ICES Journal of
Marine Science

ICES Journal of Marine Science (2012), 69(7), 1134–1140. doi:10.1093/icesjms/fss098

Adaptation to climate-change effects on fisheries in the Shiretoko World Natural Heritage area, Japan

Mitsutaku Makino[1]* and Yasunori Sakurai[2]

[1]*National Research Institute of Fisheries Science, Fisheries Research Agency, 2-12-4 Fukuura, Kanazawa, Yokohama 236-8648, Japan*
[2]*Faculty of Fisheries Sciences, Hokkaido University, 3-1-1 Minato-cho, Hakodate, Hokkaido 041-8611, Japan*

**Corresponding author: tel: +81 45 7887655; fax: +81 45 7887655; e-mail: mmakino@affrc.go.jp.*

Makino, M., and Sakurai, Y. 2012. Adaptation to climate-change effects on fisheries in the Shiretoko World Natural Heritage area, Japan. – ICES Journal of Marine Science, 69: 1134–1140.

Received 28 September 2011; accepted 23 April 2012; advance access publication 7 July 2012.

In the Shiretoko World Natural Heritage area, many factors have been observed that imply effects of climate change on ecosystems, such as decreases in seasonal sea ice, changes in fishing grounds, and the appearance of non-local species. This study summarizes observed and anticipated effects of such climate change on fisheries in the heritage area and discusses policy and research needs for adapting to these changes. International research and monitoring at the scale of large marine ecosystems (LMEs) is the basis of all policy measures for adapting to climate change. Several measures need to be combined, taking into account the various socio-ecological aspects of fisheries and scales of ecosystems. Such measures of adaptation should be incorporated also into the cross-sector coordination system and the Integrated Management Plan, which were established to manage the World Heritage area. Also, culture is an important part of society, and the World Heritage programme may offer clues for creating a new and peaceful culture based on the LME.

Keywords: adaptation, climate change, fisheries, UNESCO World Natural Heritage.

Introduction

The Shiretoko Peninsula and its adjacent marine areas, i.e. the Shiretoko World Natural Heritage (WNH) area (Figure 1), became part of the UNESCO (UN Educational, Scientific and Cultural Organization) World Natural Heritage List in 2005. The Shiretoko ecosystem is characterized by rich low-trophic-level activity created by algal blooms following the melting sea ice. The area's high level of primary production supports a wide range of species, including marine mammals, seabirds, and species that are commercially important to local fisheries.

Many factors in recent years have been indicating changes in the Shiretoko ecosystem, such as decreases in the amount of seasonal sea ice, changes in the location of fishing grounds, and the appearance of non-local species. In February 2008, UNESCO and IUCN (the International Union for the Conservation of Nature) suggested that the Japanese government develops a Climate Change Strategy that includes (i) a monitoring programme that identifies both long- and short-term impacts of climate change and (ii) adaptive management strategies that can be applied to minimize any impacts of climate change on the value of the WNH site (UNESCO and IUCN, 2008). To address this suggestion, this study summarizes the observed and anticipated effects of climate change on the Shiretoko WNH ecosystems and fisheries, then discusses policy and research needs for adapting to these changes. The objective of the study is to provide the baseline information for developing a Climate Change Strategy for fisheries in the Shiretoko WNH area.

The Shiretoko WNH site

Ecosystems and fisheries

The Shiretoko WNH area is the southernmost limit of seasonal sea ice in the northern hemisphere and is affected by both the East Sakhalin cold current and the Soya warm current (Ohshima *et al.*, 2001). The area is also influenced by Okhotsk Sea Mode Water derived from the formation of dense shelf water in the Sea of Okhotsk (Yasuda, 2004) and creating a complex, rich marine ecosystem of both migrating and resident species (Ministry of the Environment and Hokkaido Prefectural Government, 2007). In early spring, the Shiretoko ecosystem is characterized by rich low-trophic-level activity created by algal

