4 National Approaches Used to Describe and Delineate Marine Ecosystems and Subregions in the North Pacific

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4.1 Introduction

With marine ecosystems facing increasing and often unsustainable human demands, the need for comprehensive, integrated cross-sectoral resource management becomes ever clearer (Duda and Sherman, 2002). Many hold that the most responsible strategy is ecosystem-based management (EBM), wherein factors such as ecological interactions, socio-economic forces and human impacts are explicit components of monitoring, assessment and policy. While EBM has been variously defined by many authors, some concepts are pervasive across all definitions: it is spatially discrete; it is adaptive; it incorporates dynamics, interactions and uncertainty associated with physical, chemical and biological constituents; it emphasizes sustainability; and it considers human objectives, activities and impacts to be essential components (Arkema *et al.,* 2006). Because accounting for spatially explicit trends, processes and relationships is a main component of EBM, it follows that the spatial characteristics of marine ecosystems should be identified in order to provide a context for identifying stakeholders, defining objectives, conducting research, and implementing policies focused on sustainable management of species, goods and services (Juda, 1999; FAO, 2003, NOAA, 2004).

The six member countries of PICES are all moving toward EBM of marine resources (section 2), and must therefore, identify and characterize discrete areas of marine waters at scales relevant to scientists, managers, policy makers and stakeholders. This challenge is complicated by several factors. First, abiotic and biotic components of ecosystems are inherently dynamic in space and time. This fact is especially important in ecosystems that are structured by major coastal or ocean currents, as is the case for many of the large marine ecosystems (LMEs) in the PICES region (*e.g.*, Sherman and Tang, 1999). Such spatio-temporal dynamics will likely be altered by global climate change, though in different ways in different areas of the North Pacific. Second, marine ecosystems typically extend hundreds of kilometers offshore and often beyond the exclusive economic zone (EEZ) of a country. In many cases, the EEZs of multiple nations occupy the same ecosystem, often adjoining along extensive international borders. This fact can limit the ability of a country to monitor the full spatial extent of the ecosystem beyond its own territory, which in turn limits understanding of overall ecosystem function, structure and change. A related problem is that different countries may have different monitoring practices or objectives within the same ecosystem, which complicates ecosystem-scale data synthesis and interpretation. Finally, because EBM is, by definition, a multisector endeavor (Arkema *et al.*, 2006), it must account for suites of diverse resources, some of which may have very different spatial distribution or organization than others.

The challenges outlined above must be addressed if integrated management of local and transboundary ecosystems is to be achieved by PICES countries. That necessity is underscored by the Food and Agriculture Organization (FAO) of the UN, which states that the first step of an ecosystem approach to fisheries management is to identify the fisheries and the geographic area in which they exist (FAO, 2003). The same general statement could be applied to EBM of any resource. In practice, the FAO (2003) acknowledges that identifying the geographic area is an adaptive and iterative process, given that ecosystems have ‘fuzzy’ boundaries, and can be defined and re-defined along a broad, subjective hierarchy of organization as information, objectives and management relationships evolve. Nevertheless, it is clearly important for PICES member countries to engage in defining the spatial extent of marine ecosystems in the PICES region.

In this section, we outline some of the current practices that PICES member countries use to delineate ecosystems and, in some cases, ecosystem subregions in their territorial marine waters. At the 2005 PICES Annual Meeting in Vladivostok, Russia, WG 19 members were asked to compile national approaches to delineating marine ecosystems and subregions and compare these to existing or planned management and data reporting delineations. National reports on this task are presented below, starting with the People's Republic of China and moving clockwise around the Pacific Rim. Members were also asked to identify cooperative and collaborative efforts by adjacent countries to study and manage cross-jurisdictional areas and resources, with the goal of establishing common spatial definitions. We describe such collaborations in the Discussion, and also examine factors that will both impede and facilitate future collaborations.

4.2 National Summaries

4.2.1 People's Republic of China

The territorial marine waters that lie east of the People's Republic of China are dominated by the Yellow Sea and the East China Sea. Both are large, relatively shallow seas that are semi-enclosed within an array of continental land masses, straits, peninsulas and islands (Fig. 4.2.1). Oceanic and coastal currents, intense storms, large river inputs and high human population densities add considerable dynamic complexity to these ecosystems and affect some of the world's most productive, heavily exploited fisheries (Chen and Shen, 1999). Both seas are shared by multiple nations.

