Development of an ecosystem model of the western North Pacific

Mori, M.[1], Watanabe, H.[2], Hakamada, T.[1], Tamura, T.[1], Konishi, K.[1], Murase, H.[1] and Matsuoka, K.[1]

1: The Institute of Cetacean Research, 4-5 Toyomi-cho, Chuo-ku, Tokyo, 104-0055, Japan

2: National Research Institute of Far Seas Fisheries, 2-12-4 Fukuura, Kanazawa, Yokohama 236-8648, Japan

Corresponding author: mori@cetacean.jp

0. Abstract

In order to evaluate the possible impact of whales (minke whales, Bryde's whales, sei whales and sperm whales) migrating to the JARPN II survey area on Japan's fisheries resources (e.g. anchovy, Pacific saury, mackerels, etc.), an initial ecosystem model of the western North Pacific is built using the Ecopath-with Ecosim software. As for an initial test run, the impact of no harvesting and harvesting 4% of the whales for the coming 50 years on catch of the fishes was made. When running the harvesting scenario, uncertainties in the functional response forms and trophic flow are considered. Also, sensitivity of the results to uncertainties in the in-put parameters is explored. Furthermore, MSY which includes and excludes species interactions are calculated. The results shown here suggest that in average terms: 1) when minke whales are the only species that are harvested by 4% of its biomass (catch of other species are kept constant at current catch rate), depending on the functional response form assumed for the species, it is not certain whether catch of some Japanese fisheries resources (e.g. anchovy, Pacific saury, skipjack tuna, mackerels) will increase or not; 2) when sei and Bryde's whales are each the only species that are harvested by 4% of their biomass, regardless of the functional response form assumed for the species, catch of anchovy, skipjack tuna, and mackerels may increase;3) when minke, sei and Bryde's whales are all harvested by 4% of their biomass, positive amount of increase in catch is expected for most of the fish resources (i.e. anchovy, skipjack tuna and mackerels), indicating the effectiveness of harvesting several whale species simultaneously; and 4) when sperm whales are the only species that are harvested by 4% of its biomass, depending on the functional response form assumed for the species, catch of anchovy, Pacific saury, mackerels and skipjack tuna may decrease, but instead, catch of neon-flying squid may increase. Caveats pertaining to the results and the use of such ecosystem models in a management context are also discussed. The main advantages in building such a model is that it allows quantitative evaluation of the possible effects of whaling on fisheries resources, and that it provides quantitative estimates on the biomass of small surface squid and mid-deep water squid which in other ways not have been possible. In addition, for minke and Bryde's whales, obtaining further diet composition data has improved the precision of the estimate of % increase in catch of Japan's fisheries resources (i.e. Pacific saury, anchovy, mackerels) calculated by the EwE model. This suggests that continuation of the JARPN2 survey will likely contribute in improving the precision of the effect of whaling on Japan's fisheries resources, which is important for robust management of the fisheries resources in the western North Pacific.

1. Introduction

1-1. Background on JARPN and JARPNII

The Japanese Whale Research Program under Special Permit in the western North Pacific (JARPN) started in

1994 and ended in 1999. The initial objective of JARPN was to clarify the stock structure differentiation and mixing of minke whales distributed in the waters around Japan (The Government of Japan 1994). Another objective was added in 1996 which was to start a feasibility study on feeding ecology of minke whales. There were two main findings from JARPN. One was that scientific information obtained from JARPN enabled the Scientific Committee (SC) of the International Whaling Commission (IWC) to discard the sub-stock hypothesis on the Okhotsk Sea/Western Pacific ('O' stock) of minke whales which was proposed in 1993 (IWC 1997). Another finding was that most of the whales pursued single prey species aggregation and the main prey species of minke whales changed seasonally and geographically, for example, anchovy in May/June and Pacific saury in July/August. These species are the main target species for the Japanese fisheries, and the estimated prey consumption by minke whales was comparable to that of the commercial fisheries (Tamura and Fujise 2000a, b). The IWC/SC reviewed the final results of JARPN during a workshop conducted in 1999, and recommended that further research is necessary to examine the hypothesis of the occurrence of a western stock ('W' stock) of minke whales in offshore areas of the western North Pacific (IWC 2000a). Also, it was agreed that the sampling regime must be designed to allow for a more quantitative estimation of temporal and geographical variation in diet of minke whales, and an improved understanding of the distribution and abundance of relevant prey species is necessary (IWC 2000a). Therefore, it was recommended that acoustic and trawl surveys, designed to address such questions, should be conducted concurrently with future whale surveys, if possible (IWC 2000a).

To follow up on these issues, the second phase of this research program (JARPNII) started from 2000 and ended its first period in 2007, with 2000 and 2001 being a feasibility study period. The overall goal of JARPNII is to contribute to the conservation and sustainable use of marine living resources including whales in the western North Pacific, especially within Japan's EEZ. Toward this overall goal, three objectives are set, (a) feeding ecology and ecosystem studies, (b) monitoring environmental pollutants in cetaceans and the marine ecosystem and (c) elucidation of stock structure (Government of Japan 2002). The priority is put on the first objective which includes estimation of prey consumption and prey preference of cetaceans, an assessment of how cetaceans use their habitats through feeding activities, and building an ecosystem model. In this paper we focus on the ecosystem modeling aspect of JARPNII.

1-2. Background on ecosystem modeling in JARPNII and its objectives

There are mainly three motivations in building an ecosystem model in the western North Pacific. The first motivation is the drastic decrease of Japan's fisheries catch from 12,785 thousand tons in 1988 to 6,684 thousand tons in 1998. Due to this decrease, the Fisheries Agency announced the principle for the fundamental policy on fisheries and its action program to implement the policy, which first priority is given to science-based management and sustainable utilization of fisheries resources within Japan's EEZ. To aid the recovery of the resources, investigations should be carried out taking into account the management and sustainable utilization of whole ecosystem including marine mammals.

The second motivation is the possibility of competition between marine mammals and fisheries on their prey and fisheries resources. Tamura and Ohsumi (1999) estimated that the amount of yearly consumption of prey by whales is three to five times larger than the world's fisheries total catch suggesting that the effect of consumption by whales on fisheries resources may not be negligible. Also, during JARPN it was found that there was great overlap between the fishing ground of Pacific saury and the distribution of minke whales, suggesting some possibility of competition between fisheries and minke whales on Pacific saury. Furthermore, during the feasibility study of JARPNII, it was found that not only minke whales but also Bryde's whales and sei whales largely prey on Japanese anchovy. Thus, there is great interest mainly by fisheries managers on investigating the impact of whaling on Japan's fisheries resources (e.g. Pacific saury, anchovy etc.).

The third motivation in building an ecosystem model is the world-wide recognition of the importance of applying Ecosystem Approach to Fisheries (EAF). Evaluating the effect of fishing on not only the target fisheries resource but also on the ecosystem surrounding the species has become an important issue (e.g. bycatch of sea-turtles and sea birds by longline fisheries, destruction of leefs by deepsea trawl etc.). Also, there has been some criticism on Maximum Sustainable Yield (MSY) calculated from single-species dynamics model (Matsuda 2004), since for example; the MSY of minke whales which mainly prey on Pacific saury may depend on the fishing mortality of Pacific saury, thus can not be appropriately calculated without taking into account interactions between its prey species. Moreover, at the World Summit on Sustainable Development in Johannesburg, South Africa in 2002, it was agreed to encourage the application of EAF by 2010 (WSSD 2002).

With all these motivations and backgrounds, ecosystem modeling in the western north Pacific started. As a first step in building an ecosystem model, we set mainly two initial objectives. One is to evaluate the possible impact of whaling on Japan's fisheries resources, and the second is to explore whether MSY of a species calculated from single-species assessments differ to those calculated from multi-species assessment. As for a longer-term objective, we aim to apply such kind of ecosystem model for sustainable management of whales and fishes in the western North Pacific.

In this work of nature, Okamura *et al*. (2001) developed an Ecopath with Ecosim (EwE) model in sub-area 7 (see Figure 1) to investigate whether there can be the competition between whales and fisheries over marine resources in the western North Pacific area. Their results suggested that when the vulnerability parameter is high (which is likely to be the case in the western North Pacific area), competition between cetaceans and fisheries over marine resources could occur. However, they also noted that further research on the effect of uncertainty of the parameters and other aspects (e.g. effect of environmental factors) on the results needs to be investigated.

In this paper, we update/expand the EwE model of Okamura *et al*. (2001) in various aspects as detailed in the following sections.

2. Methodology

We use Ecopath with Ecosim Ver 5.1 (Christensen *et al*. 2005） in building the model. Ecopath with Ecosim (EwE) is an ecological software suite, and has three main components: Ecopath – a static, mass-balanced snapshot of the system; Ecosim – a time dynamic simulation module for policy exploration; and Ecospace – a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas (Christensen *et al*. 2005). It is currently dominating attempts worldwide to provide information on how ecosystems are likely to respond to changes in fishery management practices (Plagányi 2007). Brief description of the model is given in Appendix A (for details refer to Christensen *et al*. 2005).

Area to be modeled is the Off shore area of sub-area 7 (which excludes the continental shelf), and sub-areas 8 and 9 (see Figure 1, total area to be modeled is 2,775,043 km^2). Coastal areas and Okhotsk area (sub-area 11) are not modeled here since the ecosystem and the composition of the species differ from that of the off-shore areas. Effect of migration to these areas will be considered at a later stage of development of the model. The model consists of 31 species (or group) ranging from detritus to whales which are considered to be important species in the off-shore area. List of the species (or group) considered in the model are shown in Table 1a. Many of the data used especially for whales and its prey species are obtained from JARPNII, and the in-put data on B (biomass), P/B (ratio of production to biomass,) Q/B (ratio of consumption to biomass), DC_{ji} (fraction of the prey i in the diet of predator j), and Y (total fishery catch) for each species are shown in Tables 1a-1c (see Appendix B for detail sources of these data).

By using Ecopath, first a mass-balance model which reflects the current situation of the ecosystem (around year 2006) is constructed. Further, the connectivity of the species and the possible qualitative impact of an increase in one species may have on the other is evaluated using mixed trophic impact (MTI; see Appendix A for details). Next, by using Ecosim, the possible impact of whales on their prey species (especially those that are commercially important for Japanese fisheries) are evaluated. More specifically, the difference in catch of the prey species between the following two catch scenarios for minke whales, Bryde’s whales, sei whales and sperm whales are evaluated:

1) No catch of the target whale species for 50 years, and
2) Harvest 4% of the biomass of the target whale species every year for 50 years.

4% is chosen here, since the plausible range of Maximum Sustainable Yield Rate (MSYR) for baleen whales is currently considered to be 1-7% in the IWC (IWC 1994), and for North Pacific minke whales, it is agreed in 2003 that 4% had a high plausibility (IWC 2004).

When running the harvesting scenarios, three types of uncertainties are considered:

1) Uncertainties in the in-put parameters of Ecopath,
2) Uncertainties in the functional response form, and
3) Uncertainties in the trophic flow (e.g. top-down or bottom-up control).

For the various functional response forms, parameter settings in Ecosim and its assumptions are detailed in Appendix C. The trophic flow in Ecosim is controlled by the vulnerability parameter (v). Low v assumes that the species is less vulnerable to its predators (‘bottom-up control’) and high v assumes ‘top-down control’. v=2 indicates mixed trophic control.

As a “Reference case” scenario, we assume Type I functional response with v=2. As a sensitivity test, we change the functional response form and v. Whether, MSY of a species calculated from single-species assessments differ to those calculated from multi-species assessment is also explored.

3. Results

3-1.Building a mass-balance Ecopath model

At the first stage of the mass-balance model development, ecotrophic efficiency (*EE*) (*EE*: proportion of ones production used by consumption or harvesting) for anchovy (less 8cm) slightly exceeded 1 (*EE*=1.014). If EE>1, this means that the species is harvested or consumed more than its production. Thus, by increasing the biomass or production of the species, or by reducing the predation mortality of the species, the parameter should be adjusted to give a mass-balance model. As for anchovy (less 8cm), *P*/*B* was increased from 1.6 to 1.7 since this was judged to be the most uncertain parameter among those that were adjustable for this species. The resultant mass-balance model and its estimated parameters are shown in Table 2.

Figure 2 describes the food-web assumed in the model and the trophic level (TL) of each species calculated using Ecopath. Figure 3 indicates the possible impact of direct and indirect interactions (including competition) in a steady-state system calculated using MTI. The species on the vertical axis shows the species that give impact, and the species on the horizontal axis shows those that receive the impact. Upward bars represent positive impact, and downward bars represent negative impact. The following can be said from Figure 3:

① Increase in the biomass of Pacific saury will give positive impact on minke whales.

② Increase in the biomass of anchovy will give positive impact on minke whales, Bryde’s whales, sei whales, albacore and skipjack tuna.

However, these relationships shown in Figure 3 only stands when the system is in balance, and should not be used to predict what will happen in the future if certain interaction terms are changed (Christensen *et al*. 2005). This is explored using Ecosim and the results are shown in the following sections.

3-2.ECOSIM calculation

Possible impact of whaling on the catch of other species in the ecosystem

Percent change in catch between no harvesting and harvesting 4% of the biomass of the whales for the coming 50 years is shown in Figures 4.1 to 4.6 for minke whales, sei whales, Bryde’s whales, sperm whales and the combined effect of harvesting several whales simultaneously is also explored.

When 4% of the **minke whale** population is harvested (this amounts to about 440 whales for the initial harvesting year; which is two times the current amount of catch), the catch of their main prey, Pacific saury may increase for about 1.4% (i.e. 5,500 tons) for the “Reference case” in 50 years, compared to the case when minke whales were not harvested (Figure 4.1 upper column figure). For lower *v* (*v*=1), this effect is less obvious, and for higher *v* (*v*=5), the increase in the catch of Pacific saury may increase to about 9.5% (i.e. 36 thousand tons). Catch of several other species, for example sardine, mackerels and anchovy may also slightly increase due to reduced predation mortality by minke whales. On the other hand, the decrease in the catch of salmon shark is caused by indirect effect of the decrease in euphausiid biomass due to increased predation mortality by Pacific saury, which in turn causes the reduction of the biomass of large surface squid, which is the main diet of the salmon sharks. When different functional response forms are considered, the increase in the catch of Pacific saury range from 0-6.5% (i.e. 0-28,000 tons) in 50 years (Figure 4.1 bottom column figure). Increase in the catch of anchovy is about 0-1%, (i.e. 0-2,800 tons) and that of mackerels ranges from 0-3% (i.e. 0-11,100 tons). Slight increase (i.e. 2,800 tons) in the catch of skipjack tuna is caused by the increase in the biomass of anchovy, which is its important prey.

When 4% of the **sei whale** population is harvested (this amounts to about 280 whales for the initial harvesting year; which is almost three times the current amount of catch), the catch of their main prey anchovy increase for about 4% (i.e. 8,300 tons) for the "Reference case" in 50 years, compared to the case when sei whales are not harvested (Figure 4.2 upper column figure). The increase in the catch of sardine (6%; 2,800 tons), mackerels (4%; 17,000 tons) and skipjack tuna (8%; 8,300 tons) is also expected. Again for lower *v* (*v*=1), this effect is less obvious, and for higher *v* (*v*=5), the change in the increase in the catch of anchovy is slight, whereas mackerels catch increases for about 19% (i.e. 75,000 tons), as well as that of skipjack tuna and albacore. The increase in the catch of mackerels is caused by reduced predation mortality by sei whales, whereas the increase in the catch of skipjack tuna and albacore are caused by the indirect effect of increase in the biomass of anchovy. Catch of Pacific saury slightly decreases due to the increase in minke whale biomass caused by the increase in the biomass of mackerels and anchovy. To obtain positive catch from Pacific saury as well, minke whales may also need to be harvested more than the current harvesting rate (the result of the combined effect of harvesting sei and minke whales together is shown in later scenarios). When different functional response forms are considered, major qualitative results do not change but the magnitude of the increase in catch varies (Figure 4.2 bottom column figure). Increase in the catch of anchovy range for about 1-10% (i.e. 2,800-19,000 tons), that of mackerels range for about 4-31% (i.e. 17,000-114,000 tons), that of skipjack tuna range for about 5-16% (i.e. 5,600-17,000 tons) in 50 years, all showing positive catch regardless of the assumption of the functional response form.