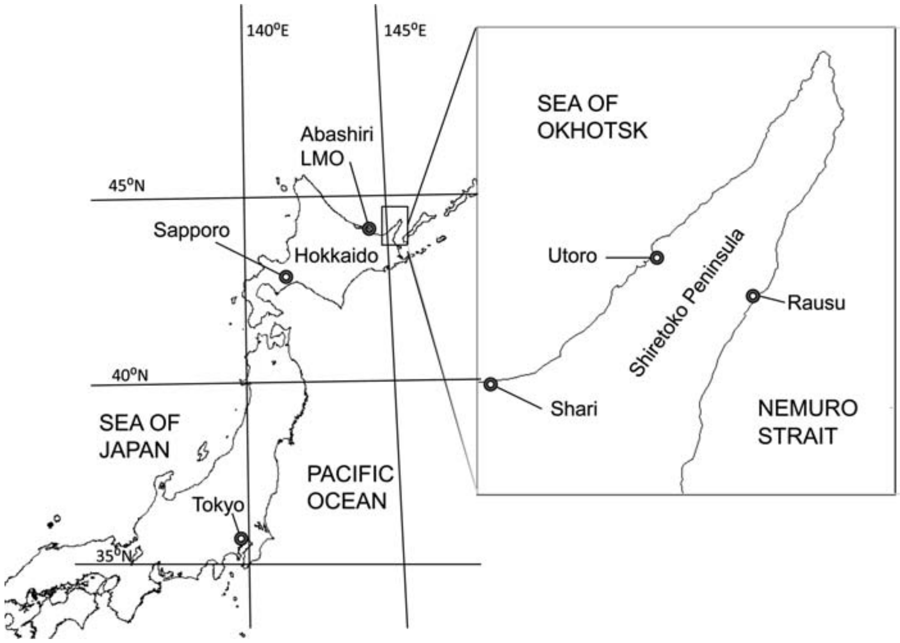

Figure 1. The location of the Shiretoko Peninsula and the towns in Hokkaido, Japan.

blooms following the melting sea ice. The area's high level of primary production supports a wide range of species, including marine mammals, seabirds, and commercially important species (Sakurai, 2007).

A distinguishing characteristic of the site is the interrelationship between its marine and terrestrial ecosystems. Large numbers of anadromous salmonids, such as chum salmon (*Oncorhynchus keta*), pink salmon (*O. gorbuscha*), masu salmon (*O. masou masou*), and dolly varden (*Salvelinus malma*), migrate up the rivers to spawn. They serve as an important source of food for terrestrial species such as brown bear (*Ursus arctos*), Blakiston's fish owl (*Ketupa blakistoni blakistoni*), Steller's sea eagle (*Haliaeetus pelagicus*), and white-tailed eagle (*H. albicilla*). The peninsula is also internationally important as a stopover point for migratory birds (IUCN, 2005). The two species of eagle listed above migrate from Russia to the area in winter, although some white-tailed eagles live permanently on the peninsula.

Commercial fisheries in Shiretoko began in 1790 with the establishment by the rulers of mainland Japan of a fish market, with the main products at that time being dried or salt-cured salmon, trout, and herring (Shari Fisheries History Editing Committee, 1979). Today, marine areas around the peninsula are among the most productive in terms of fisheries in Japan. In 2008, Shiretoko fishers caught ~64 000 t of fish, worth ~24 billion yen (US$313 million; MAFF, 2010). The main target species and gear types are salmonids, using large-scale coastal set-nets, Japanese common squid (*Todarodes pacificus*), by jigging and/or use of large-scale coastal set-nets, and walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), and Atka mackerel (*Pleurogrammus azonus*), using gillnets and/or longlines. Fish-processing industries are also active on the peninsula, and the dried Oni-Kombu kelp (*Laminaria diabolica*) produced in the area is much prized, fetching the highest prices on the Japanese market.

Governance of the Heritage area

Marine ecosystem conservation typically consists of a suite of activities across a wide range of related sectors such as fisheries, transport, and tourism. However, there is no domestic law specific to World Heritage programmes, and conservation measures have been implemented by more than one authority based on separate laws (for detail, see Makino *et al*., 2009). Therefore, a new system for cross-sector coordination was established for integrating management of the Shiretoko WNH area (Figure 2). In October 2003, the Shiretoko WNH Site Regional Liaison Committee was established, with officers from different ministries and departments in national and local government. They discuss appropriate management of the site, exchange information, and coordinate various interests among related sectors. The Shiretoko WNH Site Scientific Council was established in July 2004. It provides scientific advice regarding both the establishment of an Integrated Management Plan (see below) and support for research and monitoring. The Council has two working groups and two committees (Figure 2). In April 2010, the Shiretoko WNH Site Committee on the Proper Use of Nature and Ecotourism was founded. It conducts research and discusses appropriate user rules for tourists.

Through these organizations and their interrelationships, stakeholder participation is ensured, information and opinions are exchanged, and consensus between the wide-ranging interests of multiple users of ecosystem services is achieved, increasing the legitimacy of Integrated Management Plans and related rules. This is the core institutional framework for integrated management in the Shiretoko WNH area (Makino *et al*., 2009).