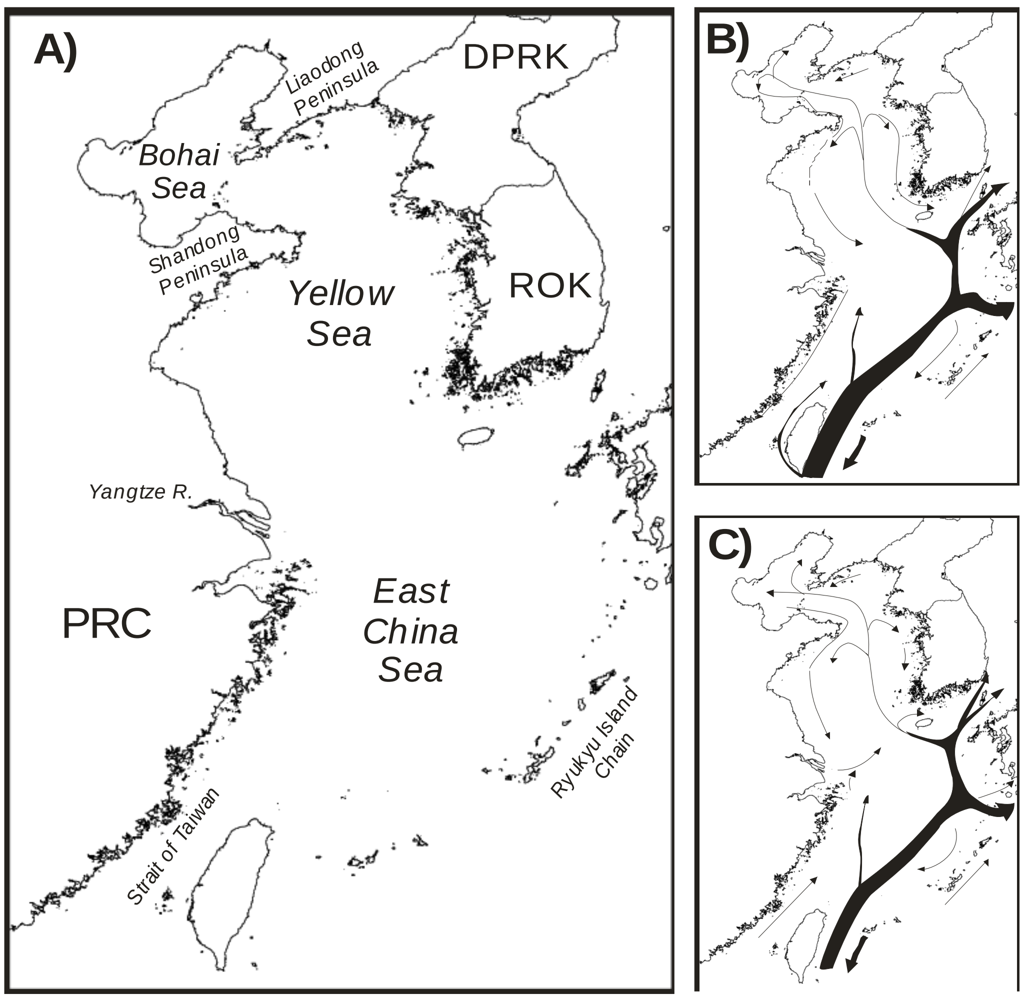

Fig. 4.2.1 Map of marine waters in PICES area waters off the coast of the People's Republic of China (PRC). Panel A shows general features; panels B and C show major currents in winter and summer, respectively (adapted from Chen and Shen, 1999).

Generally speaking, China has not formally defined or delineated marine regions or subregions, although its waters are broadly recognized as large marine ecosystems (LMEs) that are spatially defined by enclosing land masses (*e.g.*, Sherman and Tang, 1999; Sherman, 2006). The Yellow Sea LME is essentially bounded on the north and west by the Chinese mainland (north of the Yangtze River delta) and on the east by the Democratic People's Republic of Korea and the Republic of Korea. The Yellow Sea is quite shallow (mean depth $\bar{d}$ = 44 m) and lies entirely over the continental shelf. Its relatively cool, fresh waters are fed by several major rivers, including the Yangtze and Huang He. A major feature of the Yellow Sea is the Bohai Sea ($\bar{d}$ = 18 m), a large gulf formed by the Liaodong and Shandong peninsulas and heavily influenced by riverine inputs. The East China Sea LME is bounded approximately by the Yellow Sea, Korean Peninsula and Japanese island of Kyushu to the north, the Chinese mainland on the west, the island of Taiwan to the south, and the Ryukyu island chain to the east. At its eastern extent is the northerly flowing Kuroshio Current; its southern extent connects to the South China Sea LME through the Taiwan Strait. Compared to the Yellow Sea, the East China Sea is deeper ($\bar{d}$ = 270 m) and more variable bathymetrically, with 81% of its area over the shelf, 11% over continental slope, and the remainder over the deep Okinawa Trough to the west of the Ryukyu island chain. However, nearly all of China's Exclusive Economic Zone (EEZ) waters in the East China Sea are shallower than 150 m.

Although China has not formally delineated these waters, the spatio-temporal heterogeneity of physical, chemical and biological variables within the East China, Yellow and Bohai seas is well studied and widely documented (*e.g.*, Su, 1998; Chen and Shen, 1999). Fixed spatial delineations of these waters may be impossible due to the seasonal complexity of coastal and boundary currents in the Yellow Sea and East China Sea LMEs (Fig. 4.2.1). However, there are spatio-temporal generalizations that can be made. Li *et al.* (2006) examined over 70 years of oceanographic data from these waters and developed an index of 'spiciness' (the extent to which water is warm and salty); the equilibrium line (EL) of this index was intended to approximately differentiate the relatively cool, fresh, river-influenced Yellow Sea water mass from the East China Sea. Although the EL generally ran southwest from the southern coast of the Korean Peninsula to the Chinese mainland, its shape and stability were highly seasonal due to the dynamics of at least seven regional coastal and warm currents, the Kuroshio Current, and seasonal monsoons. Ultimately, they concluded that four major water masses (cold and dilute, warm and salty, mixed coastal, and mixed warm) exist in these two LMEs; the water masses are associated with certain currents and have distinct seasonal ontogenies (Li *et al.*, 2006). Su (1998) and Chen and Shen (1999) identified several other water masses within the East China Sea, seasonally defined by temperature, salinity and depth. Of note is a persistent mass of cool water near the bottom of the Yellow Sea (Su, 1998).

Similarly, empirical and statistical methods have been used to identify zones of distinct biological communities in relation to large-scale environmental variables. Chen and Shen (1999) concluded that zooplankton distributions in the East China Sea were controlled by the different water masses, with the highest zooplankton densities occurring near water mass convergences in the spring and summer. Jin *et al.* (2003) used a multivariate classification method to identify spatial and seasonal assemblages of commercially important fish in the Yellow and East China seas. They concluded that four distinct assemblages exist in spring, and four others in autumn. The assemblages were distinguished along two spatial axes: Yellow Sea *vs.* East China Sea and nearshore *vs.* offshore, based on environmental variables such as depth, temperature, salinity and dissolved oxygen (Table 4.2.1). The spatial arrangements, species compositions and dominance of pelagic *vs.* demersal species of the assemblages varied somewhat by season (Jin *et al.*, 2003), which underscores the spatio-temporally dynamic nature of these waters. Some of the differences in species composition relates to migratory species. For example, the aforementioned persistent cool water mass in the central to southern Yellow Sea (Su, 1998) provides an overwintering habitat for many commercially important, seasonally migratory species in the Yellow and Bohai seas, including small yellow croaker *Pseudosciaena polyactis*, largehead hairtail *Trichiurus lepturus*, Japanese anchovy *Engraulis japonicus*, penaeid shrimp *Penaeus orientalis*, and several mackerel species (Zhao, 1990). This water mass even supports large numbers of cold temperate species, including Pacific herring *Clupea pallasi* and a genetically isolated stock of Pacific cod *Gadus macrocephalus* (Grant *et al.*, 1987).