When 4% of the **Bryde's whale** population is harvested (this amounts to about 120 whales for the initial harvesting year; which is almost three times the current amount of catch), catch of anchovy (3%; 5,600 tons), mackerels (2%; 8,300 tons) and skipjack tuna (5%; 5,600 tons) increase for the "Reference case" scenario in 50 years (Figure 4.3 upper column figure). Instead, the catch of sardine decreases for about 6% (i.e. 2,800 tons). This decrease is caused by the increase in the biomass of minke and sei whales which both slightly consume sardine (and currently only these two whale species is assumed to feed on sardine in the model). This again suggests that to obtain positive catch from sardine as well, minke and sei whales may also need to be harvested more than the current harvesting rate (the result of this combined effect of harvesting Bryde's, sei and minke whales is shown in later scenarios). For higher *v* (*v*=5), catch of mackerels and skipjack tuna more than double, and anchovy catch increases for about 5% (i.e. 11,000 tons). When different functional response forms are considered, anchovy catch increases for about 1-10% (i.e. 2,800-19,000 tons), that of mackerels for about 2-15% (i.e. 8,300-61,000 tons), and that of skipjack tuna for about 5-18% (i.e. 5,600-19,000 tons) (Figure 4.3 bottom column figure) again all showing positive catch regardless of the assumption of the functional response form.

When **minke**, **sei** and **Bryde's whale** populations are all harvested simultaneously for 4% of their biomass, catch of Pacific saury, anchovy, sardine, mackerels and skipjack tuna all increase for about 10% for the "Reference case" in 50 years compared to when none of these whales are harvested (Figure 4.4 upper column figure). This result suggests that rather than harvesting each whale species separately, it is effective when all three whale species above are harvested in combination. When different functional response forms are considered, anchovy catch increases for about 4-19% (i.e. 8,300-39,000 tons), mackerels catch increase for about 7-55% (i.e. 31,000-191,000 tons), Pacific saury catch increase for about 0-2% (i.e. 0-8,300 tons), sardine catch increases for about 0-12% (i.e. 0-5,600 tons), and skipjack tuna catch increase for about 10-39% (i.e.11,000-39,000 tons) (Figure 4.4 bottom column figure).

When 4% of the **sperm whale** population is harvested (this amounts to about 2,000 whales for the initial harvesting year; which is 200 times the current amount of catch), catch of neon-flying squid increase for about 6% (2,800 tons) for the "Reference case" scenario in 50 years due to reduced predation mortality by sperm whales (Figure 4.5 upper column figure). When stronger top-down effect is considered (*v*=5), biomass of large surface squid decreases due to increase in predation mortality by neon-flying squid. Catches of blue shark increases for about 50% (5,600 tons) due to the increase in the biomass of their prey of mid-deep water squid which is reduced from predation mortality by sperm whales. Catch of Pacific saury decrease due to the decrease in their main prey euphausiids biomass caused by the increase in the predation mortality by mid-deep water squid released from sperm whale predation. When different functional response forms are considered, increase in blue shark catch range from 0-100% (i.e. 0-14,000 tons), and that of neon-flying squid range from 5-23% (i.e. 5,600-25,000 tons) (Figure 4.5 bottom column figure).

When 4% of **all the whales caught during the JARPN II s**urvey (i.e. the above four whale species) were harvested simultaneously, catch of skipjack tuna, neon-flying squid, mackerels and anchovy increases regardless of the functional response form assumed; however, for Pacific saury, for most of the case catch decreases (this is due to the effect of sperm whale harvesting explained above) (Figure 4.6).

Uncertainties in the in-put parameter

The analysis up-to now does not take into account uncertainties in the in-put parameters. Thus, to take this uncertainty into account, the basic input parameter, *B*, *P/B*, *Q/B* and *EE* were varied by -50% and +50% (in steps of 10%) for each component and the resulting percent change in the "missing" estimated parameters to the original parameter were calculated. The result of this analysis is summarized in Figure 5. The index is the sum of the maximum change in (estimated parameter – original parameter)/(original parameter) given ±10-50% changes in the input parameters of the species named on the y-axis. Figure 5 shows that changes in the parameters of sperm whale and mid-deep water squid exert the greatest influence on the estimated parameters (though note that the constraint of *EE*<1 is not considered here).

Because the Ecopath mass-balance was most sensitive to parameters for sperm whale and mid-deep water squid, we concentrated further sensitivity analysis on these two components. The sensitivity of the results of the various harvesting scenarios shown in the previous section to changes in the basic parameters for these two components was explored. *B*, *P/B* and *Q/B* for the sperm whale were altered by ±50%, and how the results shown in the previous section will change was evaluated. *P/B*, *Q/B* and *EE* for mid-deep water squid were also altered by ±50%.

Table 3 shows the sensitivity test scenarios and the resultant percent change in catch compared to the result of the "Reference case" scenario for the harvesting scenarios that actually did have some effect. Other harvesting scenarios (i.e. harvesting minke, sei and Bryde's whales) that are not shown in this Table did not have any effect by this change. This result was predictable beforehand, since the diet of sperm whales hardly overlap with those of minke, sei or Bryde's whales. For the sperm whale harvesting scenario, sensitivity test which reduced 50% of *P/B* of mid-deep water squid (s8) resulted in the largest change (-1.3%) in the catch of Pacific saury. In absolute terms this amounts to only a 2% (8,300 tons) decrease in the catch of this species. At maximum, catch of large-surface squid increased 2% compared to the "Reference case" scenario, which amounts to in absolute terms 4% (5,600 tons) increase in the catch of this species. Catch of neon-flying squid at maximum, decreased/increased 2.8% compared to the "Reference case" scenario, which amounts to in absolute terms 3% (3,000 tons) or 8% (8,000 tons) increase in the catch of this species. Catch of mackerels at maximum decreased 1.3% compared to the "Reference case" scenario, which amounts to in absolute terms 1.3% (5,600 tons) decrease in the catch of this species.

For the four whale species harvesting scenario, at maximum, catch of mackerels and Pacific saury decreased/increased 0.7% compared to the "Reference case" scenario, which amounts to in absolute terms 6.6% (28,000 tons) or 5.3% (22,000 tons), and ±0.7% (±2,900 tons) increase in catch for mackerels and Pacific saury, respectively. Catch of large-surface squid and neon-flying squid also changed for some scenarios, showing similar behavior to the sperm whale harvesting scenario.

Single-species MSY and multi-species MSY

Single-species MSY is calculated by the following procedure. First, for each harvested species, a long simulation (1000+ years) was run, where fishing mortality rate (*F*) of that species was incremented or decremented slowly, while holding all other *F* (and biomasses) constant at Ecopath base values. F_{MSY} for the species was taken to be the *F* that resulted in maximum average catch. Multi-species MSY is calculated by setting the *F* for each harvested species to its F_{MSY} estimated from the above simulation for that species. Biomasses and catches at the end of this simulation represent Ecosim predicted equilibrium values under the all-species F_{MSY} policy.

Figure 6 shows the ratio of single-species MSY to multi-species MSY for the harvested species. For most of the whale species and for some fish predators, single species MSY is estimated to be higher than the multi-species MSY. This result indicate that for most of the whales, MSY calculated from the single-species analysis could be optimistic, since it ignores the effect of predation mortality by other predators and fishing mortality on its prey species. MSY calculated from the single-species analysis for anchovy could also be optimistic, since it ignores high predation mortality by various predator species, including whales, albacore and skipjack tuna.

4. Summary and Discussions

One of the advantages in building such ecosystem model is that it allows *quantitative* evaluation of the possible effect of whaling on fisheries resources. Without such ecosystem model, predictions are often only qualitative. Table 4 summarizes the possible change in catch for some fish and squid resources between harvesting 4% of the biomass of the whales and no harvesting of the whales for the coming 50 years. The results shown in Table 4 assumes *v*=2 (mixed trophic control) since our aim was not to show results on extreme cases, such as fully bottom-up control or strong top-down control, but to show results on intermediate cases, since it is thought that the relative strength of bottom-up or top-down control in the western North Pacific area may vary by season, area and by year (Nagasawa pers. commn.). Thus the results shown here may be regarded as an average case.

Several interesting aspects can be seen from Table 4:

- When minke whales are the only species that are harvested by 4% of its biomass (catch of other species are kept constant at current catch rate), depending on the functional response form assumed for the species, it is not certain whether catch of some important Japanese fisheries resources (e.g. anchovy, Pacific saury, skipjack tuna, mackerels) will increase or not.
- When sei and Bryde's whales are each the only species that are harvested by 4% of its biomass, regardless of the functional response form assumed for the species, catch of anchovy, skipjack tuna, and mackerels will increase.
- When minke, sei and Bryde's whales are all harvested by 4% of its biomass, positive amount of increase in catch is expected for most of the fish resources (i.e. anchovy, skipjack tuna and mackerels), indicating the effectiveness of harvesting several whale species simultaneously.
- When sperm whales are the only species that are harvested by 4% of its biomass, depending on the functional response form assumed for the species, catch of anchovy, Pacific saury, mackerels and skipjack tuna may decrease. Instead, catch of neon-flying squid may increase.

These results are all deterministic and do not consider stochastic effects on species which could be caused by some changes in environmental factors, such as water temperature or water salinity etc. Thus, the results shown here should not be regarded as definitive, but only to indicate average and directional possible response on whaling to fisheries resources. At the current stage, prediction on the possible change of environmental factors is limited as well as how the species will respond to such environmental effect is not known. Pelagic fish resources in the research area have shown drastic fluctuations in a process called "species replacement" for the past 100 years (Wada 1997), but the mechanism that causes this replacement is still under investigation. In this situation, the result obtained from conducting stochastic simulations largely depends on the magnitude of the given stochasticity by the user, and often the prediction is less meaningful. As more knowledge on the relationship between environmental factors and its effect on species become available, it should be included in such ecosystem model. Also, it is very important to continue monitoring the diet composition of the species in this area including top predators, such as whales, since once "species replacement" occurs, it is known that diet composition may drastically change, and the model predictions are very sensitive to these diet compositions. In this sense, continuation of survey such as JARPN II is essential for building a meaningful ecosystem model, which will in turn be used for sustainable management of whales and fisheries resources in the area.

In addition, accumulation of long-term relative abundance estimates for the species in this area is important in understanding and monitoring the ecosystem structure. At the current stage, data on long-term relative abundance estimates only exists for sardine and mackerels for the species considered in this model. This lack of time-series data on relative abundance precludes the model to be fit to past trend estimates in an any meaningful way. Thus, attempt to estimate one plausible v or functional response form by fitting to past trend data is not conducted in this analysis, but rather our aim is to give plausible 'ranges' of results which could all be equally possible under the current situation of various uncertainties. There are many studies in the past that have used EwE to predict fisheries impact on the ecosystem, but none of the studies have actually explored the effect of assuming various functional response forms to their results. As to the knowledge of the authors, this study is the first in exploring the effect of assuming various functional response forms on the results. Furthermore, information on whether prey-preference exists or not for the species considered in the model (especially whales), and if it exists, in what circumstances does this occur (e.g. how rare must one prey species become compared to some alternative prey species) will help identify plausible functional response form to assume in the model and would help to validate the results obtained from the model. In such sense, continuation of the concurrent whale and prey survey in JARPNII is necessary.

Since this was considered to be a first step in building such ecosystem model, we tried to start the model as simple as possible. Thus, effect of whales migrating to areas outside the modeled area is not considered in this analysis. Also, lack of quantitative data for areas outside the modeled area and its possible difference in species compositions, precluded in expanding the modeled area. However, we believe that the modeled area covers the main feeding area of the whales considered in the model.

Another advantage in building such ecosystem model is that it provides quantitative estimates on the biomass of small surface squid and mid-deep water squid which in other ways not have been possible, and will contribute in further understanding of the meso-pelagic ecosystem.

Comparison with results obtained from the MRM

An ecosystem model can be developed in various scales. Some models may include detail dynamics of the nutrients and lower-trophic level species, some models may ignore its details and assume that its biomass is constant or fluctuate in a certain stochastic manner. Moreover, some models may include detail age/length-structure of the species, and some models may ignore those details. Plagányi (2007) gives a good summary on various ecosystem models which have been developed worldwide, and discusses their plausibility in use of the model in an EAF context. Moreover, FAO (2008) suggests that there is no one single right model, and that the greatest leverage is gained by considering combinations of models that may be of quite different forms. Kawahara *et al*. (2008) develops an MRM for the same area considered in this analysis. Hardly any previous studies have built two different structures of ecosystem models (e.g. EwE and MRM type) for a single area, and this is one of the unique and appealing characteristic of JARPNII. Comparison with results obtained from Kawahara *et al*. (2008) is one of important future tasks.

Application of such model in a management context

In general, ecosystem models are potentially important tools for providing wider scientific information on fisheries management such as impacts of the fishery on other ecosystem components and to take into account changes in the ecosystem other than those caused by fishing that may be impacting the fishery. Also, it can be used to simulate the implications and trade offs of alternative management actions and trade-offs for the different, conflicting stakeholders or objectives, and in this way, they can provide valuable information to managers in the search for optimal management measures and approaches (FAO 2008). Moreover, ecosystem models can have an important role to play in Management Strategy Evaluation (MSE) or the Management Procedure (MP) approach, especially as Operating Models (OMs) which provide the basis for simulation testing to assess how well alternative candidate harvest rules achieve the objectives sought by the management authority (FAO 2008).

The ecosystem model built in this study is not suitable for calculating detail total allowable catch (TAC) for species considered in the model. Rather, it may be used as for example as an OM to test whether TAC calculated from Revised Management Procedure (RMP) of some whale species do not deteriorate or give negative impact on other species in the ecosystem. If this was to give any negative impact on some other species in the ecosystem, TAC calculated from RMP may be revised. By doing so, this will ensure sustainability of the ecosystem including whales and fisheries resources. Also, such ecosystem model may be used for exploring possible trade-offs between various harvesting scenarios. As Table 4 shows, depending on the harvesting scenario, possible effect of whaling on fisheries resources varies, and the catch of some species may increase or decrease. Thus, such model may be used as a tool by fisheries managers in deciding what kind of fishing strategies to take, considering various trade-offs in catch between the species.

5. Future tasks

As briefly noted in the previous section, whales considered in this analysis also migrate to areas other than the modeled area. As more data accumulate for other areas, this effect will be considered. Also, some of the in-put data especially for the low-trophic level species are still primitive and more work needs to be done in collecting more appropriate data. Moreover, as more knowledge on the relationship between environmental factors and its effect on species become available, it will be included in such ecosystem model. Comparison with results obtained from Kawahara *et al*. (2008) is also expected.

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Table 1a. Input data on B, P/B, Q/B used in Ecopath. Shaded part is estimated from the model. Italic part is calculated within Ecopath using the assumptions that (1) body growth for the species as a whole follows a von Bertalanffy growth curve with weight proportional to length-cubed; and (2) the species population as whole has had relatively stable mortality and relative recruitment rate for at least a few years, and so has reached a stable age-size distribution. The sources of the data are explained in Appendix B. *EE* of mid-deep water squid is assumed to be low (0.2) since there is no fishery for this resources and also it is considered that the proportion of the production that is used within the system for this species is low.

	English name	Habitat area (fraction)	Biomass in hab.area	Production /biomass	Consumption /biomass	Ecotrophic efficiency
1	Minke whale	1	0.011	0.120	5.20	
2	Bryde's whale	1	0.047	0.100	4.38	
3	Sei whale	1	0.056	0.060	4.16	
4	Other baleen whales	1	0.068	0.057	3.80	
5	Sperm whale	1	0.263	0.102	4.20	
6	Baird's beaked whale	1	0.025	0.110	5.53	
7	Short-finned pilot whale	1	0.009	0.100	7.42	
8	Ziphiidae	1	0.031	0.100	7.06	
9	Other toothed whales	1	0.040	0.100	11.03	
10	Northern fur seal	1	0.002	0.235	39.03	
11	Marine birds	1	0.004	0.100	54.57	
12	Albacore	1	0.059	0.410	1.94	
13	Sword fish	1	0.007	0.600	2.05	
14	Skipjack tuna	1	0.079	0.900	6.00	
15	Blue shark	1	0.016	0.390	3.10	
16	Salmon shark	1	0.005	0.390	5.10	
17	Lanternfish	1	5.405	2.680	13.35	
18	Neon flying squid	1	0.097	3.620	10.80	
19	Large surface squid	1	0.360	2.480	10.80	
20	Small surface squid	1		3.650	10.80	0.9
21	Mid-deep water sea squid	1		2.560	10.80	0.2
22	Mackerels	1	0.366	1.030	6.87	
23	Pacific pomfret	1	0.136	0.750	3.75	
24	Sardine	1	0.048	0.770	5.14	
25	Anchovy (<8cm)	1	*0.369*	1.600	*28.02*	
26	Anchovy (>=8cm)	1	1.405	1.600	14.04	
27	Pacific saury	1	1.586	0.740	10.00	
28	Phytoplankton	1	26.580	85.960	–	
29	Euphausiids	1	40.670	2.555	12.05	
30	Copepods eaten by whales	1	21.297	5.000	10.00	
31	Other Copepods	1	21.297	5.000	10.00	
32	Detritus	1	132.900	–	–	

Table 1b. Diet composition matrix used in the Ecopath model. The sources of the data are explained in Appendix B.