Integrated Management Plan

The Integrated Management Plan was developed by the Marine Working Group of the Scientific Council. The Plan defines measures to conserve the marine ecosystem, strategies for maintaining

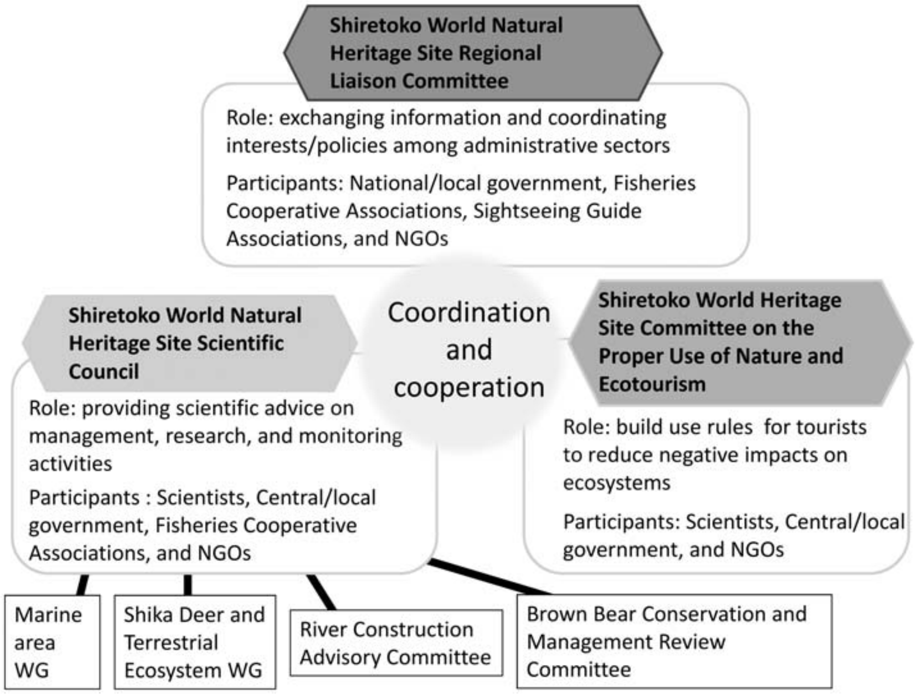

Figure 2. New organizations for cross-sector coordination in the Shiretoko WNH area (modified after Makino *et al.*, 2009).

major species, monitoring methods, and policies for marine recreational activities. The objective of the Plan is "to satisfy both conservation of the marine ecosystem and stable fisheries through sustainable use of living marine resources in the marine area of the heritage site".

Under the Plan, local fishers are identified as an integral part of the ecosystem, and the data they provide are used to monitor the ecosystem cost-effectively. Local Fisheries Cooperative Associations (FCAs), organizations of local fishers, have been collecting and compiling catch data for more than 60 years, covering many of the indicator species and other major marine species (Matsuda *et al.*, 2009).

Climate effects and research needs for adaptation

Framework for the discussion

Fisheries management has various objectives. For example, the conservation of marine ecosystems and fisheries resources is essential to all fisheries activities. In addition, as an industry, improvement of economic efficiency is an important part of fisheries management. Fishery products are one of the major sources of animal protein for the Japanese nation, so the national importance of a stable seafood supply, as well as related food safety, cannot be overemphasized. Taking all of this into account, the Fisheries Research Agency of Japan summarized five principal aspects of the policy objectives of fisheries management (FRA, 2009): (i) the resource and environmental aspect, (ii) the food provision aspect, (iii) the industrial and economic aspect, (iv) the local and community aspect, and (v) the cultural and science aspect. We apply this framework in discussing the climate effects and measures of adaptation for fisheries in the Shiretoko WNH area.

Resources and the environment

Vertical mixing and seasonal upwelling provide nutrients that support the rich and diverse marine ecosystem (Sakurai, 2007).

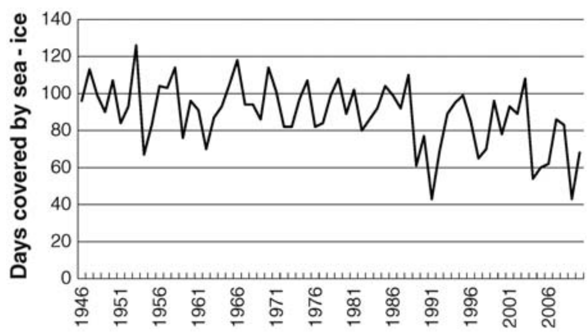

Figure 3. Changes in sea-ice days observed at Abashiri LMO from 1946 to 2010. Data from Japan Meteorological Agency (1947–2011).