Table 4.2.1 Biological and environmental characteristics associated with major seasonal assemblages of commercially valuable fish in the Yellow and East China seas. The three most abundant species (by mass) in each assemblage are listed. Environmental data are means ± standard errors (Source: Jin *et al.*, 2003).

Assemblage	Key species	Depth (m)	T (ºC)	Salinity (psu)	DO (mg/L)
		Autumn, 2000			
AG1	*Harpodon nehereus, Pampus argentus, Setipinna taty*	33.4 ± 2.2	20.1 ± 0.3	31.8 ± 0.2	7.2 ± 0.1
AG2	*Engraulis japonicus, Liparis tanakae, Lophius litulon*	66.5 ± 3.7	11.5 ± 1.1	32.5 ± 0.1	6.6 ± 0.2
AG3	*Pseudosciaena polyactis, Trichiuris lepturus, Harpodon nehereus*	62.8 ± 2.9	20.7± 0.4	33.9 ± 0.1	6.0 ± 0.3
AG4	*Trachurus japonicus, Trichiuris lepturus, Psenopsis anomala*	104.0 ± 5.5	19.1 ± 0.5	34.4 ± 0.1	5.2 ± 0.2
		Spring, 2001			
SG1	*Lophius litulon, Pseudosciaena polyactis, Cleisthenes herzensteini*	50.6 ± 7.7	7.2 ± 0.3	32.2 ± 0.1	10.4 ± 0.1
SG2	*Pseudosciaena polyactis, Engraulis japonicus, Thryssa kammalensis*	57.4 ± 2.7	9.8 ± 0.3	32.9 ± 0.1	10.1 ± 0.1
SG3	*Acropoma japonicum, Engraulis japonicus, Trichiurus lepturus*	79.5 ± 3.4	17.7 ± 0.6	34.2 ± 0.1	7.7 ± 0.3
SG4	*Acropoma japonicum, Pagrosomus major, Seriola aureovittata*	116.6 ± 6.4	17.8 ± 0.4	34.5 ± 0.0	7.1 ± 0.3

4.2.2 Republic of Korea

The Republic of Korea is surrounded by three large, dynamic semi-enclosed seas, each of which is considered an LME (Sherman, 2006). East of the Korean Peninsula lies the East Sea, to the west is the Yellow Sea, and to the south is the East China Sea (Fig. 4.2.2; Huh and Zhang, 2005). All three ecosystems extend well beyond the EEZ of Korea. General characteristics of the Yellow and East China seas were outlined above in the National Summary for China. The East Sea is considerably deeper ($\bar{d}$ = 1700 m) than either of the other LMEs. Korean waters in the East Sea are strongly influenced by the North Korea Cold Current, part of the southerly flowing Liman Current that originates in the Sea of Okhotsk; and by the Tsushima Warm Current which moves north through the Korea Strait and causes upwelling along the east of the Korean Peninsula. These currents meet near the 40ºN parallel, creating a strong frontal region (Rebstock and Kang, 2003).

Delineation of Korean waters has been done primarily based on oceanographic characteristics. For decades, National Fisheries Research and Development Institute (NFRDI) researchers have surveyed seasonal oceanographic data (*e.g.*, temperature, salinity, seawater density, and zooplankton biomass at surface and 50-m depths) in the three seas (*e.g.*, Zhang *et al.*, 2000; Rebstock and Kang, 2003). Principal components analysis (PCA) and artificial neural network (ANN) analysis of these data revealed transitions among water masses (Zhang *et al.*, 2000; J. B. Lee, NFRDI, unpublished data). For example, the analyses spatially distinguished the relatively cool, fresh, river-influenced waters of the Yellow Sea from the warmer, saltier waters of the East China Sea and the even saltier, denser waters of the East Sea. Seasonal, interannual, interdecadal and stochastic climate variability is very important in determining the size and strength of current and frontal systems in this area (Zhang *et al.*, 2000; Rebstock and Kang, 2003). Surveys also reveal strong differences in the zooplankton communities; for example, chaetognaths have dominated the Yellow Sea zooplankton community since the 1980s, while copepods were most prevalent in the other seas (Rebstock and Kang, 2003).

Delineation of the LMEs in Korean waters has also been informed by the differences among fish communities (Kim, 2003; Rebstock and Kang, 2003). Importantly, many common fish species such as small yellow croaker and largehead hairtail move freely between the Yellow and East China seas. Thus, those regions may be most appropriately viewed as distinct but interconnected LMEs in terms of the conservation and management of some marine resources. In Korean waters of the East Sea, both cool water demersal and warm water pelagic fisheries are present, largely separated by the frontal region described by Rebstock and Kang (2003). Prominent fisheries in recent decades have included saury (*Cololabis saira*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*) and, more recently, mackerel and squid (*Todarodes pacificus*) (Park *et al.*, 1998; Zhang *et al.*, 2000) since an apparent regime shift in the late 1980s that brought warmer water into the East Sea.