	Prey / predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	29	30	31
1	Minke whale																														
2	Bryde's whale																														
3	Sei whale																														
4	Other baleen whales																														
5	Sperm whale																														
6	Baird's beaked whale																														
7	Short-finned pilot whale																														
8	Ziphiidae																														
9	Other toothed whales																														
10	Northern fur seal																														
11	Marine birds																														
12	Albacore															0.00															
13	Sword fish																														
14	Skipjack tuna													0.00																	
15	Blue shark																														
16	Salmon shark																														
17	Lanternfish										0.49	0.12	0.05	0.01	0.01	0.09			0.28	0.06			0.02	0.03							
18	Neon flying squid					0.04	0.00		0.11	0.30		0.12	0.02	0.38		0.06			0.01				0.01	0.04							
19	Large surface squid	0.02		0.00	0.01	0.06	0.01	0.82	0.07	0.19			0.06	0.21	0.04	0.10	0.79		0.16				0.01	0.23							
20	Small surface squid						0.01			0.19		0.16	0.01	0.02	0.01	0.04	0.03		0.25	0.08			0.01	0.37							
21	Mid-deep water sea squid					0.86	0.02	0.01	0.81		0.16		0.00	0.07		0.48	0.14		0.04				0.01	0.02							
22	Mackerels	0.04	0.05	0.07							0.04	0.12		0.00	0.00																
23	Pacific pomfret	0.00										0.12		0.11		0.05															
24	Sardine	0.00		0.00																											
25	Anchovy (<8cm)	0.00	0.38	0.31								0.06	0.37		0.42				0.01	0.03			0.03	0.01							
26	Anchovy (>=8cm)	0.29	0.30	0.26	0.05					0.15		0.06	0.44		0.40	0.01			0.14				0.07								
27	Pacific saury	0.46		0.02	0.05							0.12											0.02	0.03							
28	Phytoplankton																								0.70				0.12	0.26	0.26
29	Euphausiids	0.10	0.25	0.22	0.65					0.03		0.12	0.00		0.09			0.24	0.00	0.46	0.06	0.60	0.50	0.00		0.20	0.20	0.50			
30	Copepods eaten by wh	0.02		0.13	0.25													0.36				0.20	0.15		0.15	0.10	0.10	0.24	0.09		
31	Other Copepods																	0.18			0.78	0.20	0.15		0.15	0.70	0.70		0.09		
32	Detritus																												0.70	0.74	0.74
	Import	0.06	0.02			0.04	0.96	0.17	0.01	0.15	0.31		0.05	0.19	0.03	0.18	0.04	0.22	0.09	0.37	0.17		0.02	0.26				0.26			
	Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 1c. Whaling and fishery in-put data (t/km^2/year) used in the Ecopath model. The sources of the data are explained in Appendix B.

	English name	JARPN2	Other whaling	Fishing
1	Minke whale	0.0004		
2	Bryde's whale	0.0003		
3	Sei whale	0.0007		
4	Other baleen whales			
5	Sperm whale	6.85E-05		
6	Baird's beaked whale		0.0003	
7	Short-finned pilot whale		6.25E-05	
8	Ziphiidae			
9	Other toothed whales		0.000254	
10	Northern fur seal			
11	Marine birds			
12	Albacore			0.01
13	Sword fish			0.00
14	Skipjack tuna			0.04
15	Blue shark			0.00
16	Salmon shark			0.00
17	Lanternfish			
18	Neon flying squid			0.04
19	Large surface squid			0.05
20	Small surface squid			
21	Mid-deep water sea squid			
22	Mackerels			0.15
23	Pacific pomfret			0.00
24	Sardine			0.02
25	Anchovy (<8cm)			0.01
26	Anchovy (>=8cm)			0.08
27	Pacific saury			0.15
28	Phytoplankton			
29	Euphausiids			
30	Copepods eaten by whales			
31	Other Copepods			
32	Detritus			

Table 2. Parameters of the mass-balance Ecopath model (the values indicated in grey are estimated by the model).

Group name	Trophic level	Biomass (t/km2)	Prod./ biom. (/year)	Cons./ biom. (/year)	Ecotrophic efficiency	Production / consumption
Minke whale	3.99	0.011	0.120	5.200	0.303	0.023
Brydes whale	3.83	0.047	0.100	4.380	0.064	0.023
Sei whale	3.73	0.056	0.060	4.160	0.208	0.014
Other baleen whales	3.23	0.068	0.057	3.800	0.000	0.015
Sperm whale	4.17	0.263	0.102	4.200	0.003	0.024
Bairds beaked whale	4.15	0.025	0.110	5.530	0.109	0.020
Short-finned pilot whale	4.40	0.009	0.100	7.420	0.069	0.013
Ziphiidae	4.24	0.054	0.100	7.060	0.000	0.014
Other toothed whales	4.46	0.040	0.100	11.030	0.064	0.009
Northern fur seals	4.08	0.002	0.235	39.030	0.000	0.006
Marine birds	4.24	0.004	0.100	54.570	0.000	0.002
Albacore	4.08	0.059	0.410	1.940	0.254	0.211
Sword fish	4.81	0.007	0.600	2.050	0.130	0.293
Skipjack tuna	3.97	0.079	0.900	6.000	0.563	0.150
Blue shark	4.27	0.016	0.390	3.100	0.661	0.126
Salmon shark	4.35	0.005	0.390	5.100	0.717	0.076
Lanternfish	3.06	5.405	2.680	13.350	0.047	0.201
Neon flying squid	4.12	0.097	3.620	10.800	0.976	0.335
Large surface squid	3.41	0.360	2.480	10.800	0.738	0.230
Small surface squid	3.01	0.279	3.650	10.800	0.900	0.338
Mid-deep water squid	3.11	2.707	2.560	10.800	0.200	0.237
Mackerels	3.30	0.366	1.030	6.870	0.557	0.150
Pacific pomfret	4.20	0.136	0.750	3.750	0.274	0.200
Sardine	2.30	0.048	0.770	5.140	0.480	0.150
Anchovy (less 8cm)	3.04	0.381	1.700	28.198	0.925	0.060
Anchovy (>=8cm)	3.04	1.405	1.600	14.040	0.385	0.114
Pacific saury	3.12	1.586	0.740	10.000	0.238	0.074
Phytoplankton	1.00	26.580	85.960	–	0.074	–
Euphausiids	2.18	40.670	2.555	12.050	0.505	0.212
Copepods eaten by whales	2.00	21.297	5.000	10.000	0.782	0.500
Other copepods	2.00	21.297	5.000	10.000	0.817	0.500
Detritus	1.00	132.900	–	–	0.269	–

Table 3. (a) Sensitivity test scenarios (s1~s12) and (b) the resultant percent change in catch compared to the "Reference case" scenario for harvesting scenarios that did have some effect. Other harvesting scenarios that are not shown here did not have any effect.

(a)

		B	P/B	Q/B	EE
Sperm whale	50%	s1	s3	s5	–
	–50%	s2	s4	s6	–
Mid-deep water squid	50%	–	s7	s9	s11
	–50%	–	s8	s10	s12

(b)

(b-1. Sperm whale harvesting scenario)

	anchovy (>=8cm)	pacific saury	skipjack tuna	mackerels	large surface squid	neon flying squid
s1	0	–0.7	0	–0.6	2	0
s2	0	0	0	0	0	–2.8
s3	0	0	0	0	0	–2.8
s4	0	–0.7	0	–0.6	2	2.8
s5	0	–0.7	0	0	0	0
s6	0	0	0	0	0	–2.8
s7	0	0	0	0	0	0
s8	0	–1.3	0	–1.3	0	0
s9	0	–0.7	0	–0.6	0	0
s10	0	0	0	0	0	0
s11	0	0	0	0	0	0
s12	0	0	0	–0.6	2	0

(b-2. Minke, sei, Bryde's and sperm whale harvesting scenario)

	anchovy (>=8cm)	pacific saury	skipjack tuna	mackerels	large surface squid	neon flying squid
s1	0	0	0	0	0	0
s2	0	0.7	0	0.7	–2	–2.8
s3	0	0.7	0	0.7	0	–2.8
s4	0	–0.7	0	0	2	2.8
s5	0	0	0	0	0	0
s6	0	0.7	0	0.7	–2	–2.8
s7	0	0.7	0	0.7	0	0
s8	0	0.7	0	–0.7	0	0
s9	0	0	0	0	0	0
s10	0	0.7	0	0.7	0	0
s11	0	0	0	0	0	–2.8
s12	0	0	0	0	0	0

Table 4. Summary of change in catch (in % and tons) for some fish and squid resources between harvesting 4% of the biomass of the whales and no harvesting of the whales for the coming 50 years. Numbers shown in brackets for the whale harvesting scenarios shows the current biomass of the whale and the biomass in 50 years if the species were harvested annually by 4% of its biomass.

Harvesting scenario/Species	Anchovy (>8cm)	Pacific saury	Skipjack tuna	Mackerels	Neon-flying squid	Blue shark
Minke whales (29,741t →27,750t)	0–1% (0–2,800 tons)	0–6.5% (0–28,000 tons)	0–2.5% (0–28,000 tons)	0–3% (0–11,100 tons)	–	–
Sei whales (15,5978t →77,701t)	1–10% (2,800–19,000 tons)	−3–(−1)% (−12,000–(−4,000) tons)	5–16% (5,600–17,000 tons)	4–31% (17,000–114,000tons)	(−2.5)–0% (−3,000–0 tons)	–
Bryde's whales (130,816t→72,151t)	1–10% (2,800–19,000 tons)	−2–(−1)% (−8,000–(−4,000) tons)	5–18% (5,600–19,000 tons)	2–15% (8,300–61,000 tons)	(−2.5)–0% (−3,000–0 tons)	–
Minke, sei, Bryde's whales	4–19% (8,300–39,000 tons)	−0.6–2% (−2,800–8,300 tons)	10–39% (11,000–39,000tons)	7–55% (31,000–191,000 tons)	(−5)–(−3)% (−6,000–(−3,000) tons)	–
Sperm whale (729,030t →394,056t)	−3–5% (−6,000–11,000 tons)	−15–(−1)% (−70,000–(−6,000 tons)	−5–5% (−5,600–5,6000tons)	−11–(−1)% (−44,000–(−2,800) tons)	5–23% (5,600–25,000 tons)	0–100% (0–14,000 tons)
Minke, sei, Bryde's, sperm whales	4–21% (8,300–42,000 tons)	−15–(−1)% (−70,000–(−6,000 tons)	10–42% (11,000–42,000tons)	7–42% (31,000–150,000 tons)	3–15% (3,000–17,000 tons)	0–100% (0–14,000 tons)

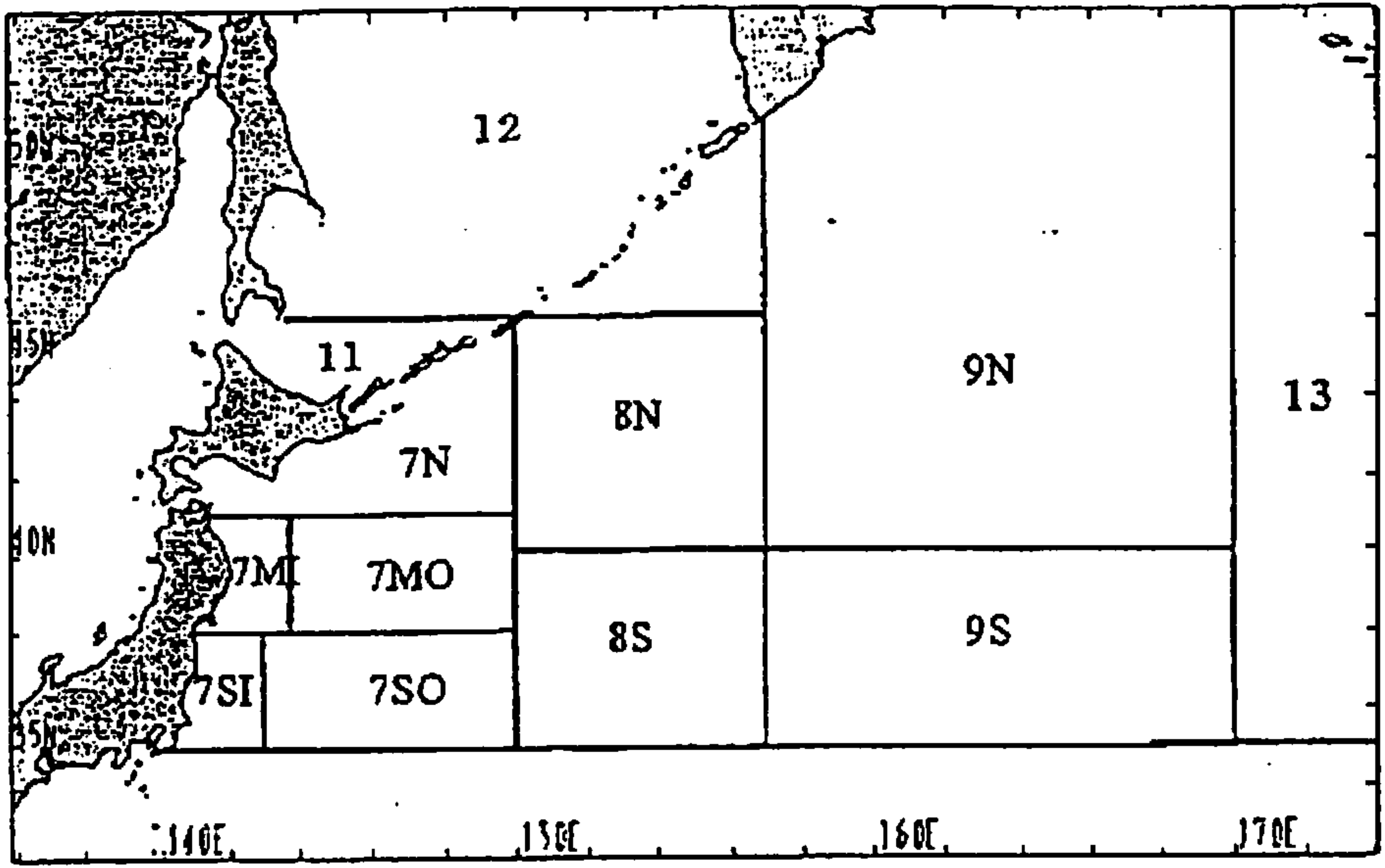


Figure 1. The research area and strata for the JARPNII surveys (extracted from Government of Japan 2002).