Figure 3 is a time-series of 65 years of changes in the number of days of sea-ice cover at the Abashiri Local Meteorological Observatory (LMO), which is located ∼50 km west of the Shiretoko Peninsula (Figure 1). Although there are frequent short-term (1–3 years) oscillations, and several medium-term (10–20 years) regime shifts, the changes show clear evidence of a long-term (30–50 years) decreasing trend. Over this period, the 10-year average decreased by 22%, from 95.8 d through 1946–1955 to 74.6 d through 2001–2010. It is thought that the current level of nutrient supply by the Okhotsk Sea Mode Water and Oyashio Current is sufficient and that the decrease in sea ice will not immediately limit primary production (Ono *et al.*, 2001). If this decreasing trend continues, however, the long-term impact on the Shiretoko ecosystems could be substantial.

There are several studies on the effects of long-term climate change on the main fish resources of Shiretoko fisheries. Chum salmon has been identified as a decreasing species (Kaeriyama, 2008; Kishi *et al.*, 2010), and ocean acidification could produce negative effects on invertebrates (Kurihara, 2008), such as the short-spined sea urchin *Strongylocentrotus intermedius*. In addition, local fishers report that the size and the shape of Oni Kombu kelp are gradually changing, and now more resemble those of temperate water kelp. Walleye pollock (Sakurai, 2009) and Pacific saury *Cololabis saira* (Ito *et al.*, 2010) in the Shiretoko area are considered to be resilient to such long-term climate changes, and Kichiji rockfish (*Sebastolobus macrochir*), because they typically live deeper than 100 m, are little influenced by such changes (Kuwahara *et al.*, 2006). Japanese common squid (Sakurai, 2006; Rosa *et al.*, 2011) and Pacific herring *Clupea pallasii* (Megrey *et al.*, 2007) are expected to increase in abundance over the long term. In addition, according to official fisheries statistics, increasing numbers of Japanese amberjack (*Seriola quinqueradiata*) are being caught with large-scale coastal set-nets off Hokkaido Island. As the fishing pressure of such large coastal set-nets is believed to be relatively stable (Fisheries Agency and Fisheries Research Agency, 2010), the increase in catch implies a northward expansion of the Japanese amberjack fishing grounds. Fishers in the Shiretoko area expect Japanese common squid and amberjack to be substitutes for the species that are decreasing in abundance.

Because the Shiretoko marine ecosystem forms part of the large marine ecosystem (LME) of the Okhotsk Sea, similar phenomena have been reported on the Russian side (Radchenko *et al.*, 2010), so joint monitoring and cooperative research programmes on the LME are needed. Because Japan and Russia have territorial disputes over parts of the LME, however, scientific collaboration can take a lead. At the same time, more fine-scale analysis of the effects of climate change on major fish resources is essential. At present, local fishers are required to monitor and report local-scale (fishing ground scale) changes. Based on the overall results, strict and cautious resource management needs to be implemented for species increasing in abundance, such as Japanese common squid and Pacific herring, which should not be seen as a temporary bonus, but rather as forming the main components of future fisheries in Shiretoko. On the other hand, for species decreasing in abundance, mitigating measures need to be introduced. For example, most of the chum salmon harvested in Japan are from stock hatched artificially, with less genetic diversity and a narrower spawning period than wild stocks (Nagata, 2011). To enhance the genetic diversity of the species, therefore, restoration of the environment of natural spawning rivers is important as a medium-term measure of adaptation.

Food provision

The Japanese are keen consumers of fish. The annual *per capita* intake of seafood in Japan was 61.5 kg in 2008, the second highest in the world, after Iceland. Fish products are the second largest source of total protein intake for the Japanese population, and the largest source of animal protein intake (MAFF, 2009).

The global demand for food is expected to increase for at least another 40 years, and the effects of climate change are a threat to global food security (Godfray *et al.*, 2010). Moreover, Japanese food self-sufficiency ratio is <40%, so Japan is vulnerable in terms of food security, and increasing this ratio is an important policy concern. Hokkaido prefecture, in which Shiretoko is located, is the largest fisheries site in Japan, with some 30% of the total Japanese catch landed there. It is expected, therefore, to continue to play a vital role in the nation's seafood supply in the long term.

If species such as Japanese common squid and Pacific herring are to become more available to fisheries in future, efforts need to be aimed at more-efficient utilization, e.g. new processing technologies, new transportation logistics, and new markets and recipes. From the perspective of increasing the self-sufficiency ratio, such efforts are very important for species prone to great variation in stock size, such as herring, if they are to become available for human consumption and not merely used as fertilizer or animal feed. Also, because Shiretoko is oceanographically vulnerable to incidents such as oil spills and chemical discharge in the Russian Far East (Ohshima and Simizu, 2008), tight communication between the two countries and the establishment of international contingency plans for seafood safety are required.

