general, the diet was dominated by aescids, followed by euphausiids, and copepods. For the purpose of this model, the diet of juvenile salmon was set at 100% Zooplankton.

Table 4. Summary of biomass estimates and Q/B for a low and high model of juvenile salmon species usage of the Hecate Strait[a].

Species	Biomass (t x 10^3)			t·km^{-2}	Consumption (t x 10^3)			Q/B
	low	high	Mean		low	high	mean	
Sockeye	0.66	95.47	48.07	1.045	0.05	5.80	2.93	0.061
Pink[b]	3.60	101.42	52.51	1.142	0.72	10.51	5.62	0.107
Pink[c]	11.72	111.20	61.46	1.336	2.33	14.36	8.35	0.136
Chum	3.50	56.90	30.20	0.657	0.48	5.16	2.82	0.093
Coho	4.46	11.03	7.74	0.168	0.51	5.74	3.13	0.404
Chinook	1.01	6.15	3.58	0.078	0.13	0.45	0.29	0.081
			Sum= 4.425			Mean Q/B=		0.147

[a]data from Healey (1986)
[b]predictions are for odd year runs
[c]predictions are for even year runs

Pacific Ocean Perch (POP, *Sebastes alutus*)

The trawl fishery is the largest commercial fishery in British Columbia, by weight, although in the study area defined here, the total of Pacific salmon species catches are higher. POP is in turn the largest single species landed in the trawl fishery, and is the rockfish species that is best understood. POP stock assessments are often used by DFO as guidelines by which other quotas are set, for instance the TAC for the shortspine thornyhead is set at 10% of the TAC for POP, based on historical landing data (Richards 1994). In 1997-1998, the TAC for POP was set for 2,818 t in area 5C/5D,

Table 5. Diet composition for three juvenile salmon species in the Hecate Strait, over the years 1986-87. Note that all diet items represent zooplankton species[a].

Prey taxa	Pink (% volume)			Chum (% volume)			Sockeye (% volume)		
	1986	1987	Mean	1986	1987	Mean	1986	1987	Mean
Euphasiid	10.00	20.20	15.10	10.20	4.40	7.30	29.40	21.00	25.20
Calanoida	2.20	26.20	14.20	1.90	20.90	11.40	2.80	36.10	19.45
Brachyura	0.60	23.70	12.15	0.40	1.00	0.70	0.30	5.80	3.05
Pinotheridae	-	1.30	0.65	-	0.10	0.05	-	0.60	0.30
Crangonidae	-	0.10	0.05	-	-	-	-	0.40	0.20
Hyppolytidae	-	-	-	0.10	-	0.05	0.20	-	0.10
Hyperiidae	0.30	1.90	1.10	3.90	2.60	3.25	4.90	2.10	3.50
Cirripedia	5.10	0.70	2.90	-	0.20	0.10	-	0.20	0.10
Pteropoda	0.20	7.50	3.85	-	3.60	1.80	-	3.80	1.90
Polychaeta	-	0.30	0.15	-	-	-	-	0.50	0.25
Gastropoda	-	0.30	0.15	-	-	-	-	0.10	0.05
Ascidiacea	-	16.60	8.30	81.10	64.30	72.70	59.80	27.40	43.60
Chaetognatha	80.40	0.10	40.25	-	0.30	0.15	0.30	-	0.15
Fish larvae	0.90	0.90	0.90	2.00	2.00	2.00	2.10	1.30	1.70
Miscellaneous	0.30	0.20	0.25	0.40	0.60	0.50	0.20	0.70	0.45

greater than 50% of the total rockfish quota of 5,200 t. (DFO 1996) The trawl and hook and line fishery split the quotas at 76% and 24% respectively. In the Hecate Strait area, the majority of trawl catches of POP are from the southern area, and come from the Moresby Gully stock, which straddles our boundaries (author's pers. obs). In the DFO landings database, however, the catches from just south of our area are counted as coming from area 5C. These catches have been assumed to come from area 5C for the purposes of this model as well

Surprisingly for such an important species, there are few published data. Estimates of biomass come from Richards (1995), who estimated a total biomass of 25,200 t, for a value of 0.549 $t \cdot km^{-2} \cdot year^{-1}$. The data for estimating P/B are from Richards (1995), and assume that F=M=0.05, for a P/B of 0.1 year-1. Q/B is set at 3.44 $year^{-1}$ (Buckworth 1996). Diet composition (Table 6) was drawn from several sources, and is set at 89.4% zooplankton, 8.1% crustaceans, and 2.5% macrobenthos.