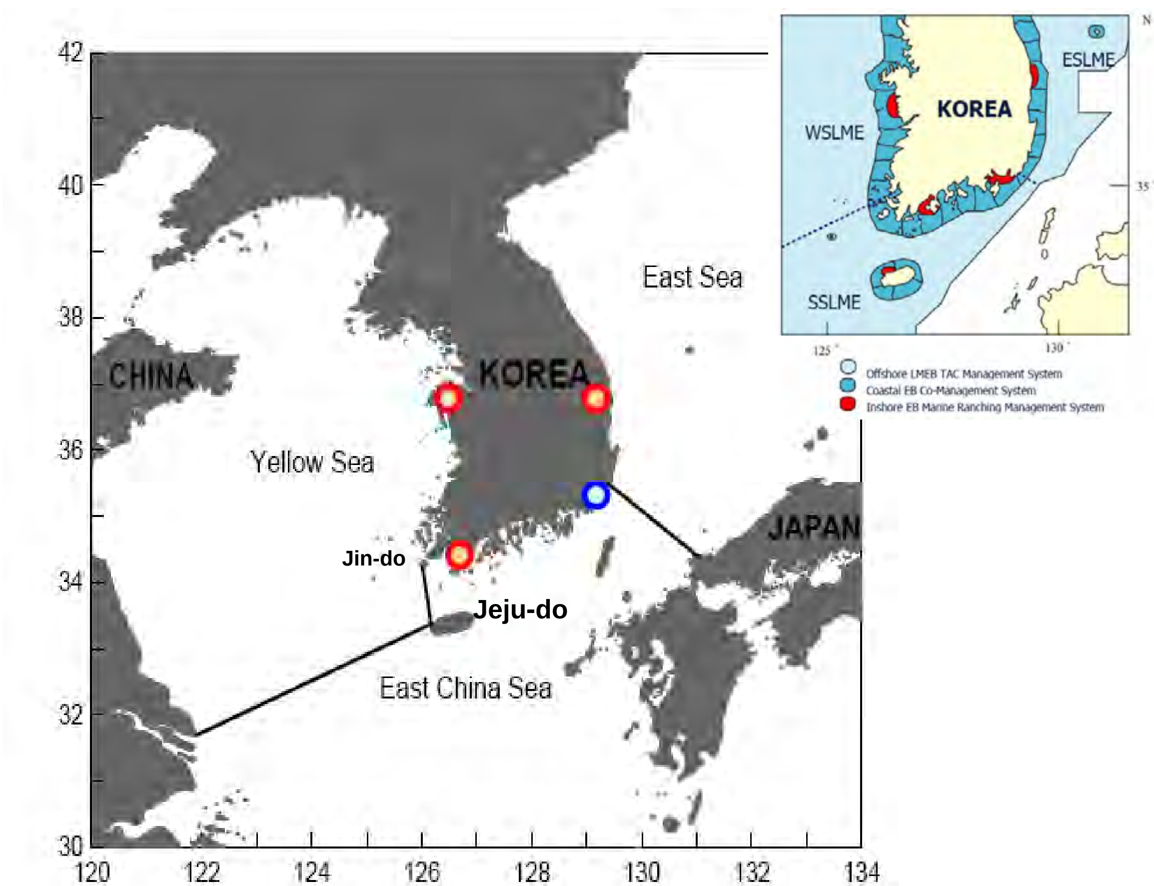

Fig. 4.2.2 Delineation of marine regions in the Republic of Korea waters. Inset represents offshore, coastal, and inshore regions proposed by Huh and Zhang (2005).

For management purposes, marine waters of Korea have been divided into subregional management zones by many different government agencies using geographic, meteorological, oceanographic and biological criteria. We will follow the management zonation scheme proposed by NFRDI. At the coarsest scale, NFRDI recognizes three general categories of management zones that are essentially defined by their distance from the coastline (Fig. 4.2.2): offshore zones, which extend to the EEZ limit; coastal zones around the mainland and large islands, such as Jeju-do and Ulleung-do; and inshore zones – tidal flats, bays and lagoons where marine ranching occurs. Further delineation of these zones is described below.

There are three offshore zones in Korean waters, which are spatially consistent with the three LMEs around the Korean Peninsula (Fig. 4.2.2). Resource management decisions in the offshore zones are made by the central government of Korea. Management in offshore zones is supported by scientific research by regional institutes of NFRDI, in the form of regular surveys of oceanographic and biological variables and quantitative assessments of fishery resources. In the Yellow and East China seas (Fig. 4.2.2; also see the People's Republic of China National Summary) the offshore zones extend from the coastal zone to the seaward extent of the EEZ. The NFRDI line that marks the transition from the East China Sea offshore zone to the Yellow Sea offshore zone extends from the island of Jin-do (near the southwest tip of the Korean Peninsula) to Chagui Island (near Jeju-do) and then across to the mouth of the Yangtze River (China). This line is geographically consistent with the transition between the two LMEs predicted by the ANN analysis (see above). NFRDI divides the waters in the Korea Strait between Korea and Japan along a line between Ulgi Lighthouse (southeast coast of Korea) and the southwest tip of Honshu (Japan). The remainder of this offshore zone is delineated by the extent of the EEZ.

Coastal zones around Korea (Fig. 4.2.2) are managed in a largely self-regulatory manner by local stakeholders in the adjacent metropolitan area or county. Management is supported with information provided by both local governments, which may conduct their own resource monitoring and assessment programs, and by the central government. The seaward extent of coastal zones (and thus of coastal management practices) may be on the verge of change: coastal zones have traditionally been defined as waters to which fishing vessels could sail and still return to their home port on the same day, but the speed of modern vessels necessitates a more concrete means of delineation. For example, some have suggested delineating the coastal zone as waters inside a fixed distance from the shore (analogous to the 3-nautical mile (~5.56 km) nearshore zone in U.S. waters which is primarily managed by individual states), although the distance that Korea would use is under debate.

Finally, there are several regions, designated 'inshore waters' by NFRDI, that are used for marine ranching (Fig. 4.2.2). Marine ranching in Korea began with the Tongyeong marine ranching project on the southeastern coast in 1998, following several decades of overfishing and environmental degradation related to intensive aquaculture and heavy coastal development (OECD, 2003). Marine ranching is a process by which specific coastal fisheries are enhanced through science-based restoration programs such as stocking key life history stages of target species, habitat enhancement, pollution control and prevention of overfishing. The management of inshore waters is self-regulatory. Management decisions are made by a fishery committee comprised of the leaders of local fishery cooperatives and advised by scientists and central government representatives (OECD, 2003). Scientists conduct regular surveys and assessments of the target resources to ensure that the decision process is well-informed. The spatial extents of marine ranching areas have been determined through negotiation and joint agreement by scientists, stakeholders, and fishery committees.

4.2.3 Japan

Marine waters around the perimeter of Japan are dominated by major ocean current systems, semi-enclosed seas, and open coast (Fig. 4.2.3). The Japanese approach to ecosystem definition and delineation explicitly distinguishes pelagic ecosystems, which are dominated by the dynamics of the circulation regimes, and demersal ecosystems, which are somewhat more fixed and characterized by the bathymetry of the seas and coastlines.