Industry and the economy

Most fishers in Shiretoko are small-scale and their financial basis is weak. In light of this vulnerability, catch composition is of great importance in the area. For example, Figure 4 shows the composition of fish production (values) in two towns in the Shiretoko WNH area over the past 5 years. In Shari town, located on the western side of the Shiretoko Peninsula, >90% of fisheries income is derived from salmonids, most of which are chum salmon, a decreasing species under long-term climate change. In Rausu town, the average value of fish production during the period 2004–2008 is higher than in Shari town, and it is not dominated to the same extent by salmonids. Note too that, for the past 10 years, the climate-related marine conditions in the western

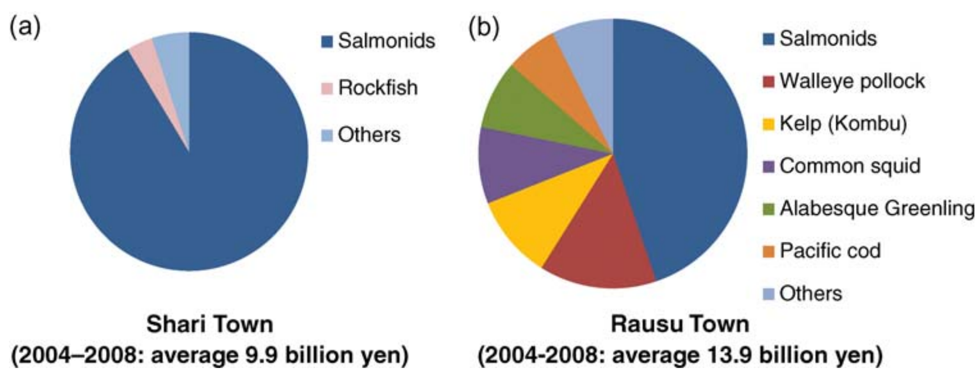

Figure 4. Fishery production values in the Shiretoko Peninsula for the years 2004–2008. Data from the Japanese Ministry of Agriculture Forestry and Fisheries, 2006–2010.

North Pacific Ocean have been favourable for chum salmon (Irvine and Fukuwaka, 2011), presumably as a result of the medium-term oceanographic regime shift towards a cold phase.

Historically, Shiretoko fishers have experienced considerable instability in their fish resources as a result of medium-term regime shifts. For example, herring was one of the main target species for coastal fishers in Shari town before the Second World War. Then, in the late 1960s, Japanese common squid landings in Shari town amounted to >4000 t year^{-1}. In Rausu town, too, common squid made up more than half of the total landings by the value in that period. According to the legal system aimed at adapting to such resource fluctuations, fishing rights and licenses are revised every 5–10 years, with the revision process based on plans drafted by local fishers (Makino, 2011). To enhance adaptive capability in the face of climate change, government and scientists in this revision process would need to provide the results of ecosystem monitoring and future prospects in a form easily understood by Shiretoko fishers. A combination of fishing rights/licenses for species both increasing and decreasing in abundance will stabilize the fishers' total income and increase their economic resilience.

Hitherto, research on the economic implications of climate change on fisheries has been fragmentary (Hannesson *et al.*, 2006), and information and knowledge on adapting to climate change is limited (Brander, 2010). More economic analysis, in concert with the work of natural scientists, is clearly required.

Local and community support

In the Shiretoko WNH area, the fisheries sector is the most important source of job creation along with tourism. For example, >40% of workers in Rausu town are engaged in fisheries activity (Rausu Town, 2010). Therefore, establishing a fisheries system resilient to climate change, by introducing measures of adaptation such as those mentioned above, will lead to a corresponding increase in the resilience of such local communities.

Geographically, the Shiretoko Peninsula is mountainous, and almost all fishers and their families live along the coast or rivers. In addition, climate change is expected to increase the rainfall. The latest future projections of western North Pacific typhoons indicate that the frequency of typhoon generation will decrease, whereas the average instantaneous maximum wind velocity will increase (Murakami *et al.*, 2011). Hence, the risk of floods in the area where Shiretoko fishers reside will increase. However, the need to conserve salmonid pathways limits the opportunities for new dam construction on the rivers in the Shiretoko Peninsula (Nakamura and Komiyama, 2010). Also, a rise in sea level increases the risk of high tides and tsunamis (IPCC, 2007).

Hazard maps and evacuation plans have been drawn up by the town governments (for examples of both for Shari town, see http://www.town.shari.hokkaido.jp/02life/20bousai_yobou/20bousaimap/kouzui.html), and these are crucial in protecting the lives of local residents. However, at the moment, they do not incorporate the effects of climate change. Therefore, in the medium term, the maps and plans need to be revised according to climate-change scenarios. In the long term, land-use planning has to be investigated and revised to adapt to climate change.