Rockfish/ Small Benthic Fish

This group was treated the same as the herring and small pelagics box, and includes the majority of sculpins, for which little information exists. Thus, this box is likely over-aggregated. Data for P/B and Q/B were set as for POP. The biomass was left unknown, for the model to generate, and the EE was set at 0.95. Diet composition (Table 6) is set at 4.8% crustaceans, 7% macrobenthos, and 91% zooplankton.

Flatfish

As for rockfish and POP, several flatfish species are heavily targeted in the Hecate Strait area, most notably english sole, dover sole and rock sole (author's pers. obs). They are included in this model for that reason. Published data for this species are difficult to find. Biomass was taken from Fargo *et al.* (1990), and represents a combined total for six species of flatfish, including english, dover, petrale, rex and rock soles, as well as the Pacific sanddab. The value thus obtained is 2.83 $t \cdot km^{-2} \cdot year^{-1}$. Values for P/B = 0.975 (0.4-1.15) and Q/B =3.21 $year^{-1}$ were found in Venier and Kelson (1996). No studies on diet composition for any of the flatfish species were found, except that Hart (1973) suggested that various flatfish species (here combined) eat clams and clam siphons, small

Table 6. Averaged diet composition of several rockfish species, with the diet for the Pacific Ocean Perch (POP) considered separately.

Prey	rockfish[a,b,c] (% volume)	POP[c] (% wet wt)
Crustaceans	0.048	0.084
Euphasiids	0.511	0.841
Copepods	0.392	0.043
Amphipods	0.004	0.010
Larvacae	0.003	0.000
Fish	0.035	0.000
Miscellaneous	0.007	0.025

[a] data from Lorz *et al.* (1983)

[b] data from Reilly *et al.* (1992)

[c] data from Brodeur and Pearcy (1984)

molluscs, small crabs, shrimps, and brittle stars. For the purposes of this model, the diet is set at 100% macrobenthos.

Turbot (*Atheresthes stomias*)

turbot are ubiquitous in the trawl fishery (author's pers. obs.) but until recently, with the introduction of IVQ's and area specific quotas in the fishery, they were considered a 'nuisance' or 'trash' species and generally discarded at-sea. Available data indicate, however, that the species has a high biomass (Fargo *et al.* 1981). Such a high biomass suggests that exclusion of this species from any ecosystem model of the Hecate Strait area must introduce some bias. Only one published source for turbot was found however, which included the biomass estimate, but no other data. The biomass was set at 0. t·km^{-2}·year^{-1}. The P/B and Q/B values used were the same reported for flatfish in general by Venier and Kelsonx (1996). No information was found on diet composition. Based on the physical structure of the mouth and gills and personal field observations, their diet was preliminarily set at 10% ratfish/skates, 20% juvenile sablefish, 20% crustaceans, 40% macrobenthos, and 5% zooplankton and rockfish/small benthic fish. Further information is needed for this group.

Lingcod (*Ophiodon elongatus*)

Lingcod in the Hecate Strait region have the advantage of being far away from most large population centres in British Columbia. As a result, they have not been heavily fished until recent years (McFarlane and Leaman 1996). The group is included here both because it is an important predator of many species, but also because it may be of future interest to compare the results of this model to others developed, for example the Strait of Georgia and the southern B.C shelf model. Both of these models are nearer to larger population centres and have experienced higher fishing pressures for longer. A biomass for this species was calculated using historical catch data from McFarlane and Leaman (1996) entered into a model developed by Martell (this vol.). The biomass calculated was 0.065 t·km^{-2}·year^{-1}. P/B, and Q/B are from Venier and Kelson (1996), their values are as follows: P/B = 0.58 (0.4-0.76); Q/B=3.3 year^{-1}. Diet composition changes as the lingcod grows, during early stages of the life cycle lingcod prey on zooplankton and crustaceans, as they mature they switch to herring, sandlance, pollock, cod and flounders (Forrester 1969). The diet composition entered into the model 29% herring, 15% crustaceans, 12% macrobenthos, 4% herring, 12% flatfish, 12% turbot, 4% spiny dogfish and 4% cannibalism.

Fishery harvests

Fishery catch data were acquired from the Department Fisheries and Ocean's (DFO) B.C. Commercial catches statistics database. The data covered the years from 1990-1995, and the catches reported in Table 7 represent average values over those years, as entered in the model. The catch rates for certain groups, such as the Macrobenthos, are aggregates of different fisheries (*i.e.,* geoduck, sea urchin, sea cucumber).