The coastal and ocean currents around Japan create four different pelagic regions that can be characterized generally in space (Fig. 4.2.3), although their inherently dynamic nature makes precise delineations difficult. Two pelagic regions derive

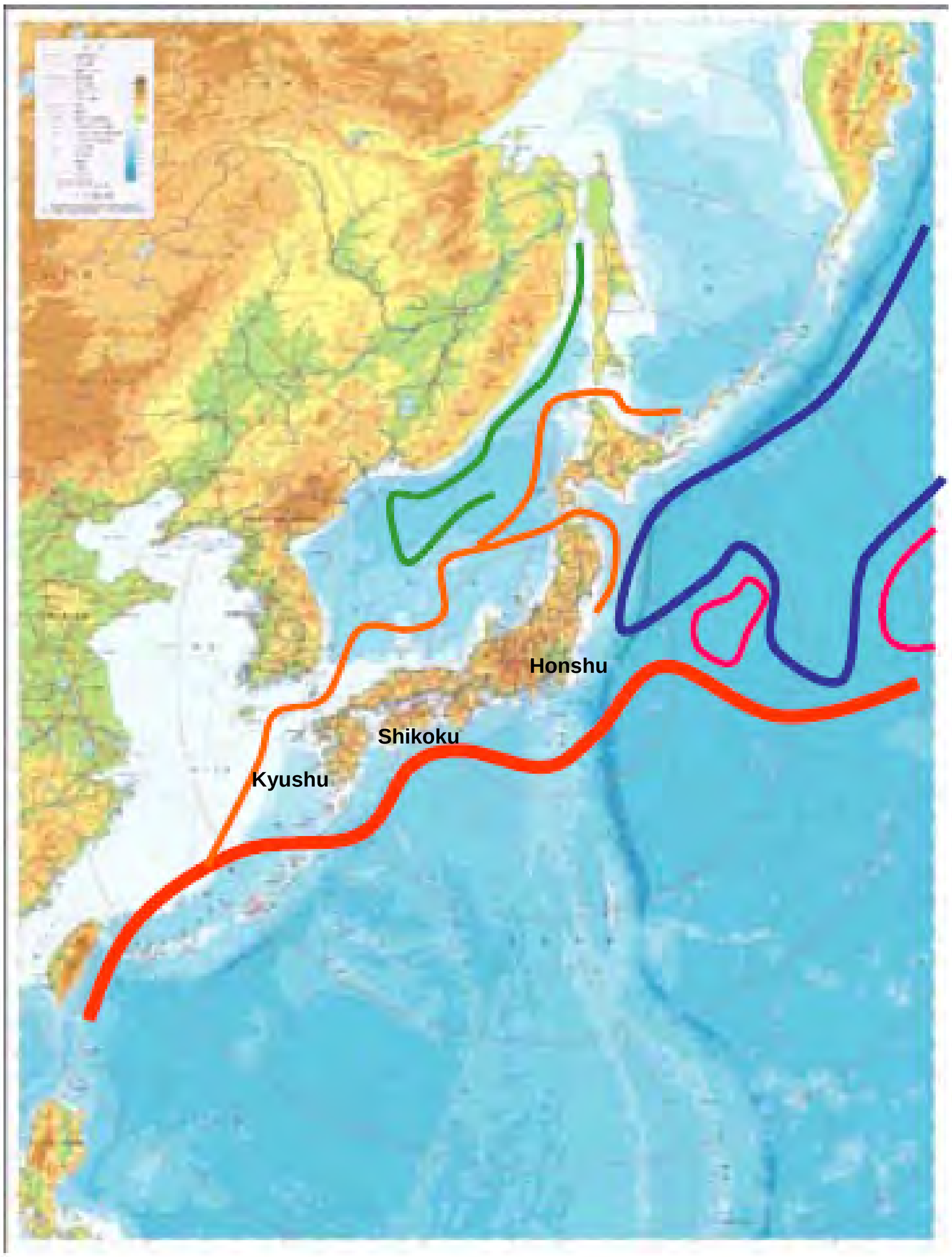

Fig. 4.2.3 Delineation of marine regions in Japanese waters (Tatsu Kishida, pers. comm.).

from the Kuroshio Current, which flows northeast from the East China Sea toward the island of Kyushu. Before reaching Kyushu, much of the current turns east-northeast and forms a boundary current, known as the Kuroshio Extension, that constitutes one pelagic region along the southeast coasts of Kyushu, Shikoku and Honshu. The smaller Tsushima Current breaks off from the Kuroshio Current and forms a second pelagic region. It flows northeast between Japan and the Korean Peninsula, moves along the west coast of Kyushu and Honshu, and then moves clockwise around the northern tip of Honshu, through the Tsugaru Strait, and southward along the east coast of Honshu. The Tsushima Current is warmer and more nutrient-poor than the southerly flowing cold currents on the western side of the Japan Sea, and exhibits 6-year cycles of variability in its flow path (Terazaki, 1999). A third pelagic region is formed by the Oyashio Current LME in northeastern Japanese waters. The Oyashio Current brings colder, fresher water southwest from the Bering Sea and Kamchatka regions to the east coasts of Hokkaido and Honshu, and then partly recirculates counterclockwise and back to the northeast (Yasuda, 2003). The fourth pelagic region is formed by a portion of the Oyashio Current that continues south and meets the Kuroshio Extension. This junction is known as the Kuroshio-Oyashio Transition Area, a complex mixed-water region influenced by numerous interacting currents, fronts and mesoscale eddies (Yasuda, 2003).

The distinctive oceanographic characteristics of the four pelagic regions support characteristic fauna that further help to distinguish the regions from adjacent waters. The spatial differences in the regions are not simply two-dimensional. Zooplankton species composition, a key indicator of the dominant current in an area, varies by depth as well as by latitude and longitude. In particular, there appear to be region-specific crustacean zooplankton communities above and below 200 m depth (Table 4.2.2); these communities are made up of species generally associated with particular ocean zones (neritic, oceanic, mesopelagic, bathypelagic) and/or climatic regions (subarctic, subtropical, tropical).