Culture

In Hokkaido, indigenous people such as the Ainu have developed a local culture based on local ecosystem services. For the Ainu, salmon is "the fish of god" and important for their traditional ceremonies, arts, and food culture. However, as mentioned earlier, salmon numbers are expected to decline with climate change. Once extinguished, culture will not return. Moreover, and importantly, indigenous culture is of huge value in terms of cultural diversity and must therefore be protected by government policy. However, local culture has, by its nature, been linked closely to local ecosystem services. In other words, local culture is modifying with the changing environment. In that sense, we should not prevent the transformation of culture, or the creation of a new culture, as forms of adaptation to the changing ecosystems.

Historically, in the Shiretoko Peninsula, there was a hunter-gatherer culture called "Okhotsk culture" between the 5th and the 9th centuries. In the 14th and 15th centuries, Ainu culture, which is the direct inheritor of Okhotsk culture, developed in the area covering the Amur River basin, Sakhalin, and the northern Hokkaido area (Segawa, 2011). Therefore, one long-term adaptation option would be not only to conserve the existing Ainu culture, but to promote the development of an extended culture based on the LME, a so-called "Neo-Okhotsk" culture. Taking the territorial disputes over the LME into account, the UNESCO Heritage Programme could be a tool for such peaceful innovation (Crosby, 2007).

Discussion and conclusions

Cooperative research and monitoring at the scale of the LME (Russia and Japan) is the basis for all policy measures for adaptation. International scientific programmes can play a vital role in this respect. Local fishers are also required to monitor and report local-scale changes in the ecosystems. Based on these results, a variety of measures need to be combined, taking into account various socio-ecological aspects of fisheries (resource and ecosystem conservation, food provision, economic development, community support, and culture promotion).

This study concentrated mostly on fisheries, but there are many ecosystem services, other than fisheries resources, that have been enjoyed by the Shiretoko local people, as well as by the national population. Similar discussions are required regarding other sectors such as tourism. The effects on endangered species in the Shiretoko WNH area, such as the Steller sea lion and the white-tailed eagle, are also important issues that need to be addressed. Therefore, the adaptation strategy for climate change has to be an integrated strategy covering all related sectors and ecosystem services in the Shiretoko WNH area. Currently, in the Shiretoko WNH area, there is a cross-sector coordination system (Figure 2) and an Integrated Management Plan. To ensure widespread stakeholder participation and to increase the legitimacy of the measures of adaptation, it is both logical and reasonable to draft an integrated Climate Change Strategy under this existing management regime. However, the social resources for adaptation (human, financial, and organizational) are limited, so we need to set priorities among the measures of adaptation and to do that in a manner based on sound science, more research on social vulnerability is required (Perry *et al.*, 2010), particularly work involving social indicators, social thresholds, non-market values, and governance flexibility.

We outlined five principal aspects of Japanese fisheries management policy objectives as a framework for the discussion. However, the objectives of fishery management differ from country to country. For example, fish-exporting countries without a large domestic market might have considerably different objectives from those of a nation such as Japan. Comparison of adaptation strategies among high-latitude communities (McGoodwin, 2011) which have different management objectives would be a useful next step. Moreover, other ecosystems could have other issues requiring alternative measures of adaptation, so comparison of various types of ecosystem would be an important logical step towards a holistic understanding of humanity's adaptation to climate change.

Acknowledgements

The authors thank two anonymous reviewers for comments on earlier drafts, which significantly improved the paper. Also, the discussions at the Shiretoko World Natural Heritage Site Scientific Council and its Marine Area Working Group offered us valuable insights into the concept of adaptation. Finally, we wish to acknowledge the data and experienced opinions from three Fisheries Cooperative Associations (Rausu, Utoro, and Shari-daiichi), which are the very valuable base of our analysis.

References

Brander, K. 2010. Climate change and fisheries management. *In* Handbook of Marine Fisheries Conservation and Management, pp. 123–136. Ed. by R. Q. Grafton, R. Hilborn, D. Squires, M. Tait, and M. Williams. Oxford University Press, Oxford. 770 pp.

Crosby, M. P. 2007. Improving international relations through marine science partnerships. *In* Law, Science and Ocean Management, pp. 271–293. Ed. by M. H. Nordquist, R. Long, T. H. Heidar, and J. N. Moore. Martinus Nijhoff Publishers, Leiden. 850 pp.