For most fisheries, however, reported landings underestimate the actual numbers or weight of each species caught (Alverson *et al.* 1994). The underestimation is due to the discards at sea not being reported or being under-reported. Buchary (1996) reported discards rates of 22% for targeted species and a ratio of 2.21 (discarded bycatch to landed catch) for non-target species. The figure for targeted species is based upon a faulty analysis, as the actual discard rates for targeted species are much lower (Table 8).

Table 9 is an adaptation of the one used by Buchary (1996) in order to determine discard rates in the trawl fishery. The higher value for discard rates for targeted species results from the inclusion of data for what historically, and for the most part presently, were by-catch species for the trawl fleet, including the redstripe rockfish, the sharpchin rockfish, sablefish, hake (not fished as a directed fishery except in the summer months), spiny dogfish (bycatch except for a small fishery in the Strait of Georgia), turbot, and skate. High reported discard/landed ratios for these species introduced significant bias to the overall reported average for target species.

Table 7. Reported landings for the Hecate Strait (statistical areas 5C/D).

Groups	Catch ($t \cdot km^{-2}$)
Macrobenthos	0.104
Crustaceans	0.041
Dogfish	0.004
Ratfish/Skates	0.004
Pacific cod	0.056
Herring/Sm Pelagics	0.130
Walleye pollock	0.011
Adult sablefish	0.013
POP	0.056
Rockfish	0.039
Flatfish	0.062
Halibut	0.027
Turbot	0.012
Lingcod	0.011

Reanalysis of the data presented in Tables 8 and 9 is revealing. Note that the reported values in Table 8 are for the summer months, while Table 9 is for the winter months. Hake is fished exclusively in the summer months,

Table 8. Catch and discard data for targeted species of the B.C. trawl fleet for April - July 1998. Neither the amount (tkm-1) nor the proportion of discards to landings were large enough to be entered as values in ECOPATH (<0.001), except for dogfish, for which the discard/landings ratio was 6%. Note that hake makes up the largest proportion of the catch. '-' indicates no data. (Source: DFO catch statistics)

Species	TAC (t)			Retained catch (t)			Discards (t)	Discard/
	5C/D	Others	Total	5C/D	Other	Total	All areas	landings
Rockfish, misc[a]	1,413	13,872	15,285	197	2,277	2,474	3	0.001
P.O. perch	2,817	3,330	6,147	999	1,110	2,109	1	0.000
Flatfish, misc[a]	2,730	3,675	6,405	327	478	805	2	0.002
Pacific cod[a]	1,000	954	1,954	405	48	453	0	0.000
Lingcod[a]	580	1,920	2,500	14	173	187	0	0.000
Spiny dogfish	-	5,440	5,440	-	98	98	6	0.061
Sablefish	-	386	386	-	88	88	1	0.011
Walleye pollock[a]	825	2,905	3,730	6	3	9	0	0.000
Pacific hake	-	84,687	84,687	-	10,498	10,498	0	0.000
Total	**9,365**	**117,169**	**126,534**	**1,948**	**14,773**	**16,721**	**13**	**0.001**
Total (no hake)	**9,365**	**32,482**	**41,847**	**1,948**	**4,275**	**6,223**	**13**	**0.002**

[a]data for 5C/D also includes area 5E for some species within groups

when almost the entire total allowable catch (TAC) is fished (indeed, often overfished) with a near zero rate of discard. The very low value is partly due to gear type (midwater gear as opposed to bottom gear), but also because Hake are caught in such quantities that entire cod-ends are passed whole to foreign vessels in the Joint-Venture fishery, or split directly into the holds without being picked through by the crew (for quality or size etc.) in the domestic shore-based fishery. The result is that all species caught are processed to either fillets or fishmeal, except for dogfish. The by-catch of dogfish in this fishery is very high, but (for the purpose of quota management) the vessels retain and land all of it in the Joint-Venture fishery. In contrast, and assuming all other things being equal, in the shore-based domestic hake fishery large dogfish catches are discarded at sea, likely without reporting or under reporting. It would be sensible to average discard rates for these species over the whole year.

The behaviour of the fishers may contribute to some of the difference between the two tables. In the intervening period between the collection of the data, DFO introduced a new management strategy for the fishery, based on an individual vessel quota (IVQ). Under the IVQ system, each vessel was given a quota for nearly every species of fish, either within a specific area or coastwide, including bycatch species. Exceeding the quota had consequences: the vessel would no longer be able to use bottom gear within the area for which the quota was exceeded unless it acquired more quota. The economic consequences were severe to a vessel that did exceed its quota, as only three choices are available: pay for more quota, do not fish some quota with a real value, or sell quota for an area. As a result, it is likely vessels began avoiding areas with higher bycatch levels in favour of cleaner catches in other areas whenever possible. An example of such a behavioral change is shown below.