As with crustacean zooplankton, certain gelatinous zooplankton, squid, and pelagic fish are associated with the pelagic regions (Table 4.2.2), and their distributions can thus help to define the extent of the regions. For example, the giant jellyfish *Nemopilema nomurai* is most closely associated with waters of the Tsushima Current. Japanese common squid *Todarodes pacificus* which spawn during the fall are also common in the Tsushima Current, although the winter-spawning common squid population is spatially ubiquitous in Japanese waters. Several fish species associated with warmer currents spawn in the southwestern portion of the Kuroshio Current and then move either into the Tsushima Current or along the Pacific Ocean side of the islands. These species include Japanese sardine *Sardinops melanostictus*, chub mackerel *Scomber japonicus* and jack mackerel *Trachurus japonicus*; for management purposes, the Tsushima and Pacific groups are treated as separate 'stocks' although there is little evidence of genetic differentiation. The Pacific stock of chub mackerel uses northerly regions extensively, with large feeding grounds in the Oyashio and Transition Area regions. Yearling jack mackerel from the Pacific stock are highly dependent on food resources in the Transition Area.

Demersal zones around Japan are delineated into six regions which are defined in more precise spatial terms than the pelagic zones. These spatial delineations derive from bathymetric and zoogeographic features. Important among these are the channels that separate the major seas in the area (Fig. 4.2.3). The Tsushima/Korea Strait forms a natural separation between the demersal regions in the relatively shallow East China Sea and the western waters of Kyushu and Honshu. The east side of the Soya Channel in the north marks the beginning of the Sea of Okhotsk. Other significant large-scale zoogeographic features include Noto-hanto, a northward-pointing peninsula on the west coast of Honshu in the waters of the Tsushima Current, and Inobu-saki, a peninsula at 35º42′ N latitude on Honshu, which marks the point at which the island angles sharply to the north and the southwest and is considered the breakpoint between the two demersal regions on the east (Pacific) coast of the main islands. The significance of these two features as zoogeographic boundaries is clear from the differences in demersal fish and invertebrate communities that are targeted by commercial fisheries on either side of them (Table 4.2.3). On the east coast north of Inubo-saki, and on the west coast north of Noto-hanto, cold-water species are prevalent (in particular, walleye pollock *Theragra chalcogramma*). Southwest of these points, the composition of major commercial species shifts. The demersal community shifts further upon moving into the East China Sea, where shallow warm-water species prevail.

Table 4.2.2 Key indicator species associated with pelagic regions around Japan.

Fauna	Pelagic ecoregion: Tsushima	Kuroshio Extension	Oyashio	Transition Area
Zooplankton, < 200 m depth	ST/N, ST/O	T/O, ST/O, ST/N	SA	SA, ST/N, ST/O
Zooplankton, > 200 m depth	SA	MP, BP	MP, BP	MP, BP
Giant jellyfish	x	–	–	–
Common squid (fall stock)	x, spawn	–	–	–
Sardine (Pacific stock)	–	x, spawn	x	x
Sardine (Tsushima stock)	x	x, spawn	–	–
Chub mackerel (Pacific stock)	–	x, spawn	x	x
Chub mackerel (Tsushima stock)	x, spawn	–	–	–
Jack mackerel (Pacific stock)	–	x, spawn	–	x*
Jack mackerel (Tsushima stock)	x, spawn	–	–	–

Zooplankton are classified by climate zone (T = tropical, ST = subtropical, SA = subarctic) and/or ocean zone (N = neritic, O = oceanic, MP = mesopelagic, BP = bathypelagic). For other groups, 'x' indicates that the species is common, and 'spawn' signifies an important spawning area.
*Mainly a feeding ground for yearlings

Table 4.2.3 Key demersal fishery species in marine waters around Japan.

Coastal region	Geographic reference	Common name	Scientific name
East	N of Inubo-saki	Walleye pollock	*Theragra chalcogramma*
		Pacific cod	*Gadus macrocephalus*
		Saffron cod	*Eleginus gracilis*
	SW of Inubo-saki	Deep-sea smelt	*Glossanodon semifasciatus*
		Big-eyed greeneye	*Chlorophthalmus albatrossis*
West	N of Noto-hanto	Walleye pollock	*Theragra chalcogramma*
		Atka mackerel	*Pleurogrammus monopterygius*
	SW of Noto-hanto, inshore	Sailfin sandfish	*Arctoscopus japonicus*
		Pointhead flounder	*Cleisthenes pinetorum*
		Flathead flounder	*Hippoglossoides dubius*
		Korean flounder	*Glyptocephalus stelleri*
	SW of Noto-hanto, offshore	Deep-sea smelt	*Glossanodon semifasciatus*
		Snow crab	*Chionectes* spp.
		Pink shrimp	*Pandalus borealis*
Southwest	East China Sea	Swordtip squid	*Loligo edulis*
		Largehead hairtail	*Trichiurus lepturus*
		Lizardfish	*Saurida* spp.
		Japanese butterfish	*Hyperoglyphe japonica*
		Japanese meagre	*Argyrosomus japonicus*
		Small yellow croaker	*Larimichthys polyactis*

Thus, pelagic and demersal regions in the Japanese EEZ are generally defined by oceanographic patterns, bathymetry and species assemblages. However, in coming years it is possible that Japanese waters will be further (and more precisely) subdivided, based on jurisdictional boundaries. Fishery resource management in Japan was long handled by self-regulating limited-access fisheries, rather than formally managed by government management agencies, but that is changing. Science-based fisheries management advice is currently generated both at local scales, by prefecture governments, and at the national level, by the Ministry of Agriculture, Forestry and Fisheries (MAFF). Policy implementation at local scales may induce spatial changes in community structure or productivity within a region. For example, in the 1990s the Akita Prefecture (north of Noto-hanto) initiated several successful actions to rebuild the population of sailfin sandfish *Arctoscopus japonicus*, including fishery closures, stock enhancement and spawning habitat improvements.

4.2.4 Russia

Russian territorial waters in the Far Eastern seas (Fig. 4.2.4) and adjacent waters of Pacific Ocean occupy part or all of four LMEs in the PICES region: the Western Bering Sea, the Sea of Okhotsk, the Sea of Japan/East Sea and the Oyashio Current (Sherman *et al.*, 2007). The Far Eastern seas are critical to the nation's fishing industry, averaging over 70% of total Russian fish and shellfish production between 2000–2005 (Sinyakov, 2006) despite accounting for just under 43% of the whole of the Russian EEZ. Historically, a variety of criteria have been used to geographically delineate the Russian EEZ into fisheries management regions (FMRs) and ecological districts although the integration and overlap of those delineations is somewhat limited.