Fisheries Agency and Fisheries Research Agency. 2010. Stock assessment report of Japanese amberjack in the fiscal year of 2010. http://abchan.job.affrc.go.jp/digests22/details/2241.pdf (in Japanese).

FRA (Fisheries Research Agency). 2009. The grand design of fisheries and resource management in Japan. http://www.fra.affrc.go.jp/kseika/GDesign_FRM/GDesign.html.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., *et al.* 2010. Food security: the challenge of feeding 9 billion people. Science, 327: 812–828.

Hannesson, R., Barange, M., and Herrick, S. F. (Eds). 2006. Climate Change and the Economics of the World's Fisheries. Examples of Small Pelagic Stocks. Edward Elgar, Cornwall. 310 pp.

IPCC (Intergovernmental Panel on Climate Change). 2007. IPCC Fourth Assessment Report: Climate Change 2007 (AR4). Cambridge University Press, Cambridge. 142 pp.

Irvine, J. R., and Fukuwaka, M. 2011. Pacific salmon abundance trends and climate change. ICES Journal of Marine Science, 68: 1122–1130.

Ito, S., Rose, K. A., Miller, A. J., Drinkwater, K., Brander, K. M., Overland, J. E., Sundby, S., *et al.* 2010. Ocean ecosystem responses to future global change scenarios: a way forward. *In* Marine Ecosystems and Global Change, pp. 287–322. Ed. by M. Barange, J. G. Field, R. P. Harris, E. E. Hofmann, R. I. Perry, and F. E. Werner. Oxford University Press, Oxford. 412 pp.

IUCN (International Union for Conservation of Nature). 2005. World Heritage Nomination. IUCN Technical evaluation report, Shiretoko (Japan). ID no. 1993. http://whc.unesco.org/archive/advisory_body_evaluation/1193.pdf.

Japan Meteorological Agency. 1947–2011. Statistics on sea ice at Abashiri Local Meteorological Observatory. http://www.jma-net.go.jp/sapporo/seaice/statistic/abashiri.pdf (in Japanese).

Kaeriyama, M. 2008. Ecosystem-based sustainable conservation and management of Pacific salmon. *In* Fisheries for Global Welfare and Environment, pp. 371–380. Ed. by K. Tsukamoto, T. Kawamura, T. Takeuchi, T. D. Beard, and M. J. Kaiser. Terrapub, Tokyo. 470 pp.

Kishi, M. J., Kaeriyama, M., Ueno, H., and Kamezawa, Y. 2010. The effect of climate change on the growth of Japanese chum salmon (*Oncorhynchus keta*) using a bioenergetics model coupled with a three-dimensional lower trophic ecosystem model (NEMURO). Deep Sea Research II, 57: 1257–1265.

Kurihara, H. 2008. Effects of CO_2-driven ocean acidification on the early developmental stages of invertebrates. Marine Ecology Progress Series, 373: 275–284.

Kuwahara, K., Aketa, M., Kobayashi, S., Takeshita, A., Yamasita, H., and Kido, K. 2006. The anticipated changes in habitats of Japanese fisheries resources by global warming. Chikyu Kankyo, 11: 49–57 (in Japanese).

MAFF (Ministry of Agriculture, Forestry and Fisheries). 2009. Food balance sheet of 2008. Nourin-Toukei-Kyokai, Tokyo (in Japanese).

MAFF (Ministry of Agriculture, Forestry and Fisheries). 2010. Annual statistics of fisheries and aquaculture production. Nourin-Toukei-Kyokai, Tokyo (in Japanese).

Makino, M. 2011. Fisheries Management in Japan: Its Institutional Features and Case Studies. Springer, Dordrecht. 200 pp.

Makino, M., Matsuda, H., and Sakurai, Y. 2009. Expanding fisheries co-management to ecosystem-based management: a case in the Shiretoko World Natural Heritage, Japan. Marine Policy, 33: 207–214.

Matsuda, H., Makino, M., and Sakurai, Y. 2009. Development of an adaptive marine ecosystem and co-management plan at the Shiretoko World Natural Heritage Site. Biological Conservation, 142: 1937–1942.

McGoodwin, J. R. 2011. Building resilience to climate change in high-latitude fishing communities; three case studies from Iceland and Alaska. *In* World Fisheries: a Social-Ecological Analysis, pp. 359–380. Ed. by R. E. Ommer, R. I. Perry, K. Cochrane, and P. Cury. Wiley-Blackwell, Oxford. 418 pp.

Megrey, B. A., Rose, K. A., Ito, S., Hay, D. E., Werner, F. E., Yamanaka, Y., and Aita, M. N. 2007. North Pacific basin-scale differences in lower and higher trophic level marine ecosystem responses to climate impacts using nutrient–phytoplankton–zooplankton model coupled to a fish bioenergetics model. Ecological Modelling, 202: 196–210.