Table 10 shows the discard rates for non-target species, grouped according to the functional groups used in this model. Note that the discarded proportion over this period (discarded biomass/[landed + discarded]) for turbot is 0.34; the biomass column gives a total amount of discards for a twelve month period. The rate is about half of the rate for 1996 (0.709). This can be attributed directly to the positive change in value of turbot to the fishers, as a consequence of both the costs of merely discarding it and of declining TACs for other species. The latter results in

Table 9. Discard rates for species caught in the B.C. trawl fishery for a 30 day period in February - May 1996.[a]

Groups	Retained catch (t)		Estimate/	Discarded at sea (t)			Released/
	At sea estimate	Landed	landed	Marketable Dead	Marketable Alive	Unmarketable (Dead and live)	retained
Rockfish	4,463	4,542	0.98	5.81	0.00	170	0.04
Flatfish	1,254	1,254	1.00	1.08	5.69	131	0.11
Turbot	921	775	1.19	0.00	0.05	653	0.84
Sablefish	38	37	1.01	4.43	17.33	45	1.78
Pacific cod	133	129	1.03	0.13	0.23	7	0.06
Lingcod	179	252	0.71	0.19	1.66	5	0.03
Spiny dogfish	64	62	1.03	0.00	0.00	547	8.82
Skate	67	117	0.58	0.00	0.00	112	0.96
Pacfic hake	3	2	1.61	0.00	0.00	35	16.84
Walleye pollock	450	492	0.92	0.00	0.00	41	0.08

adapted from Buchary (1996)

fishers targeting the previously underutilized species.

Several conclusions can be arrived at from the above data. Thus, discard rates for targeted species in the trawl fishery are quite low. Also, discard rates for non-targeted species are much higher, as much as several orders of magnitude. The rates for individual groups vary drastically, however, from as low as 0.37 for rockfish too as high as 38 for

As this model is entirely preliminary, I will not attempt a detailed analysis of it at this time.

Balancing the Model

The initial run of the model was surprisingly successful, with only three groups having EE values of greater than 1: Pacific cod (EE=18.4), herring/small pelagic (EE=2.4), and Flatfish (EE=1.1). Dalsgaard and Pauly

Table 10. Catch and discard data for non-target species in the B.C. trawl fishery for the period April - July 1998. Note that discard ratios may be several orders of magnitude higher than for targeted species, and that it is not legal for trawlers to retain herring. '-' indicates either no data available, or value too small (<0.001) to be displayed.

Species	Total at-sea estimate (t)	Retained catch (t)		Estimate/ landed	Discarded at sea (t)			Discards/ landed
		At - sea estimate	Landed		Marketable	Unmarketable (Dead and live)	Total t/km²	
Anemone (general)	1	-	-	-	-	1	-	-
Crabs	1	-	-	-	-	1	-	-
Flatfish	137	43	55	15.27	-	93	0.002	1.71
Grenadier	27	-	-	-	0.01	27	0.001	-
Pacific herring	8	-	-	0.28	-	8	-	36.61
Ratfish	86	-	2	0.08	-	86	0.002	37.98
Rockfish	246	173	197	5.24	0.23	73	0.002	0.37
Skate	169	57	96	9.84	-	112	0.002	1.17
Squid	1	-	-	-	-	1	-	-
Turbot	2,557	1,896	1,936	0.98	-	660	0.014	0.34
Total (for species <1000)	**676**	**273-**	**350-**	**-**	**0.24-**	**1062**	**-**	**-**
Total (all groups)	**3,233**	**2,170**	**2,286**	**0.95**	**0.24**	**1,064**	**0.139**	**0.47**

ratfish. Finally, it is important for persons with knowledge of a fishery to verify estimates of discard rates. For the purpose of this model, the discards from Table 10 are included in the basic input.

Results and Discussion

Table A (Appendix II) shows the basic parameter estimates and trophic levels as calculated by ECOPATH, and Table C (Appendix II) shows the diet matrix used in the balanced model. Figure 2 shows a graphic version of the model.

(1997) identified two approaches to balancing an ECOPATH model: a subjective approach, based on identifying input parameters deemed to be questionable and modifying them according to personal knowledge until balance is achieved; and a rigorous approach, using the Ecoranger utility. This utility, through a Monte-Carlo approach and interpreted within a Bayesian context, identifies the likely values for input parameters. The latter requires more knowledge of the system than available here; therefore the former approach was taken to balance the model.