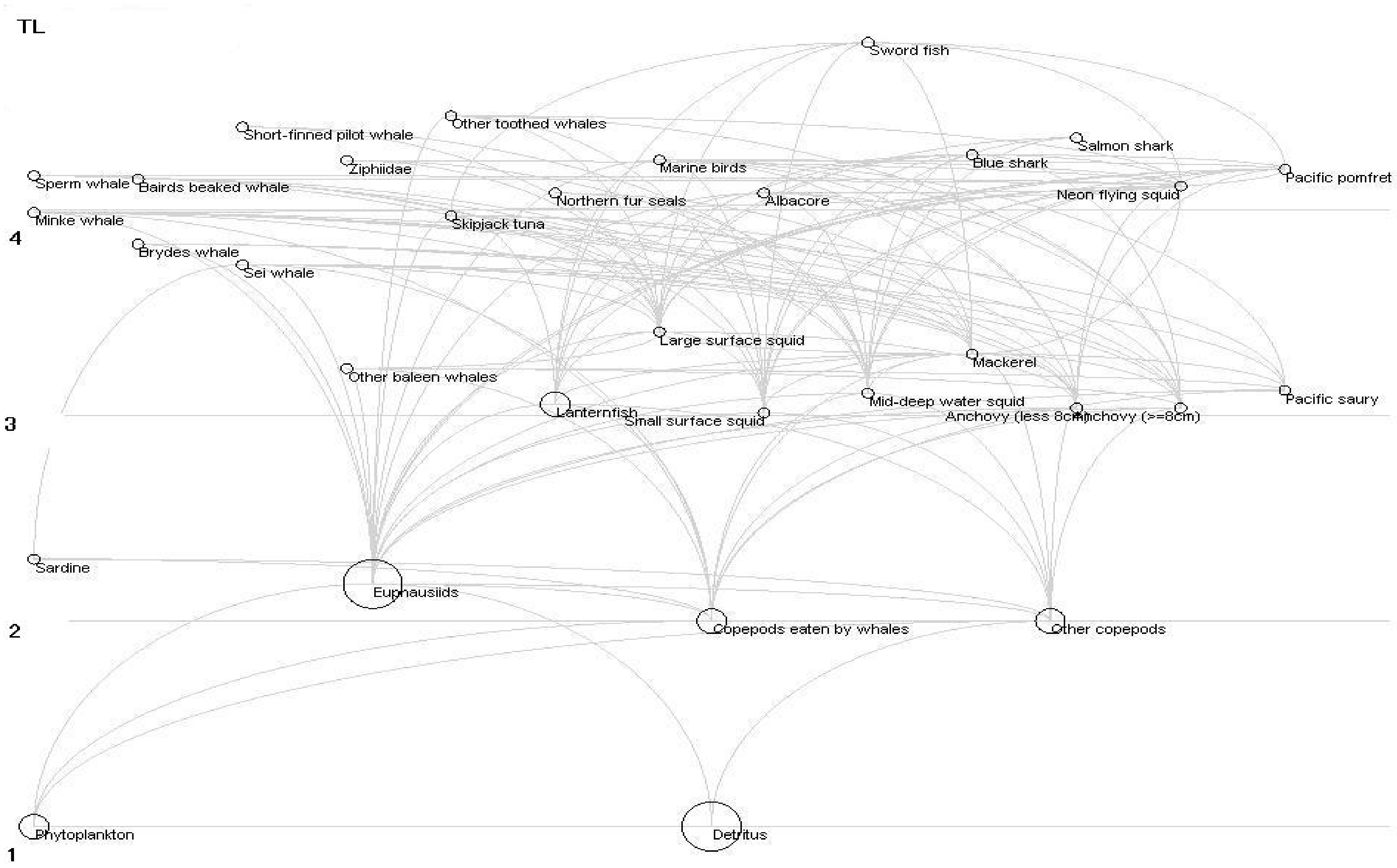

TL
4
3
2
1
Sword fish
Other toothed whales
Short-finned pilot whale
Salmon shark
Blue shark
Ziphiidae
Marine birds
Pacific pomfret
Sperm whale
Bairds beaked whale
Neon flying squid
Northern fur seals
Albacore
Minke whale
Skipjack tuna
Brydes whale
Sei whale
Large surface squid
Mackerel
Other baleen whales
Mid-deep water squid
Pacific saury
Lanternfish
Small surface squid
Anchovy (less 8cm)
Anchovy (>=8cm)
Sardine
Euphausiids
Copepods eaten by whales
Other copepods
Phytoplankton
Detritus

Figure 2.Food web assumed in the model and the trophic level of each species estimated by Ecopath.

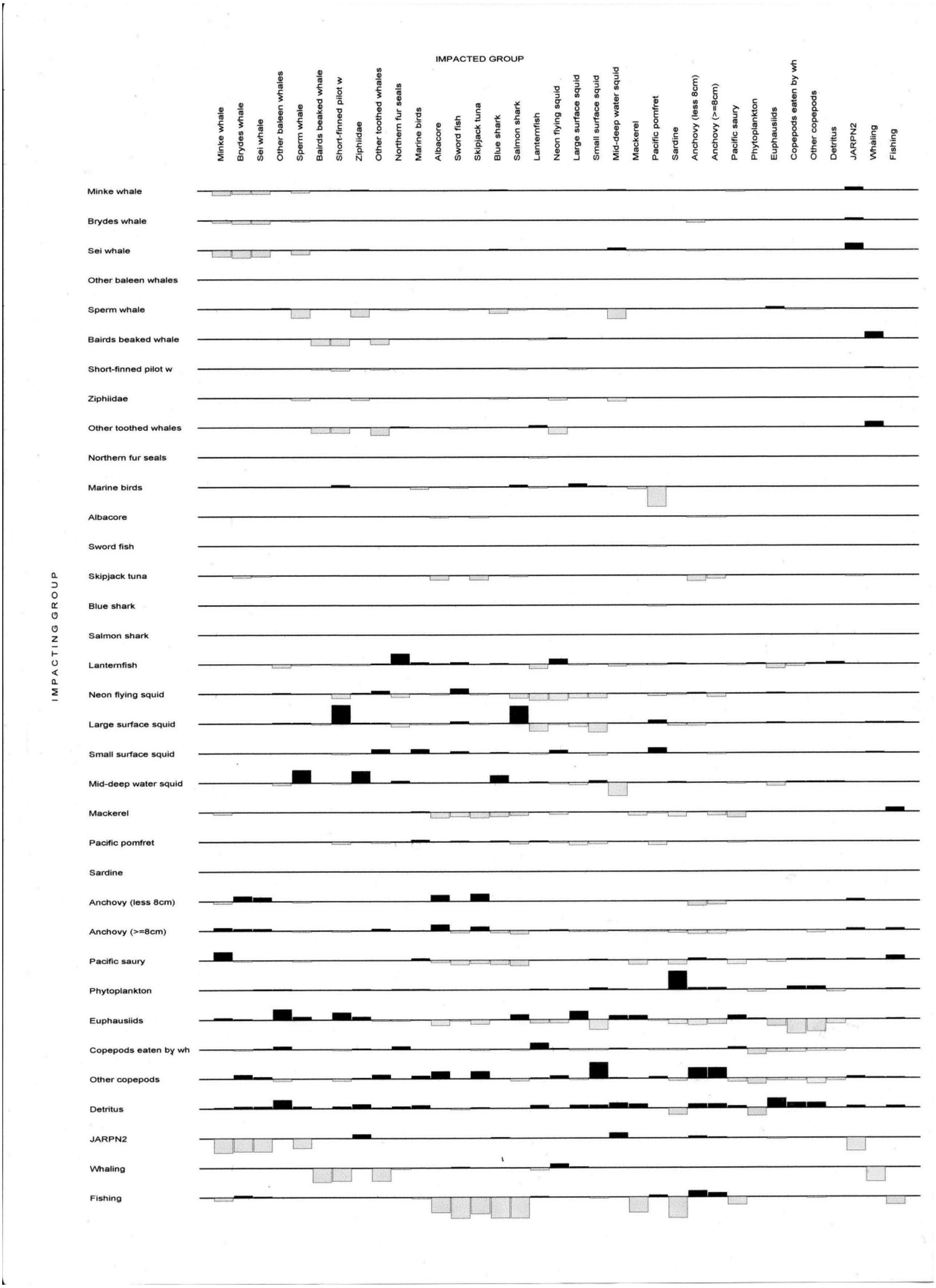
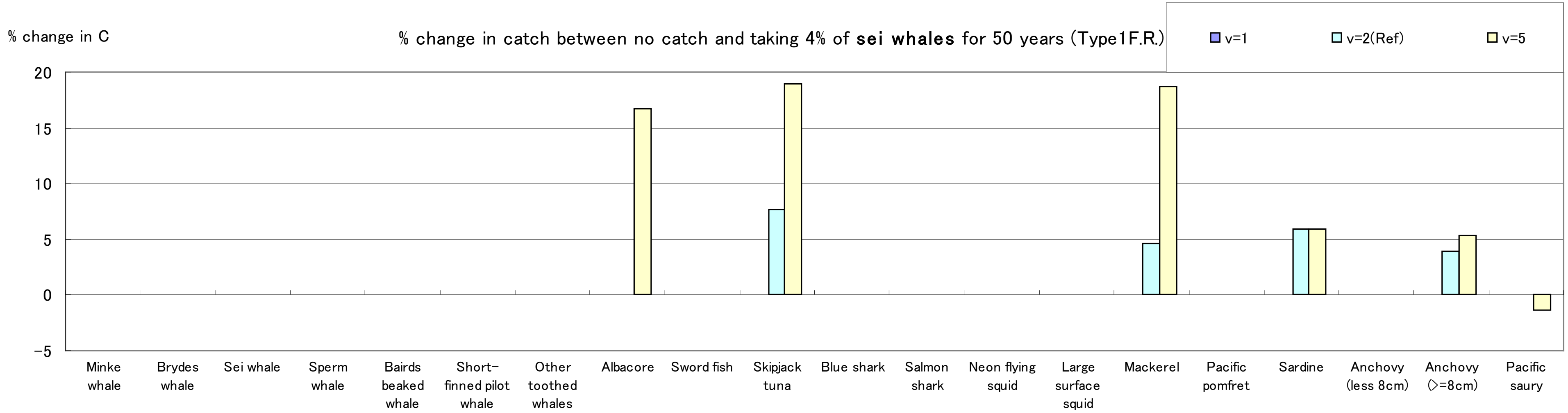


Figure 3. Effect of the short-term increase of the species shown on the vertical axis on the species shown on the horizontal axis. Upward bars represent positive impact, and downward bars represent negative impact.

Figure 4.1 Percent (%) change in catch for the harvested species, between no catch and taking 4% of **minke whales** for the coming 50 years (fishing effort for the other harvested species is kept as current). The top figure shows sensitivities to changes in the vulnerability (*v*) parameter, and the bottom figure shows sensitivities to changes in the functional response function assumed.



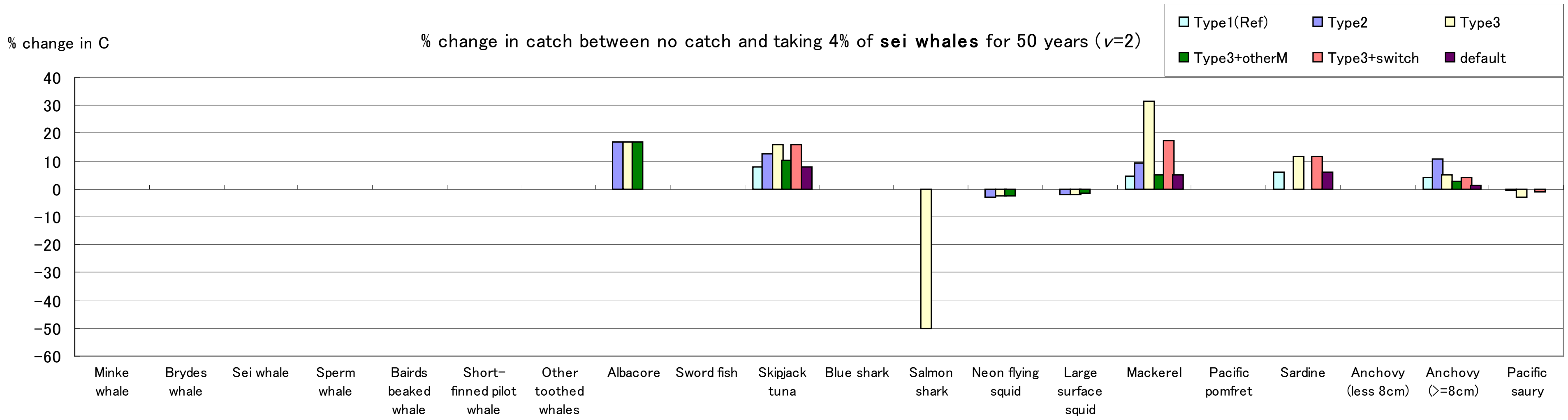


Figure 4.2 Percent (%) change in catch for the harvested species, between no catch and taking 4% of **sei whales** for the coming 50 years (fishing effort for the other harvested species is kept as current). The top figure shows sensitivities to changes in the vulnerability (*v*) parameter, and the bottom figure shows sensitivities to changes in the functional response function assumed.

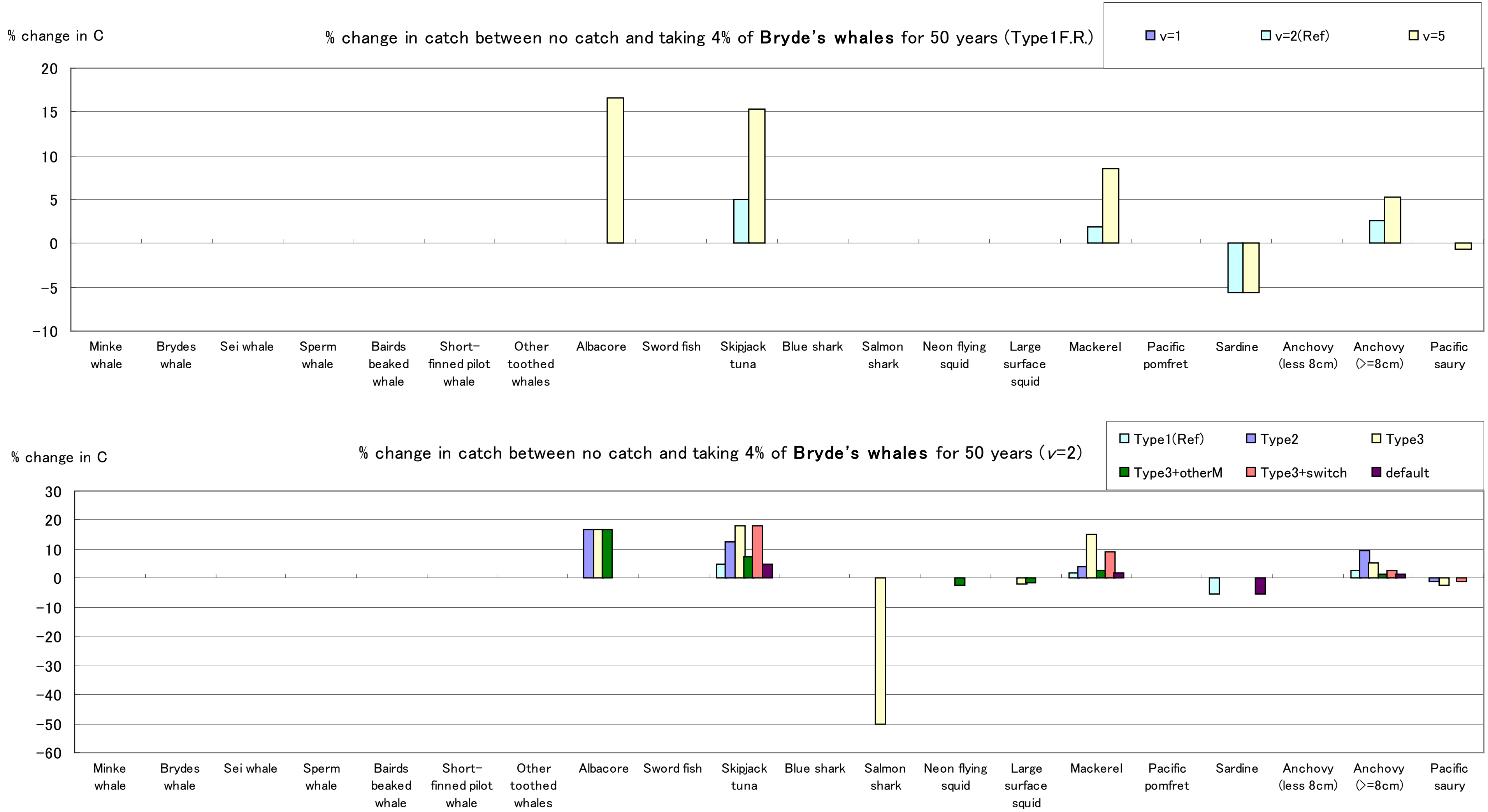
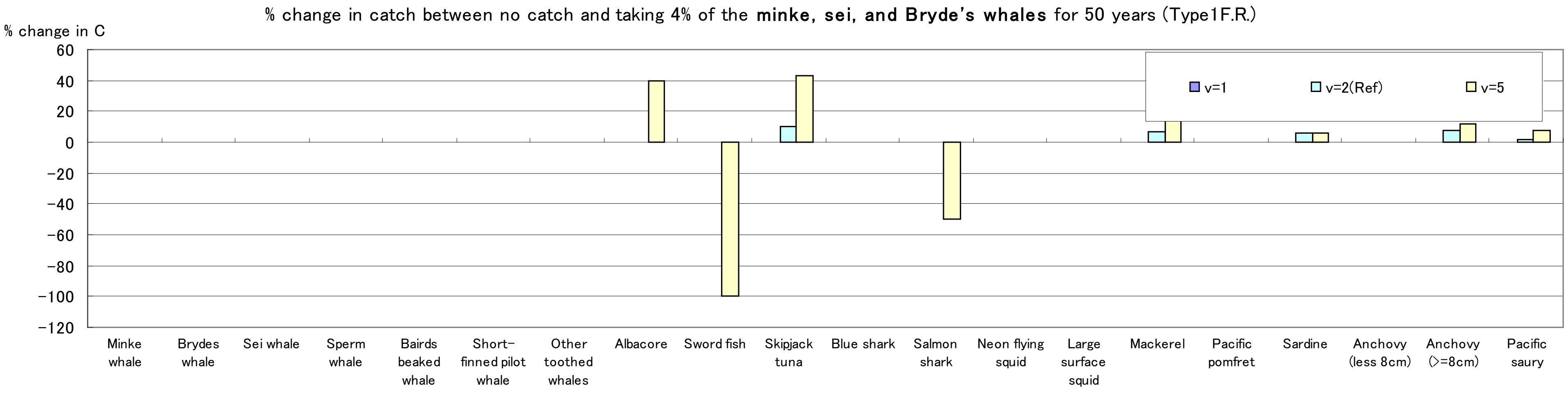


Figure 4.3 Percent (%) change in catch for the harvested species, between no catch and taking 4% of **Bryde's whales** for the coming 50 years (fishing effort for the other harvested species is kept as current). The top figure shows sensitivities to changes in the vulnerability (*v*) parameter, and the bottom figure shows sensitivities to changes in the functional response function assumed.