Ministry of the Environment and Hokkaido Prefectural Government. 2007. The multiple use integrated marine management plan. http://shiretoko-whc.com/data/management/kanri/seawg_kanri_en.pdf.

Murakami, H., Wang, B., and Kitho, A. 2011. Future change of western North Pacific typhoons: projections by a 20-km-mesh Global Atmospheric Model. Journal of Climate, 24: 1154–1169.

Nagata, M. 2011. Sustainable use and conservation of Hokkaido salmon. Proceedings of Japan–Russia cooperative symposium on the conservation of Okhotsk ecosystems, Hokkaido University, Sapporo, 14–15 May 2011. 24 pp.

Nakamura, F., and Komiyama, E. 2010. A challenge to dam improvement for the protection of both salmon and human livelihood in Shiretoko, Japan's third Natural Heritage Site. Landscape and Ecological Engineering, 6: 143–152.

Ohshima, K. I., Mizuta, G., Itoh, M., Fukamachi, Y., Watanabe, T., Nabae, Y., Suehiro, K., *et al.* 2001. Winter oceanographic conditions in the southwestern part of the Okhotsk Sea and their relation to sea ice. Journal of Oceanography, 57: 451–460.

Ohshima, K. I., and Simizu, D. 2008. Particle tracking experiments on a model of the Okhotsk Sea: toward oil spill simulation. Journal of Oceanography, 64: 103–114.

Ono, T., Midorikawa, T., Watanabe, Y. W., Tadokoro, K., and Saino, T. 2001. Temporal increase of phosphate and apparent oxygen utilization in the subsurface waters of western Subarctic Pacific from 1968 to 1998. Geophysical Research Letters, 28: 3285–3288.

Perry, R. I., Ommer, R. E., Allison, E. H., Badjeck, M. C., Barange, M., Hamilton, L., Jarre, H., *et al.* 2010. Interactions between changes in marine ecosystems and human communities. *In* Marine Ecosystems and Global Change, pp. 221–242. Ed. by M. Barange, J. G. Field, R. P. Harris, E. E. Hofmann, R. I. Perry, and F. E. Werner. Oxford University Press, Oxford. 412 pp.

Radchenko, V. I., Dulepova, E. P., Figurkin, A. L., Katugin, O. N., Ohshima, K., Nishioka, J., McKinnell, S. M., *et al.* 2010. Status and trends of the Sea of Okhotsk region, 2003–2008. *In* Marine Ecosystems of the North Pacific Ocean, 2003–2008, pp. 268–299. Ed. by S. M. McKinnell, and M. J. Dagg. PICES Special Publication, 4. 393 pp.

Rausu Town. 2010. Town Directory of 2010. Rausu Town, Japan.

Rosa, A. L., Yamamoto, J., and Sakurai, Y. 2011. Effects of environmental variability on the spawning areas, catch, and recruitment of the Japanese common squid, *Todarodes pacificus* (Cephalopoda: Ommastrephidae), from the1970s to the 2000s. ICES Journal of Marine Science, 68: 1114–1121.

Sakurai, Y. 2006. How climate change might impact squid populations and ecosystems: a case study of the Japanese common squid, *Todarodes pacificus*. GLOBEC Report, 24: 33–34.

Sakurai, Y. 2007. An overview of the Oyashio ecosystem. Deep Sea Research II, 54: 2526–2542.

Sakurai, Y. 2009. Effects of global warming on fisheries resources. *In* Challenges of Agricultural Sciences on Global Warming, pp. 49–73. Ed. by Association of Japan Agricultural Scientific Societies. Youken-dou, Tokyo. 211 pp. (in Japanese).

Segawa, T. 2011. New perspective on Ainu history. *In* Revisiting the Ainu history, pp. 14–30. Ed. by H. Minoshima. Bensei-shuppan, Tokyo. 213 pp. (in Japanese).

Shari Fisheries History Editing Committee. 1979. Shari Fisheries History. Shari Town. 786 pp. (in Japanese).

UNESCO and IUCN (United Nations Educational, Scientific and Cultural Organization and International Union for the Conservation of Nature). 2008. Shiretoko Natural World heritage Site, Japan. The Report of the Reactive Monitoring Mission, 18–22 February 2008. http://whc.unesco.org/document/100685.

Yasuda, T. 2004. North Pacific Intermediate Water: process in SAGE (Subarctic Gyre experiment) and related projects. Journal of Physical Oceanography, 60: 385–395.

Handling editor: Audrey Geffen