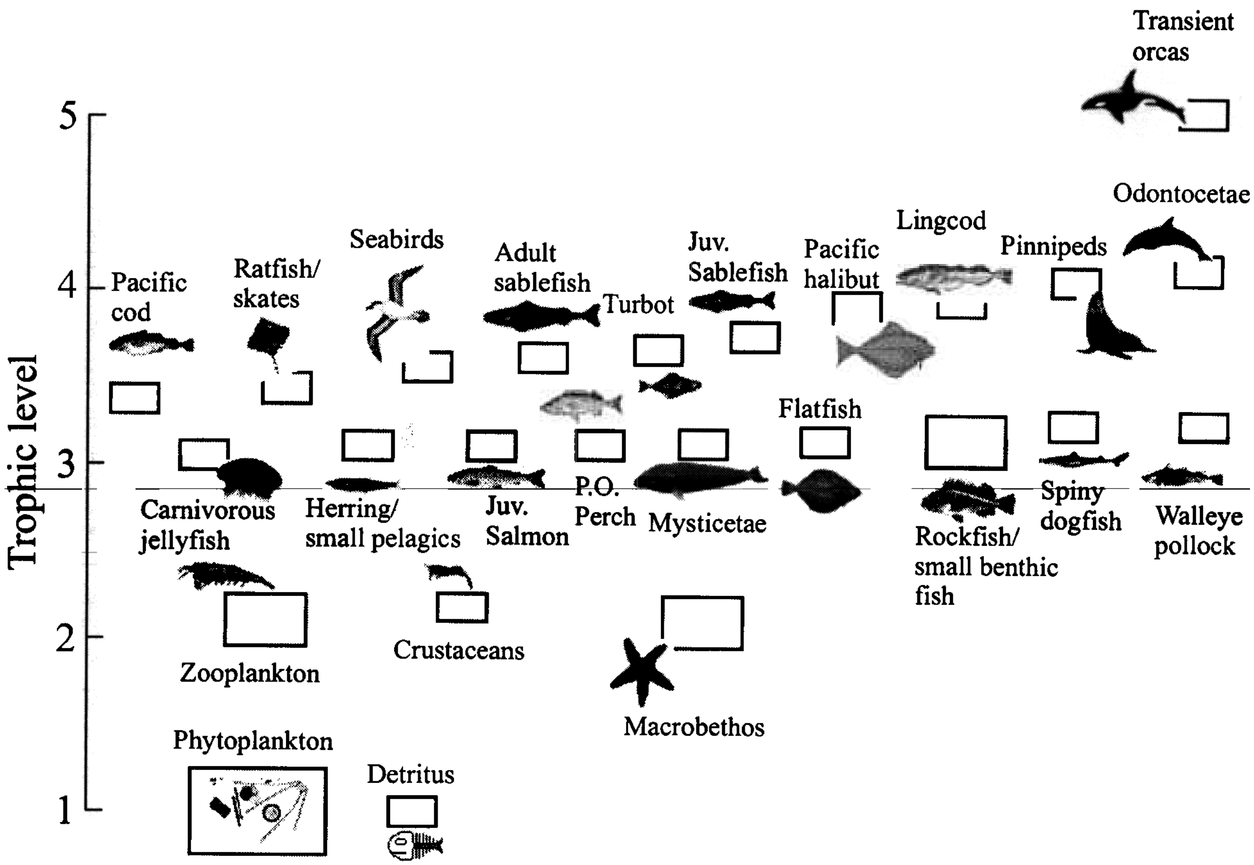

Figure 2. Pictorial representation of the trophic flow diagram produced by ECOPATH, for the present day model. For comparison, this flow diagram and the diagram for the 100 year model are scaled to the same size, using the size of the phytoplankton box as a guide (values did not change between models).

However, very little other than the diet compositions needed to be changed in order to balance the model:

1. The EE for the herring/Small pelagics box was changed to a value of 0.98, to reduce their calculated biomass. Otherwise, the biomass continued to be estimated by the ECOPATH software.

2. The biomass of turbot was increased to the high range, from 0.709 – 1.13 $t \cdot km^{-2} \cdot year^{-1}$. This was done to reflect the probable role it plays in the diets of other species, to reduce the diet pressure placed on other species, and as a reflection of the uncertainty in the biology of the species or of the role it plays in ecosystems.

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