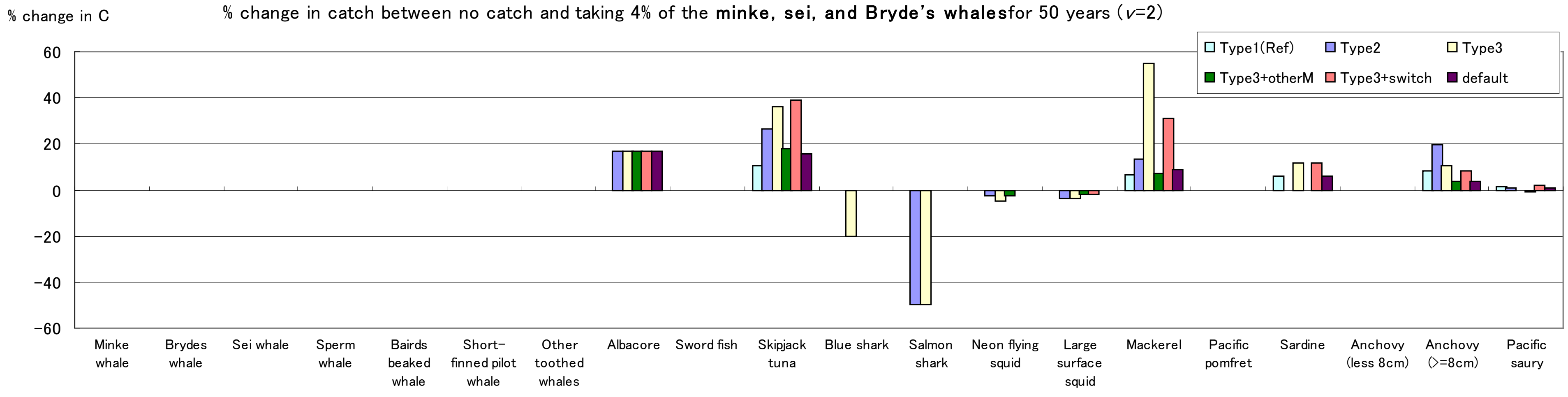


Figure 4.4 Percent (%) change in catch for the harvested species, between no catch and taking 4% of **minke, sei and Bryde's whales together** for the coming 50 years (fishing effort for the other harvested species is kept as current). The top figure shows sensitivities to changes in the vulnerability (*v*) parameter, and the bottom figure shows sensitivities to changes in the functional response function assumed.

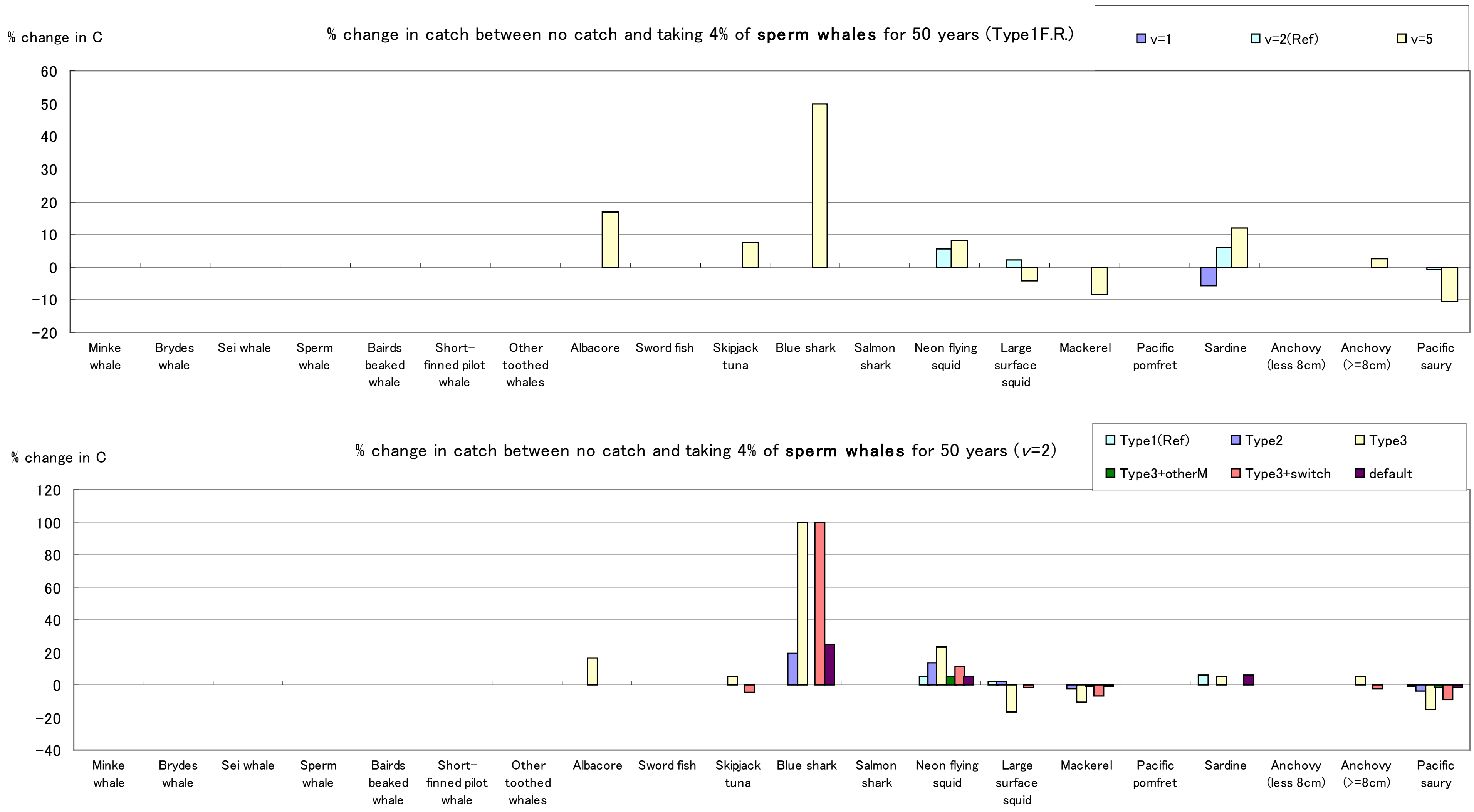


Figure 4.5 Percent (%) change in catch for the harvested species, between no catch and taking 4% of **sperm whales** for the coming 50 years (fishing effort for the other harvested species is kept as current). The top figure shows sensitivities to changes in the vulnerability (*v*) parameter, and the bottom figure shows sensitivities to changes in the functional response function assumed.

Figure 4.6 Percent (%) change in catch for the harvested species, between no catch and taking 4% of **the whales caught in JARPN2 (minke, sei, Bryde's and sperm whales)** for the coming 50 years (fishing effort for the other harvested species is kept as current). The top figure shows sensitivities to changes in the vulnerability (*v*) parameter, and the bottom figure shows sensitivities to changes in the functional response function assumed.

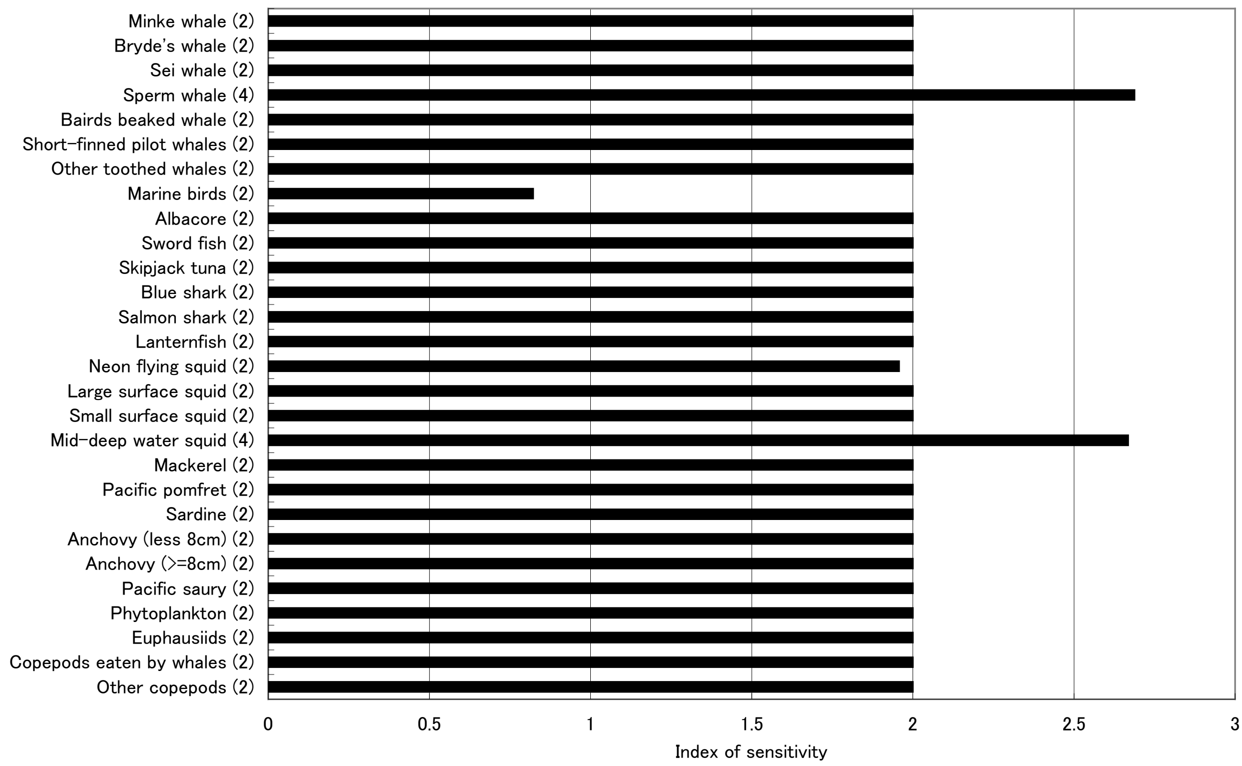


Figure 5. Sensitivity analysis results for JARPN2_v3, using an index of sensitivity (the sum of the ratio of the maximum change in the estimated parameter to the original parameter, given ±10-50% changes in the input parameters of the components named on the y-axis). The numbers shown in parenthesis on the y-axis is the count of estimated parameters affected by at least 30% by changes in the in-put parameter of B, P/B, Q/B and EE of the species named on the y-axis.

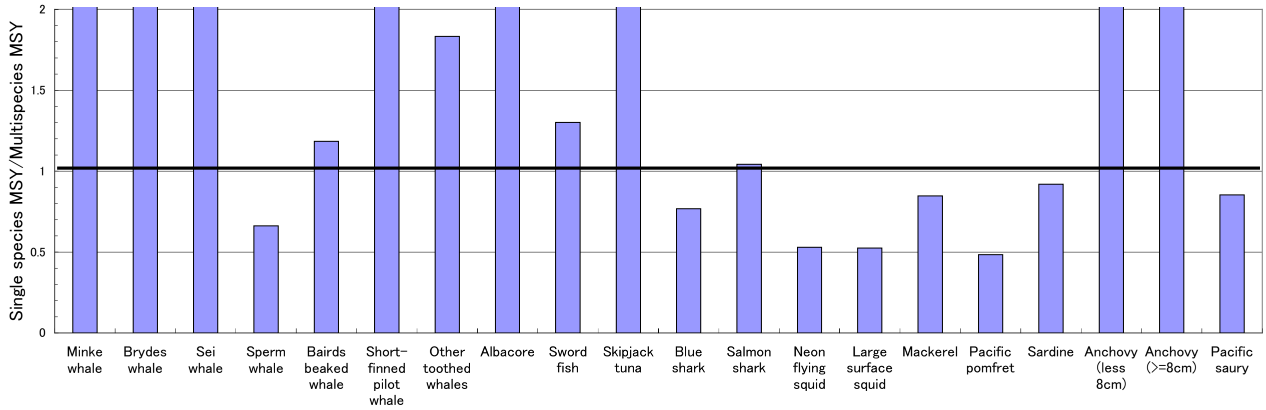


Figure 6. Ratio of single-species MSY to multi-species MSY for the harvested species.

Appendix A: Description of the Ecopath with Ecosim (EwE) model

The Ecopath model

Ecopath (Polovina 1984a, 1984b; Christense et al. 2005) parameterizes models based on two master equations, one ensuring balance among each functional group and one balancing the flows within each functional group. The first equation ensures balance among groups in the model:

$$P_i = Y_i + B_i \cdot M2_i + E_i + BA_i + P_i \cdot (1 - EE_i) \qquad \text{(A-1a)}$$

where, for group *i*, P_i is the total production rate, Y_i is the total fishery catch rate, B_i is the biomass, $M2_i$ is the total predation rate for group *i*, E_i is the net migration rate (emigration - immigration), BA_i is the biomass accumulation rate and $M0_i = P_i \cdot (1 - EE_i)$ is the "other mortality" rate, where EE_i being "ecotrophic efficiency".

Equation (1a) can also be expressed as:

$$B_i \cdot \left(\frac{P}{B}\right)_i - \sum_{j=1}^{n} B_j \cdot \left(\frac{Q}{B}\right)_j \cdot DC_{ji} - \left(\frac{P}{B}\right)_i \cdot B_i \cdot (1 - EE_i) - Y_i - E_i - BA_i = 0 \qquad \text{(A-1b)}$$

where P/B is the ratio of production to biomass, Q/B is the ratio of consumption to biomass, and DC_{ji} is the fraction of the prey *i* in the diet of predator *j*.

The second equation, which balances the flows within each group, is

$$\text{Consumption} = \text{production} + \text{respiration} + \text{unassimilated food} \qquad \text{(A-2)}$$

$$Q_i = P_i + R_i + GS_i \cdot Q_i$$

where, for group *i*, Q_i is consumption, R_i is respiration, and GS_i is the proportion of food that is not assimilated.

Each group in the model is represented by the above two balanced equations and requires six input parameters. Diet composition and catch are mandatory and three of the other four parameters (B , P/B , Q/B , and EE) must be entered.