At the largest scale, Russian FMRs are based on FAO Major Fishing Areas, which delineate major geographic complexes of fisheries. Based on the spatial distributions of key commercial target species for Russian fleets (Karedin, 2001), the Major Fishing Areas were first divided into smaller FMRs and sub-areas in 1975, prior to global establishment of EEZs. The basic idea of FMR delineation was that a spatial unit would encompass the area inhabited by one commercial fishery stock, corresponding to a biological population. It was assumed that this method of delineation would also sufficiently encompass the key distributional features of other species about which less was known. Further study of population structure, seasonal migrations, and ontogenetic migrations of key commercial species led to a refinement of FMR delineations, first in 1980 and again in 1988, although to some extent they still reflected the original single-species framework. The refined FMR patterns were also established to account for the potential spatial limitations of fisheries following the establishment of EEZs. The current FMR pattern, established in 1989, is the most elaborate (Fig. 4.2.4), although the changes relative to prior FMR patterns were not done, based on scientific analyses or recommendations. Rather, they were adopted according to the initiative of the State Industrial Fisheries Association (Dalryba) to solve discrepancies between stakeholders in the Sakhalin, Kamchatka and Magadan regions.

Prior to the 1980s, Russian studies of commercially fished species were single species in nature. Biological and statistical information was primarily summarized and compared across existing FMR units, or was pooled at the scale of larger geographic regions (*e.g.*, regional seas). The concept of delimiting the Far Eastern seas into ecological districts arose in the 1980s, stemming from oceanographic studies of biological productivity. In early research on the ecological differentiation of global ocean habitats, Russian oceanographers introduced the term 'natural oceanic region' to describe an area with relatively homogeneous climatic, hydrologic and chemical conditions, which formed the backdrop for biological processes, community structure and ecosystem function (Muromtsev and Gershanovich, 1986; Gershanovich *et al.*, 1990; Shuntov, 2001).

In the 1980s, Dr. Vjatcheslav Shuntov of the Pacific Research Institute of Fisheries and Oceanography (TINRO-Center), Vladivostok suggested division of the Far Eastern seas and adjacent Pacific Ocean waters into biostatistical districts (Fig. 4.2.5) in order to better integrate community ecology, ecosystem and applied fisheries research. This system of delineation was facilitated by studies of surface water circulation patterns, bottom relief, and distribution of water masses, identified by thermal and salinity characteristics. The proposed system of biostatistical districts was broadly accepted by the scientific community, and has been permanently adopted for all TINRO-Center reports as well as in hundreds of scientific articles and at least five monographs on community and ecosystem themes (Shuntov *et al.*, 1993; Shuntov, 1998, 2001; Dulepova, 2002; Ivanov and Sukhanov, 2002).

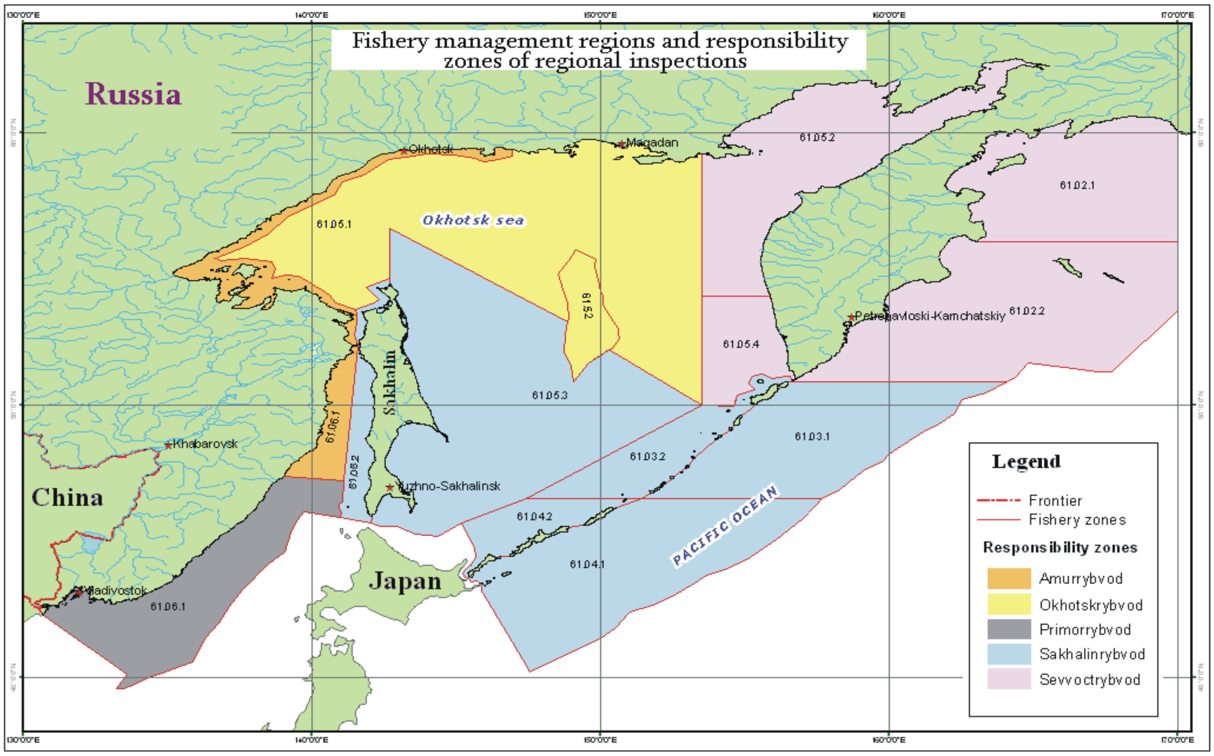

Fig. 4.2.4 Delineation of fishery management regions (FMRs) in the Russian Far Eastern seas, according to the 1989 delineation scheme (Karedin, 2001).