Representation of multi-stanza life histories

Ecopath with Ecosim users can create a set of biomass groups representing life history stages or stanzas for species that have complex trophic ontogeny. Users of this feature must enter baseline estimates of total mortality rate Z and diet composition for each stanza, then biomass and Q/B for one "leading" stanza only. For Ecopath mass balance calculations, Z entered for each stanza-group is used to replace the Ecopath P/B for that group. Further, the B and Q/B for all stanza-groups besides the leading (entry) stanza are calculated before entry to Ecopath, using the assumptions that (1) body growth for the species as whole follows a von Bertalanffy growth curve with weight proportional to length-cubed; and (2) the species population as a whole has had relatively stable mortality and relative recruitment rate for at last a few years, and so has reached a stable age-size distribution. Under the stable age distribution assumption, the relative number of age "*a*" animals is given by $l_a / \sum l_a$ where the sum is over all ages, and l_a is the population growth rate-corrected survivorship $l_a = e^{-\sum_a Z_a - a \times BA/B}$ where the sum of *Z*'s is over all ages up to "*a*" and the *BA*/*B* term represents effect on the numbers at age of the population growth rate. Further, the relative biomass of animals in stanza *s* should be $b_s = \dfrac{\sum_{a=a_{s,\min}}^{a_{s,\max}} l_a \times w_a}{\sum_{a=1}^{a_{\max}} l_a \times w_a}$, where $w_a = [1 - \exp(-K \times a)]^3$ is the von Bertalanffy prediction of relative body weight at age *a*.

Knowing the B for one leading stanza, and the b_s for each stanza *s*, the biomasses for the other stanzas can be calculated by first calculating population biomass $B = B_{leading\ s} / b_{leading\ s}$, then setting $B_s = B \cdot b_s$ for the other stanzas. Q/B estimates for non-leading stanzas are calculated with a similar approach, assuming that feeding rates vary with age as the $2/3$ power of body weight (a "hidden" assumption in the von Bertalanffy growth model) (Christensen et al. 2005).

Mixed trophic impact

Once the linear equations are solved and missing parameters are estimated (often EE becomes the estimated parameter), one can conduct analyses such as ‘mixed trophic impact (MTI)’ using the tool prepared in Ecopath software. MTI allows assessing the effect that changes in the biomass of a group will have on the biomass of the other group in the system (for details see Christensen et al. 2005). The MTI for living groups is calculated by constructing an n×n matrix, where the i, j^{th} element representing the interaction between the impacting group i and the impacted group j , which is expressed as:

$$MTI_{i,j} = DC_{i,j} - FC_{j,i} \ , \tag{A-3}$$

where DC_{ij} is the diet composition term expressing how much j contributes to the diet of i, and FC_{ij} is a host composition term giving the proportion of the predation on j that is due to i as a predator. When calculating the host compositions the fishing fleets are included as ‘predators’ (Christensen et al. 2005).

The Ecosim model

Ecosim consist of biomass dynamics expresse through a series of coupled differential equations. The equations are derived from the Ecopath master equation (A-1a) and take the form

$$\frac{dB_i}{dt} = g_i \cdot \sum_j Q_{ji} - \sum_j Q_{ij} + I_i - (M_i + F_i + e_i) \cdot B_i \tag{A-4}$$

where dB_i/dt represents the growth rate during the time interval dt of group i in terms of its biomass B_i , g_i is the net growth efficiency (production/consumption ratio), M_i is the non-predation natural mortality rate, F_i is the fishing mortality rate, e_i is emigration rate, I_i is immigration rate. The two summations estimates consumption rates, the first expressing the total consumption by group i, and the second the predation by all predators on the same group i. The consumption rates, Q_{ji} , are calculated based on the ‘foraging arena’ concept, where B_i ’s are divided into vulnerable and invulnerable components (Walters et al. 1997, Figure 1), and it is the transfer rate (v_{ij}) between these two components that determines if control is top-down (i.e. Lotka-Volterra), bottom-up (i.e. donor-driven) or of an intermediate type. The consumption rate is expressed as:

$$Q_{ij} = \frac{a_{ij} \cdot v_{ij} \cdot B_i \cdot P_j \cdot T_i \cdot T_j \cdot S_{ij} \cdot M_{ij} / D_j}{v_{ij} + v_{ij} \cdot T_i \cdot M_{ij} + a_{ij} \cdot M_{ij} \cdot P_j \cdot S_{ij} \cdot T_j / D_j} \tag{A-5}$$

where a_{ij} is the effective search rate for predator i feeding on a prey j, v_{ij} is the vulnerability expressing the rate with which prey move between being vulnerable and not vulnerable, B_i is prey biomass, P_j is predator abundance, T_i represents prey relative feeding time, T_j is predator relative feeding time, S_{ij} is user-defined seasonal or long term forcing effects, M_{ij} is the mediation forcing effects, and D_j is the effects of handling time as a limit to consumption rate. For further details refer to (Christensen et al. 2005).

Appendix B: Sources of the in-put data used in the model

Minke whale

1) Diet composition

Data from Tamura *et al*. (2009a) which is based on data collected from JARPNⅡsurvey. 46.08% Pacific saury, 29.16% anchovy (large), 9.85% euphausiids, 5.48% others, 4.17% mackerelss, 2.43% copepods, 2.35% large surface squid, 0.27% pacific pomfret, 0.19% anchovy (small), 0.003% sardine.

2) Biomass

The abundance estimate is from Hakamada *et al*. (2009). This is based on the JARPN2 sighting survey from 2002-2007, and the abundance estimate for Areas 7, 8 and 9 (excludes Russian EEZ) is 6,609 with CV=0.620. Mean body-weight is calculated as 4.5 tons by Tamura *et al*. (2009a) which is based on data collected from JARPNII survey. Thus, the biomass is 29,741 tons.

3) P/B or Z

As for natural mortality (*M*), 0.10 which is the average of the values used in the comprehensive assessment of NP minke whales is used (IWC 2000b). The current fishing mortality (*F*) is about 0.02. Thus, $Z=M+F=0.12$ will be used.

4) Q/B

Data from Tamura *et al*. (2009a) which is based on data collected from JARPNⅡsurvey will be used. Q/B=5.20 (range 4.6-6.3).

5) Catch

220 minke whales are caught every year, with mean body-weight of 4.5 tons. Thus, the total catch is 990 tons/year.

Bryde's whale

1) Diet composition

Data from Tamura *et al*. (2009a) which is based on data collected from JARPNⅡsurvey. 38.35% anchovy (small), 29.94% anchovy (large), 24.49% euphausiids, 4.83% mackerels, and 2.39% others.

2) Biomass

The abundance estimate is from Hakamada *et al*. (2009). This is based on the JARPN2 sighting survey from 2002-2007, and the abundance estimate is 9,344 with CV of about 0.3. Mean body-weight is calculated as 14 tonnes by Tamura *et al*. (2009a) which is based on data collected from JARPNⅡsurvey. Thus, the biomass is 130,816 tons.

3) P/B or Z

As for *M*, 0.08 which is used in the comprehensive assessment of NP Bryde's whales will be used (IWC 2006). The current *F* is about 0.016. Thus, $Z=M+F=0.10$ will be used.

4) Q/B

Data from Tamura *et al*. (2009a) which is based on data collected from JARPNⅡsurvey will be used. Q/B=4.38 (range 3.2-6.3).

5) Catch

50 Bryde's whales are caught every year, with mean body-weight of 14 tons. Thus, the total catch is 700 tons/year.

Sei whale

1) Diet composition

Data from Tamura *et al*. (2009a) which is based on data collected from JARPNⅡsurvey. 31.19% anchovy (small), 25.55% anchovy (large), 21.60% euphausiids, 13.15% copepods, 6.88% mackerelss, 1.46% Pacific saury, 0.11% sardine and 0.07% large surface squid.

2) Biomass

The abundance estimate is from Hakamada *et al*. (2009). This is based on the JARPN2 sighting survey from 2002-2007, and the abundance estimate is 7,646 with CV of about 0.3. Mean body-weight is calculated as 20.4 tonnes by Tamura *et al*. (2009a) which is based on data collected from JARPNⅡ survey. Thus, the biomass is 155,978 tons.

3) P/B or Z

Masaki (1976) estimated the *M* of sei whales based on the age composition data obtained during 1965 to 1972. *M* for female sei whales is estimated to be 0.06 and that for males to be 0.054, which average 0.057. Current *F* is 0.007, thus $Z=0.06$ is used.

4) Q/B

Data from Tamura *et al*. (2009a) which is based on data collected from JARPNⅡsurvey will be used. Q/B=4.16 (range 2.9-6.3).

5) Catch

100 sei whales are caught every year, with mean body-weight of 20.4 tons. Thus, the total catch is 2,040 tons/year.

Other baleen whales

Here, we consider blue whale, fin whale, humpback whale and right whale.

1) Diet composition

Data from Nemoto and Kawamura (1977). It is the average of the diet composition of the four baleen whale species considered here (blue, fin, humpback and right whales). 65% euphausiids, 25% copepods, 9% fish (here we assume 4.5% anchovy (large) and 4.5% Pacific saury since these are the main fishes taken by minke whales), and 1% large surface squid.

2) Biomass

There is no estimate of abundance available, thus the following guess estimate is used:

Fin whale 2,000 × 80 tonnes = 160,000 tonnes,

Blue whale 100 × 170 tonnes = 17,000 tonnes,

Humpback whale 200 × 65 tonnes = 13,000 tonnes, totaling 190,000 tonnes.

3) P/B or Z

Since there is no available estimate for these species, we use the same *M* estimate as assumed for sei whales; Z=0.057.

4) Q/B

Data from Tamura (2003). Q/B=3.80 (range 2.2-6.3).

5) Catch

There is no catch taken.

Sperm whale

1) Diet composition

Data from Tamura *et al*. (2009b) which is based on data collected from JARPNⅡsurvey. 86.3% mid-deep water squid, 3.7% neon-flying squid, 6.4% large surface squid and 3.6% others.

2) Biomass

Hakamada *et al*. (2009) estimated the abundance in Area7~9 to be 38,370 (CV=0.2) and this estimate is used. Mean body-weight is calculated as 19 tonnes by Tamura *et al*. (2009b) which is based on data collected from JARPNII survey. Thus, the biomass is 729,030 tons.

3) P/B or Z

Based on IWC (1983), *M* is estimated to be 0.102. F=0.0002, thus Z=0.102.

4) Q/B

Data from Tamura *et al*. (2009b) which is based on data collected from JARPNⅡ survey will be used. Q/B=4.20 (range 2.9-6.3).

5) Catch

10 sperm whales are caught every year, with mean body-weight of 19 tons. Thus, the total catch is 190 tons/year.

Baird's beaked whale

1) Diet composition

Ohizumi *et al*. (2003) estimated the diet composition of Baird's beaked whale sampled at Wada local whaling base on the Pacific coast of central Japan on 1999 (July-August). This results in 0.04% neon-flying squid, 1.3% small surface squid, 0.86% large surface squid, 2.2% mid-deep water squid and 95.6% others (mainly *Coryphaenoides longifilis*).

2) Biomass

Miyashita and Kato (1993) estimated the abundance to be 5,000 (95%CI: 2,500-10,000) based on the 1991-1992 survey. The mean body-weight is estimated to be 14 tons (Kasamatsu 2000) thus, resulting in a biomass estimate of 70, 000 tons (95%CI: 35,000-140,000).

3) P/B or Z

F is estimated to be 0.01. *M* is assumed to be same as sperm whales (i.e. *M*=0.1). Thus, *Z*=0.11.

4) Q/B

Data from Tamura (2003) is used. Q/B=5.53 (range 5.0-6.3).

5) Catch

52 Baird's beaked whales are caught every year in the Pacific region, with mean body-weight of 14 tons. Thus, the total catch is 728 tons/year.

Short finned pilot whale

Here, we include the northern and southern form north of 30°N.

1) Diet composition

We use the estimate of Gannon *et al*. (1997) which sampled long-finned pilot whales off the northeastern United States. Short-finned pilot whales and long-finned pilot whales belongs to the same Genus, and preliminary study of samples collected at Ayukawa (coastal area in the western North Pacific) show 100% long-finned squid (Konishi pers. commn.). The estimate used is 82% large surface squid, 1% mid-deep water squid, and 17% others.

2) Biomass

Miyashita (1993) estimated the abundance of the southern form distributed north of 30°N to be 35,000 using usual line transect formula, based on cruises conducted between 1983 to 1991 during August and September. The abundance of the northern form is estimated to be 4,300 (CV=0.61) (Anon 1992) based on cruises conducted between 1982 to 1988, totaling 40,000 whales. The mean body-weight is estimated to be 0.64 tonnes, resulting in biomass estimate of 25,600 tonnes.

3) P/B or Z

F is estimated to be 0.002. We assumed M to be same as sperm whale (i.e. M=0.1). Thus, Z=0.10.

4) Q/B

Data from Tamura (2003) is used. Q/B=7.42 (range: 6.3-8.9).

5) Catch

Catch of the northern and southern form is 271 whales for 2006, which amounts to 173 tons (Fisheries Agency of Japan 2008).

Ziphiidae

1) Diet composition

Here, we assume the same diet composition as sperm whale, which is 86.3% mid-deep water squid, 3.7% neon-flying squid, 6.4% large surface squid and 3.6% others.

2) Biomass

Based on the sighting data obtained from JARPNII survey, sighting rate of ziphiidae is 1.37 times that of minke whales, and the mean school size (including those of unconfirmed) is 2.09 times larger than that of minke whales. Assuming that the mean body weight is same for minke whales and ziphiidae, biomass of ziphiidae could be 2.9 times larger than that of minke whales.

3) P/B or Z

Again, since there is no data, we assume that P/B is same as sperm whale (P/B=0.10).

4) Q/B

Data from Tamura (2003) of the cuvier's beaked whale will be used. Q/B=7.06 (range 6.23-8.23).

5) Catch

There is no catch taken.

Other toothed whale

Here we consider the following seven species: bottlenose dolphin, pantropical spotted dolphin, striped dolphin, pacific white-sided dolphin, northern-right whale dolphin, risso's dolphin and dall's propoise (truei type).

1) Diet composition

We use data from Pauly *et al*. (1998) and take the biomass weighted average diet composition for the seven species considered here; which results in 59.2% fish, 37.94% cephalopoda, and 3.02% euphausiids. More precisely, we further divide this as 29.6% lanternfish, 14.8% anchovy (large), 18.97% small surface squid, 18.97% large surface squid, and 14.8% others.

2) Biomass

The abundance estimate of Government of Japan (2002, Appendix 1, Table 1) will be used except for dall's propoise. We use Fisheries agency of Japan (2008) for the abundance estimate of dall's propoise. The total biomass for the 7 species is 109,911 tons. CV for each abundance estimate is about 0.2, which results in a 95% CI of 96,514-123,309 tons. Since some of the dalli type dall's porpoise also migrate to the western north pacific area, this estimate may be a little underestimate.

3) P/B or Z

Since there is no data, we assume that P/B is same as sperm whale (P/B=0.10).

4) Q/B

Data from Tamura (2003) will be averaged for the seven species. Q/B=11.03 (range 6.3-16.4).

5) Catch

Total catch for these species is about 705 tons for year 2006 (Fisheries Agency of Japan 2008).

Northern fur seal

1) Diet composition

Yonezaki (pers. comm.) suggests diet composition of 49.4% lanternfish, 23.9% pollock, 4.2% mackerels, 15.7% mid-deep water squid and 6.8% others which is based on recent surveys in Area 7.

2) Biomass

The abundance in the western subarctic region (WSA) is unknown. Hunt *et al*. (2000 Appendix Table 9.11) estimates the abundance in the western tropical zone (WTZ) to be 190,000 animals. The abundance is derived from line transect method. The mean body-weight is 28 kg resulting in a biomass estimate of 5,320 tons. The uncertainty associated with this estimate is unknown.

3) P/B or Z

We use the estimate used by Aydin *et al*. (2003) for the northern fur seals in the subarctic region of the Pacific. The estimate is to be 0.235.

4) Q/B

We use the estimate used by Aydin *et al*. (2003) for the northern fur seals in the subarctic region of the Pacific. The estimate is to be 39.03. It is estimated from the daily ration and caloric requirement estimates in Hunt *et al*. (2000).

5) Catch

There is no catch taken.

Marine birds

1) Diet composition

Average value for the marine birds in the WTZ and WSA calculated in Hunt *et al*. (2000) is used. This results in 16% small surface-squid, 12% euphausiids, neon-flying squid, lanternfish, Pacific saury, mackerels, anchovy (small and large) and pacific pomfret.

2) Biomass

The density in WSA is 3.8 kg/km^2, and that in WTZ is 3.2 kg/km^2 (Hunt *et al*. 2000). JARPN II area overlaps with both areas, thus we take the mean of these two areas, which results in density estimate of 3.5 kg/km^2.

3) P/B or Z

We use the estimate used by Aydin *et al*. (2003) for the WSA ECOPATH models of 0.1.

4) Q/B

We take the average value of WSA and WTZ in Hunt *et al*. (2000) which results in an estimate of 54.57.

5) Catch

There is no catch taken.

Albacore

1) Diet composition

Watanabe *et a*l. (2004a) estimated the diet composition of albacore taken in JARPN II survey area 8 and 9 during spring to autumn in 2001 and 2002, resulting in an estimate of 43.8% anchovy (large), 36.9% anchovy (small), 4.8% lanternfish, 0.1% mid-deep water squid, 0.3% euphausiids, 6.4% large surface squid, 0.9% small surface squid, 2% neon-flying squid and 4.9% of others.

2) Biomass

Immature albacore mainly migrate to the JARPNII survey area. Biomass of immature albacore in the northern pacific area (north of 30ºN and 130ºE to 120ºW) in 2006 is about 330 thousand tons (Fisheries Agency of Japan 2008). Assuming equal density among the distributional areas, biomass in the JARPN II survey area results in an estimate of 165 thousand tons.

3) P/B or Z

We assume M=0.3 which is normally used in the assessment of this stock, and F is about 0.11. Thus, we assume Z=0.41.

4) Q/B

According to Watanabe *et al*. (2004a), albacore consume 1.08% of its body-weight per day, and the approximate length staying in the JARPN II survey area is about 180 days. Thus, we assume Q/B=1.94.

5) Catch

Catch is taken from Anon. (ISC) 2007. The category of “pole-and line, purse seine, troll and others” are considered here. Catch in 2005 is about 18,000 tons (According to K. Watanabe (pers. comm.) this estimate may be a little over-estimate since there is also pole-and line fisheries in the area 25º-35 ºN).

Swordfish

1) Diet composition

According to Watanabe *et al*. (2004b) and Watanabe (pers. comm.), we assume the following diet composition: 38.2% neon-flying squid, 20.9% large surface squid, 2.1% small surface squid, 6.5% mid-deep water squid, 11.1% pacific pomfret, 1.12% lanternfish, 0.35% mackerels, 0.4% skipjack tuna and 19.3% others.

2) Biomass

According to Yokawa (pers.comm.), the biomass of swordfish migrating to the JARPNⅡ survey area is about 5,000-33,000 tonnes (here we use the mean of 19,000 tons).

3) P/B or Z

Since there is no data, we assume the same value assumed in Cox *et al*. (2002a) of 0.60 which is used for the ECOPATH model in the Central north pacific, which is based on 1990-1998 average estimated from single-species model assessments (Cox *et al*. 2002b).

4) Q/B

According to Watanabe (unpublished), swordfish consume 1.14% of its body-weight per day. The approximate length staying in the JARPNⅡ survey area is about 180 days. Thus, we assume Q/B=2.05.

5) Catch

Catch in the JARPNⅡ area is unknown, but in the North West Pacific Area (north of the equator and west of the date-line), the total catch in 2005 is 6,972 tons (Fisheries agency of Japan 2008). When estimating the biomass, it is assumed that 1/3-1/10 of the total biomass in the North West Pacific area migrate to the JARPNⅡ area. Thus, assuming that the same percentage of the catch is taken in the JARPNⅡ area result in a catch of 697-2,324 tons (average 1,511 tons).

Skipjack tuna

1) Diet composition

According to Watanabe (unpublished), based on the survey in 2003 and 2004 in the JARPNⅡ area, the suggested diet composition is 42% anchovy (small), 40% anchovy (large), 9% euphausiids, 1% small surface squid, 4% large surface squid, 0.5% lanternfish, 0.2% mackerels and 3.3% others.

2) Biomass

According to Langley *et al*. (2005), average biomass from 2000 to 2004 is about 220,000 tons in Region 2 (north of 25ºN, east of 140 ºE to 165 ºE). This estimate may be a little overestimate since it includes the area 25 ºN-35 ºN. P/B or Z

3) P/B or Z

According to Fisheries Agency of Japan (2008), *M* of the mature fish is about 0.4, and *F* is about 0.5. Thus, we assume *Z*=0.9.

4) Q/B

According to Nakatsuka *et al*. (2006) based on the specimens captured in the Kuroshio-Oyashio transition region in May and June 2006, skipjack tuna consume about 3.6% of its body-weight/day. Thus, if we assume this species to spend 180 days in the JARPNⅡ survey area, results in an estimate of about Q/B=6.0.

5) Catch

According to Fisheries Agency of Japan (2008), average catch from 2004-2007 is about 110,000 tons.

Blueshark

1) Diet composition

According to Kubodera *et al*. (2007) and Watanabe (unpublished), the suggested diet composition is 8.7% lanternfish, 4.5% pacific pomfret, 0.75% anchovy (large), 47.6% mid-deep water squid,10.2% large surface squid, 4% small surface squid, 5.8% neon-flying squid, 0.3% albacore and 18.3% others.

2) Biomass

According to Kleiber *et al*. (2001), biomass estimate of this species in the North Pacific area range from about 400,000-1,200,000 tons. By multiplying this value with the percentage of JARPNⅡ area results in an estimate of 20,000-70,000 tons (average 45,000 tons).

3) P/B or Z

Since there is no data, we assume the same value assumed in Cox *et al*. (2002a) of 0.39 (average of mature and immature animals) which is used for the ECOPATH model in the Central north pacific, which is based on single-species model assessments.

4) Q/B

Since there is no data, we assume the same value assumed in Cox *et al*. (2002a) of 3.1 (average of mature and immature animals) which is used for the Central north pacific ECOPATH model. This results in growth efficiency of 13%, which is in the plausible range of 10-30%.

5) Catch

According to Fisheries agency of Japan (2008), catch in 2006 in the JARPNⅡ area is about 11,453 tons.

Salmonshark

1) Diet composition

According to Kubodera *et al*. (2007) and Watanabe (unpublished), the suggested diet composition is 14.3% mid-deep water squid, 79.3% large surface squid, 2.8% small surface squid and 3.6% others.

2) Biomass

Since there is no suitable data, we multiply the biomass of blue shark with the catch ratio of salmonshark and blue shark (0.28). This results in an estimate of 5,600-19,600 tons.

3) P/B or Z

Since there is no actual estimate, we assume the same value as for blueshark of P/B=0.39.

4) Q/B

According to Wetherbee *et al*. (1990), daily consumption of sharks is 0.4-3.2% of its body-weight. Assuming that salmon shark feed every day, Q/B range from 1.5 to 11.7. We use the mean of Q/B=5.1.

5) Catch

According to Fisheries agency of Japan (2008), catch in 2006 is 3,881 tons.

Lanternfish

1) Diet composition

According to Moku *et al*. (2000) based on the survey data obtained during the summers of 1994 to 1996 in the subarctic and transitional waters of the western North Pacific, average diet composition of *Diaphus theta*, *Stenobrachius leucopsarus*, and *Stenobranchius nannochir* is 36% copepods eaten by whales, 18% other copepods, 24% euphausiids, and 22% others.

2) Biomass

According to Brodeur and Yamamura (2005), biomass (g/m^2) range from 2.8-18.5 g/m^2. The average density results in a biomass estimate of 30,000,000 tons. This estimate includes Bathylagidae, Gonostomatidae, thus we use the half of this estimate; 15,000,000 tons.

3) P/B or Z

Moku *et al*. (2000) based on the survey data obtained during the summers of 1994 to 1996 in the subarctic and transitional waters of the western North Pacific estimated Q/B=13.35. Thus, using the relationship of *g* (growth efficiency) =0.1-0.3, results in an estimate of P/B=1.34-4.01 (mean is 2.68). Here we use P/B=2.68.

4) Q/B

According to Moku *et al*. (2000), the daily consumption of *D. theta* is 6.3%, *S. leucopsarus* is 3.0%, and *S. nannochir* is 0.33% of its body weight. For some sub-tropical species, the daily consumption is around 5% of its body-weight. The average of these becomes 3.7%. Assuming that lanternfish feed year around results in an estimate of Q/B=13.35.

5) Catch

There is no catch taken.

Mackerels

1) Diet composition

We assume same value as in Okamura *et al*. (2001), except that we assume that no sardine is eaten, since the biomass of this species has declined dramatically in recent years. This results in a diet composition of 50% euphausiids, 30% copepods, 10% anchovy (3% small and 7% large), 2% lanternfish, Pacific saury, 1% large surface squid, small surface squid , neon-flying squid and mid-deep-water squid.

2) Biomass

According to Fisheries Agency of Japan (2008), biomass in 2006 is around 555,000 tons for common mackerels, and 459,000 tons for southern mackerels, totaling 1,015,000 tons.

3) P/B or Z

M is around 0.4 (Honma 1987), and average *F* is 0.63. Thus, average *Z*=1.03.

4) Q/B

We use the relationship of *g* =0.1-0.3. This result in an estimate of Q/B=3.43-10.3. Here, we assume the mean of Q/B=6.87.

5) Catch

Catch in 2006 is 428,384 tons (Fisheries agency of Japan 2008).

Pacific pomfret

1) Diet composition

According to Watanabe *et al*. (2003) and (2006), which is based on survey samples collected in April and May 2000 in the transition zone of the central North Pacific, and samples collected in July 2002 in the transitional domain and subarctic region of the central North Pacific, the following diet composition is suggested: 0.3% euphausiids, 22.9% large surface squid, 37.2% small surface squid, 3.9% neon-flying squid, 2.3% mid-deep water squid, 3.3% lanternfish, 3.1% Pacific saury, 1.4% anchovy (small) and 25.7% others.

2) Biomass

Although there is no direct estimate of the biomass of pacific pomfret, data from drift net survey in this area from 2000-2006 (Hokkaido University, 2000-2006) suggest that, the biomass of pacific pomfret is at least 1.4 times that of neon-flying squid. Thus, here we assume 1.4 times the biomass of the neon-flying suid.

3) P/B or Z

Since there is no suitable information for this particular area, we use the estimate used by Aydin *et al*. (2003) of 0.75 for the pacific pomfret in the western subarctic region of the Pacific.

4) Q/B

Since there is no suitable information for this particular area, we use the estimate used by Aydin *et al*. (2003) of 3.75 for the pacific pomfret in the western subarctic region of the Pacific. This estimate is derived from assuming growth efficiency of 0.2.

5) Catch

There seems to be some by-catch but there is lack of reasonable estimate, thus here we provisionally assume that 1% of the total biomass is caught by by-catch etc.

Japanese sardine

1) Diet composition

We use the same estimate as in Okamura *et al*. (2001), of 70% phytoplankton, and 30% copepoda.

2) Biomass

According to Fisheries agency of Japan (2008), the biomass in 2006 is estimated to be 132,000 tons.

3) P/B or Z

According to Fisheries agency of Japan (2008), *M* is 0.4 and *F*=0.37, thus we assume *Z*=0.77.

4) Q/B

Since there is no suitable information, we use the relationship *g*=0.1-0.3, resulting in an estimate of Q/B=2.57-7.7. Here we assume Q/B=5.14

5) Catch

The catch in 2006 is 48,571 tons.

Japanese anchovy

1) Diet composition

We use the same estimate as in Okamura *et al*. (2001), of 20% euphausiids, and 80% copepoda for both small and large anchovy.

2) Biomass

According to Fisheries Agency of Japan (2008), the biomass estimate of anchovies larger than 5cm is 4,800,000 tons. If we assume that the biomass of those less than 5cm is half the biomass of the 0-age classes (<8cm), biomass of those between 5-8cm is about 11-27% of those biomass larger than 5cm, according to the stock assessment of anchovy between 200-2005 in Fisheries agency of Japan (2008). Thus, the biomass between 5-8cm would be around 530,000 – 1,300,000 tons. Thus, the biomass of the large component of anchovy would be around 3,500,000-4,300,000 tons. Here we assume the mean of 3900,000 tons for the large component.

3) P/B or Z

According to Fisheries agency of Japan (2008), *M* is around 1.5 and *F*=0.1 for the large component of anchovy, thus we use *Z*=1.6 for the large component. For the small component, *M* =1 is assumed in Fisheries agency of Japan (2008), but it notes that the actual *M* should be higher when fishing of the small component is considered. Thus, here we use the same Z as the large component.

4) Q/B

Although there is no suitable data in JARPN II area, Tudela and Palomera (1995)estimated Q/B for European anchovy to be 3.9% of its body-weight/day. Thus assuming that this species feed year around, Q/B=14.04.

5) Catch

According to Fisheries agency of Japan (2008), the average catch (2000-2005) for the small component is about 5,000 tons, and the average catch for the larger component is about 300,000 tons.

Pacific saury

1) Diet composition

According to Sugisaki and Kurita (2004), which is based on seven cruises conducted from 1999 to 2002 in the JARPN II survey area in different seasons, 23.8% is copepods eaten by whales, 50.1% is euphausiids, and 26.1% is others.

2) Biomass

According to Fisheries agency of Japan (2008), the biomass in 2007 is estimated to be 4,400,000 tons.

3) P/B or Z

According to Fisheries agency of Japan (2008), M=0.64 is used for the assessment of this species. Recent F is 0.1, thus Z=0.74 is used.

4) Q/B

According to Sugisaki and Kurita (2004), in Autumn-Winter, Pacific saury consumes about 4% of its body-weight. When in spring-summer, Pacific saury consumes 7% of its body-weight. Thus, we assume Q/B=10.

5) Catch

Catch in 2006 is 392,148 tonnes, and the discarding is about 20,500 tonnes.

Neon-flying squid

1) Diet composition

According to Watanabe *et al*. (2004c) and Watanabe (unpublished), which examined the feeding habits of this species for different years, seasons in the transitional waters of the central North Pacific in the 1990s and 2000s, the following diet composition is suggested: 0.1% euphausiids,16.4% large surface squid, 25.4% small surface squid, 1.4% neon-flying squid, 4.1% mid-deep water squid, 28.4% lantern fish, 14% anchovy (large), 0.9% anchovy (small) and 9.3% others.

2) Biomass

According to Fisheries agency of Japan (2008), the biomass is around 140,000-400,000 tons (mean is 270,000 tons).

3) P/B or Z

M of the autumn cohort of neon-flying squid is estimated to be 0.089 per 10-day period by Ichii *et al*. (2006), which amounts to M=3.25/year. F is assumed to be 0.37, thus Z is assumed to be 3.62.

4) Q/B

According to Watanabe *et al*. (2004c), neon-flying squid consume 6.0% of its body-weight/day. Thus, assuming that they spend 180days feeding in this area, Q/B=10.8.

5) Catch

According to Ichii (pers. comm.), the average catch from 2000-2004 is about 100,000 tons (catch by China is increasing; almost 5 times the catch of Japan).

Large surface squid

Here we consider the following species: Japanese common squid, clubhook squid, Eight-armed squid, Kagi-ika, Sujiika which there DML is larger than 15cm.

1) Diet composition

Referring to the diet composition of neon-flying squid (Watanabe *et al*. 2004), we assume 46.4% euphaussids, 8.03% small surface squid, 2.51% anchovy (small), 6.27% lanternfish, and 36.8% others (mainly amphipods).

2) Biomass

The biomass of Japanese common squid (winter population) is estimated to be around 800,000 tons. Although there is no direct estimate of the biomass for other large surface squids, data from drift net survey in this area from 2000-2006 (Hokkaido University, 2000-2006) suggest that, the biomass of other large surface squid is at least 0.83 times that of neon-flying squid, which amounts to 120,000 – 330,000 (mean is 220,000) tons. This survey did not sample Kagi-ika, thus this estimate may be an underestimate. Nevertheless, the estimate is about 1,000,000 tons.

3) P/B or Z

M of Japanese common squid is often set to 0.1/month (Fisheries agency of Japan 2008), which amounts to M=1.2/year. F=0.135, thus Z for Japanese common squid may be 1.34. Considering the Z value of neon-flying squid (Z=3.62), we take the mean of these two estimate which results in an estimate of Z=2.48.

4) Q/B

We use the same value used for neon-flying squid (Q/B=10.8)

5) Catch

We use the catch of Japanese common squid of 135,000 tons (Fisheries agency of Japan (2008).

Small surface squid

Here we consider species of Gonatidae (eight-armed squid is excluded) which there DML is mainly less than 15cm.

1) Diet composition

According to Uchikawa (unpublished), small surface squid consume 77.8% other copepods, 5.56% euphausiids, and 16.7% others.

2) Biomass

There is no estimate of biomass. Thus we let the model to estimate assuming *EE*=0.9.

3) P/B or Z

Since the body size of small surface squid is smaller than the large surface squid, we assume higher *M*, such as *M*=0.1 per 10-day period. This amounts to *M*=3.65/year. Thus, here we assume *Z*=3.65.

4) Q/B

We use the same value used for the large surface squid and neon-flying squid, which is Q/B=10.8.

5) Catch

No catch is taken.

Mid-deep water squid

1) Diet composition

We use the same as in Okamura *et al*. (2001), which assume 60% euphausiids, and 40% copepods.

2) Biomass

Since there is no suitable information, we let the model to estimate the biomass assuming *EE*=0.9.

3) P/B or Z

Since there is no suitable information for this particular area, we use the estimate used by Aydin *et al*. (2003) of 2.56 for the squids in the western subarctic region of the Pacific.

4) Q/B

We use the same value used for neon-flying squid (Q/B=10.8).

5) Catch

There is no catch taken.

Phyto-plankton

1) Biomass

Since there is no suitable information, we use the estimate of Cox *et al*. (2002a) of 26.58 t/km^2 which is used for the Central north pacific ECOPATH model which was estimated in the model. Also, Saito (pers.commn) suggests an order of 15- 40 t/km^2 (average 27.5 t/km^2) for the modeled region.

2) P/B or Z

We use the estimate of 85.96 of Aydin *et al*. (2003).

Euphausiids

1) Diet composition

Based on Nakagawa *et al*. (2004) and Taki (un published), the following diet composition is assumed: 9% copepods eaten by whales, 9% copepods not eaten by whales, 12% phytoplankton and 70% detritus.

2) Biomass

We use the estimate used by Aydin *et al*. (2003) for the ECOPATH model in the western subarctic region, which is 40.67t/km^2.

3) P/B or Z

We use the estimate used by Aydin *et al*. (2003) for the ECOPATH model in the western subarctic region, which is 2.555.

4) Q/B

Since there is no suitable information for this particular area, we use the estimate used by Aydin *et al*. (2003) of 12.05 for the euphausiids in the western subarctic region of the Pacific.

Copepods eaten by whales

1) Diet composition

According to Kobari *et al*. (2003) which is based on survey in 1996-1997 in Area 7 of JARPN Ⅱ survey area, we assume 26% phytoplankton and 74% detritus.

2) Biomass

Use the estimate of Murase (pers. commn.) of 59,100,000 tons.

3) P/B or Z

According to Kobari *et al*. (2003) which is based on survey in 1996-1997 in Area 7 of JARPN Ⅱ survey area, P/B= 5.0.

4) Q/B

Based on Murase (pers. commn.), we assume Q/B=10.0.

Other copepods

Since there is no suitable information, we assume the same value as “copepods eaten by whales”.

Detritus

To estimate the biomass of detritus, we use the same method used in Okamura *et al*. (2001), which multiplies the biomass of phytoplankton by 5 (Tsujita 1982).

Appendix C: Parameter settings of the functional response in Ecosim and its assumptions

Name FR	Max. rel. feeding time	Feeding time adjust rate [0,1]	Fraction of "other" mortality sens. To changes in feeding time	Predator effect on feeding [0,1]	Density-dep. Catchability Q_{max}/Q_0 [>=1]	QB_{max}/QB_0 (for handling time) [>1]	Switching power parameter [0,2]
Type 1	2	0	0	0	1	1000	0
Type 2	2	0	0	0	1	2	0
Type 3	2	0.5	0	0.5	1	2	0
Type 3+other M	2	0.5	1	0.5	1	2	0
Type 3+switch	2	0.5	0	0.5	1	2	2
Default	2	0.5	1	0	1	1000	0

Type 1 functional relationship assumes that the feeding time is constant regardless of the density of its prey or predators, and there is no density dependent mortality or limit in handling time. Consumption rate is proportional to available prey biomass.

Type 2 functional relationship is similar to Type 1 and assumes that the feeding time is constant, though there is a limit in handling time.

Type 3 functional relationship assumes that all the species considered in the model adjust their feeding time in relation to their food and predator density (risk sensitive behaviour), and there is a limit in handling time.

Type 3 + other M functional relationship adds the density dependent mortality feature to the Type 3 functional relationship assumed above.

Type 3 + switch functional relationship adds the behaviour of taking disproportionately more of the thing as it becomes more abundant.

The default functional relationship assumes that all the species considered in the model adjust their feeding time in relation to their food density, and mortality rate of the species change in relation to feeding time (i.e. density dependent mortality), and there is no limit in handling time.

ADDENDUM

Has obtaining further data on diet composition of whales improved the precision of the estimate of % increase in catch of Japan's fisheries resources calculated by the EwE model?

The average diet composition for each JARPNII survey year including the feasibility study period (8 in all) is treated as a sampling unit. First we bootstrap 10 times over the first 5 years (3 years for sei whales) to get an uncertainty distribution (i.e. choose successive sets of 5 years' data, choosing 5 times at random with replacement from the averages for each year, and then averaging over the 5). Next we conduct exactly the same exercise but for 8 years. For each bootstrap diet composition data, we calculate the % increase in catch of some Japanese fisheries resource. From such a calculation, we obtain the average % increase in catch of their Japanese fisheries resource and the standard deviation of the bootstrap distribution which is the standard error associated with this average % increase estimate. The objective is to see if the standard error has improved by accumulating 8 years of diet composition data, compared to five years. We repeat this whole procedure 5 times to examine how precise the estimate of such standard error is.

Results for minke whales

Table a-1 shows bootstrap % increase in catch of Pacific saury between no catch and taking 4% of minke whales for the coming 50 years for cases of 5 years accumulation of diet composition data and 8 years of such. Table a-2 shows the mean and average standard error of the % increase in catch of Pacific saury over the five trials. The results indicate that estimated % increase in catch of Pacific saury decreases from 1.697% (SE=0.330) to 1.470% (SE=0.289) with further 3 years of accumulation of the diet composition data. The standard error of this estimate has improved by about 10%.

Table a-1. Bootstrap % increase in catch of Pacific saury between no catch and taking 4% of minke whales for the coming 50 years (fishing effort for the other harvested species is kept as current). "5 years" bootstrap diet composition for the first five years of JARPNII surveys, and "8 years" bootstrap that for the whole JARPNII survey period. The whole procedure is repeated for five times with different realizations of sampling with replacement (Trial 1 to Trial 5).

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Pacific saury	5years	8years	5years	8years	5years	8years	5years	8years	5years	8years
boot1	1.729	1.794	2.055	1.729	1.859	1.34	1.859	1.598	1.859	1.924
boot2	1.990	1.729	1.794	1.34	1.082	1.598	1.276	1.405	1.924	1.146
boot3	1.729	1.340	2.382	1.794	1.794	1.082	1.99	1.082	1.534	1.924
boot4	1.794	1.018	2.055	1.34	2.186	1.729	1.47	1.405	1.276	1.663
boot5	1.598	1.276	1.924	1.276	2.382	1.924	1.405	1.924	1.924	1.729
boot6	1.470	1.598	1.405	1.34	1.794	0.954	1.211	0.762	1.598	1.276
boot7	2.121	1.598	1.729	1.859	1.340	1.340	1.082	1.146	2.055	1.211
boot8	1.405	1.598	2.186	1.082	1.276	1.34	0.954	1.211	1.729	1.663
boot9	1.729	1.470	1.859	1.794	1.276	1.729	1.598	1.47	1.794	1.729
boot10	1.211	1.470	1.794	1.211	1.276	1.405	2.382	1.73	1.729	1.405
Mean	1.678	1.489	1.918	1.477	1.627	1.444	1.523	1.373	1.742	1.567
SE	0.270	0.230	0.270	0.286	0.440	0.302	0.443	0.338	0.227	0.287

Table a-2. Mean and standard error (SE) of the % increase in catch for Pacific saury for Trials 1 to 5 shown on Table a-1. Standard deviation and standard error of the SE is also shown.

Pacific saury	5 years	8years
Mean % increase in catch	1.697	1.470
Mean of the SEs for the 5 trials	0.330	0.289
Standard deviation of the SE	0.103	0.039
Precision (Standard error) of the SE	0.046	0.017

Results for sei whales

Table a-3 shows bootstrap % increase in catch of anchovy (>=8cm) between no catch and taking 4% of sei whales for the coming 50 years for cases of 3 years accumulation of diet composition data and 6 years of such[1]. Table a-4 shows the mean and average standard error of the % increase in catch of anchovy (>=8cm) over the five trials. The results indicate that estimated % increase in catch of anchovy (>=8cm) decreases from 3.654% (SD=0.696) to 2.708% (SD=0.766) with further 3 years of accumulation of the diet composition data. However, the standard error of this estimate has not improved. This could be because the amount of anchovy consumed by sei whales varies substantially from year to year – note the lesser precision of the SE estimates in Table a-4 compared to those in Table a-2.

Table a-3. Bootstrap % increase in catch of anchovy (>=8cm) between no catch and taking 4% of sei whales for the coming 50 years (fishing effort for the other harvested species is kept as current). "3 years" bootstrap diet composition for the first three years of JARPNII surveys on sei whales, and "6 years" bootstrap that for the whole JARPNII survey period. The whole procedure is repeated for five times with different realizations of sampling with replacement (Trial 1 to Trial 5).

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
anchovy (>=8cm)	3 years	6 years	3 years	6 years	3 years	6 years	3 years	6 years	3 years	6 years
boot1	2.728	3.235	2.149	2.077	3.672	3.235	4.549	3.381	4.549	4.329
boot2	3.963	3.235	3.672	3.672	4.549	2.511	3.672	3.963	3.672	2.728
boot3	3.672	1.861	2.728	2.582	4.549	2.728	3.963	1.933	2.149	2.945
boot4	3.017	3.235	3.963	2.945	3.672	3.017	3.672	3.672	4.549	3.235
boot5	3.963	3.017	4.182	2.945	4.841	3.453	3.453	3.235	2.728	1.790
boot6	2.728	1.430	3.672	1.861	3.017	2.511	4.182	0.356	4.182	1.358
boot7	2.728	1.574	4.549	2.945	2.728	3.453	4.182	1.790	3.453	2.800
boot8	3.672	2.366	3.017	2.149	3.017	2.149	4.549	2.511	4.182	3.089
boot9	3.453	4.182	2.728	2.800	3.963	3.381	3.672	2.728	4.841	1.790
boot10	4.549	2.294	3.672	2.582	3.017	3.525	3.017	2.294	3.672	2.511
Mean	3.447	2.643	3.433	2.656	3.703	2.996	3.891	2.586	3.798	2.658
SE	0.631	0.881	0.751	0.531	0.757	0.490	0.488	1.068	0.852	0.859

Table a-4. Mean and standard error (SE) of the % increase in catch for anchovy (>=8cm) for Trials 1 to 5 shown on Table a-3. Standard deviation and standard error of the SE is also shown.

anchovy (>=8cm)	3 years	6years
Mean % increase in catch	3.654	2.708
Mean of the SEs for the 5 trials	0.696	0.766
Standard deviation of the SE	0.140	0.247
Precision (Standard error) of the SE	0.063	0.111

[1] For sei whales there was no feasibility study period thus the sampling units total 6 in all.

Results for Bryde's whales

Table a-5 shows bootstrap % increase in catch of anchovy (>=8cm) and mackerel between no catch and taking 4% of Bryde's whales for the coming 50 years for cases of 5 years accumulation of diet composition data and 8 years of such. Table a-6 shows the mean and average standard error of the % increase in catch of anchovy (>=8cm) and mackerels over the five trials. The results indicate that estimated % increase in catch of anchovy (>=8cm) increases from 3.238% (SD=0.828) to 3.305% (SD=0.584), and that of mackerel decreases from 1.722% (SD=0.997) to 0.991% (SD=0.584) with further 3 years of accumulation of the diet composition data. The standard errors of these estimates have improved by about 30% for anchovy (>=8cm) and 40% for mackerel.

Table a-5 Bootstrap % increase in catch of (a) anchovy (>=8cm) and (b) mackerels between no catch and taking 4% of Bryde's whales for the coming 50 years (fishing effort for the other harvested species is kept as current). "5 years" bootstrap diet composition for the first five years of JARPNII surveys on Bryde's whales, and "8 years" bootstrap that for the whole JARPNII survey period. The whole procedure is repeated for five times with different realizations of sampling with replacement (Trial 1 to Trial 5).

(a) anchovy (>=8cm)

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
anchovy (>=8cm)	5years	8years	5years	8years	5years	8years	5years	8years	5years	8years
boot1	3.219	3.940	3.147	3.794	2.214	4.011	4.444	1.856	3.076	3.508
boot2	4.444	3.722	2.645	2.859	2.788	3.219	2.357	2.859	2.286	3.004
boot3	3.940	3.651	2.357	4.083	3.219	2.573	1.284	3.219	3.579	3.722
boot4	4.083	3.076	2.286	1.927	3.579	2.716	1.784	3.651	4.588	3.722
boot5	3.940	3.651	3.436	2.500	3.940	3.076	3.940	2.357	3.004	4.083
boot6	4.735	3.147	2.788	3.868	2.859	2.645	3.651	2.716	4.444	3.651
boot7	0.927	4.155	3.076	2.859	1.927	3.940	3.579	2.357	2.286	3.219
boot8	5.240	3.076	3.436	3.794	2.716	3.579	2.716	3.147	4.083	4.444
boot9	3.219	2.573	3.508	4.444	2.931	3.076	3.076	3.436	4.083	3.508
boot10	3.579	3.076	4.083	3.219	2.716	3.651	3.219	3.940	3.436	2.931
Mean	3.733	3.407	3.076	3.335	2.889	3.249	3.005	2.954	3.487	3.579
SE	1.174	0.489	0.565	0.792	0.591	0.527	0.983	0.648	0.826	0.464

(b) mackerels

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
mackerels	5years	8years	5years	8years	5years	8years	5years	8years	5years	8years
boot1	3.022	2.192	3.571	1.370	4.121	0.546	1.370	2.747	0.546	1.096
boot2	1.370	1.370	1.096	1.096	1.918	0.273	2.192	1.096	1.370	1.096
boot3	0.546	0.546	2.192	0.273	1.918	1.644	1.644	1.644	1.918	0.273
boot4	1.370	2.192	1.370	1.918	1.918	1.918	2.192	0.000	1.918	0.546
boot5	0.546	1.644	1.370	0.546	0.546	1.096	1.644	1.370	1.096	0.546
boot6	1.370	1.096	3.846	1.096	1.918	1.370	4.683	0.546	1.370	1.096
boot7	3.022	1.096	0.546	0.273	3.571	0.273	0.546	0.273	2.192	1.096
boot8	1.096	1.096	1.370	0.273	0.546	0.273	0.546	1.096	1.370	0.546
boot9	1.918	0.546	2.747	0.273	3.022	0.546	0.546	1.096	1.370	0.273
boot10	1.918	1.918	1.370	1.096	0.546	1.096	0.546	1.096	1.370	1.096
Mean	1.618	1.370	1.948	0.821	2.002	0.904	1.591	1.096	1.452	0.766
SE	0.874	0.606	1.104	0.578	1.264	0.607	1.278	0.766	0.467	0.361

Table a-6. Mean and standard error (SE) of the % increase in catch for (a) anchovy (>=8cm) and (b) mackerels for Trials 1 to 5 shown on Table a-5. Standard deviation and standard error of the SE is also shown.

(a) anchovy (>=8cm)

anchovy (>=8cm)	5 years	8years
Mean % increase in catch	3.238	3.305
Mean of the SEs for the 5 trials	0.828	0.584
Standard deviation of the SE	0.260	0.136
Precision (Standard error) of the SE	0.116	0.061

(b) mackerels

mackerels	5 years	8years
Mean % increase in catch	1.722	0.991
Mean of the SEs for the 5 trials	0.997	0.584
Standard deviation of the SE	0.338	0.145
Precision (Standard error) of the SE	0.151	0.065

Conclusion

For minke and Bryde’s whales, obtaining further diet composition data has improved the precision of the estimate of % increase in catch of Japan’s fisheries resources (e.g. Pacific saury, anchovy, mackerels) calculated by the EwE model. The results indicate that continuation of the JARPN2 survey will contribute by further improving the precision of the effect of whaling on Japan’s fisheries resources.