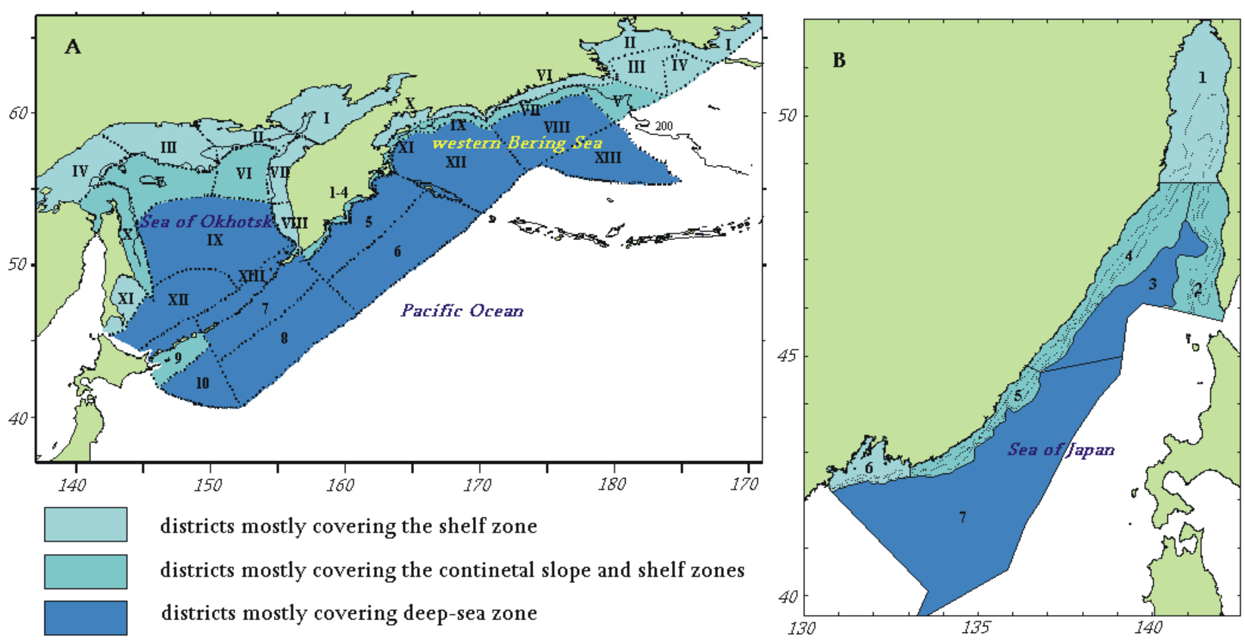

Fig. 4.2.5 Delineation of biostatistical districts in the Russian Far Eastern seas (Panel A, Vladimir Radchenko, pers. comm.; panel B, Volvenko and Kafanov, 2006).

The biostatistical districts in Russian EEZ waters can be pooled into three general groups: Western Bering Sea districts, Sea of Okhotsk districts and Pacific Ocean districts. The Western Bering Sea has 13 biostatistical districts that lie over the inner shelf (mean depth $\bar{d}$ <80 m), the outer shelf and slope ($\bar{d}$ = 209–356 m), and deep-sea domains ($\bar{d}$ = 2745–3577 m). Region XIII extends to a central portion of the sea, adjacent to a body of water that lies beyond the EEZs of either Russia or the U.S. (the so-called 'Donut Hole'). The Sea of Okhotsk has 14 districts, most of which cover continental shelf ($\bar{d}$ = 101–273 m) or slope ($\bar{d}$ = 343–503 m). Additionally, two districts adjacent to the Kuril Islands chain cover narrow insular shelf and slope but also a considerable amount of deep-sea waters ($\bar{d}$ = 1607 and 2171 m), and two districts in the central part of the sea have $\bar{d}$ of 1122 and 2934 m. The Pacific Ocean districts lie along the eastern side of the Kamchatka Peninsula and Kuril Islands (Fig. 4.2.5a), and also in Russian waters of the northwestern part of the Sea of Japan (Fig. 4.2.5b, Volvenko and Kafanov, 2006). Ten districts lie off the Kamchatka Peninsula and Kuril Islands, half of which cover shelf and slope ($\bar{d}$ = 107–420 m), and half of which cover deep-sea habitat ($\bar{d}$ = 2879–5118 m). Another seven districts in the northwestern portion of the Sea of Japan (Volvenko and Kafanov, 2006) correspond to shelf ($\bar{d}$ = 99–141 m), shelf/slope ($\bar{d}$ = 296–368 m), or deep sea ($\bar{d}$ = 1427–2879 m). Spatially aggregating data in these districts was faciliated by Volvenko (2003) who calculated the areas inside the 100-, 200-, and 500-m isobaths for all 44 districts. Quantitative information on the nekton species distribution and abundance in these waters has been calculated and published as a series of atlases and tables (most recently Shuntov and Bocharov, 2006a,b).

Although it was hoped that the biostatistical districts would be used to spatially integrate basic and applied research, in practice they have not been used for fisheries management despite their potential usefulness for applications such as area closure measures. The 1989 FMR delineations (Fig. 4.2.4) are still generally applied for that and other fishery management purposes. Some changes to the current FMR pattern were suggested by an ichthyofaunal zoning analysis by Karedin (2001) but were not adopted. Similarly, a recent ichthyofaunal zoning study of the northwestern Sea of Japan revealed spatial similarities to the biostatistical districts (Volvenko and Kafanov, 2006) and implied a much greater degree of spatial heterogeneity in the fish communities than that of the FMR pattern. There have been some recent changes to the existing FMR delineation, related to coastal fishery formalization. In late 2004, a new federal law allocated quotas to Russian coastal fisheries, distinguishing them from commercial fishery quotas; coupled with the new coastal allocation was the establishment of new coastal fisheries zones which extend from the coastline to just over 22 km (12 nautical miles) offshore within Russian territorial waters. Although fishers from coastal communities have appealed for the expansion of this zone, changes are not foreseen in the near future.

4.2.5 United States of America – Alaskan Waters

Continuing clockwise around the North Pacific Rim, we next come to the U.S. Because U.S. territorial waters are geographically separated by Canada, we will treat the northerly waters (Alaska) and the southerly waters (Pacific Coast) separately, with the Canada section in between. Before describing Alaska, we offer a brief overview of the U.S. approach to marine ecosystem delineation, which will serve as a backdrop for both reports from the U.S.

The U.S. is engaged in an ongoing process of developing criteria to facilitate management of ecosystem components that exist at different scales, are managed by multiple agencies, and are valued by diverse stakeholders. The National Oceanic and Atmospheric Administration (NOAA), which is the primary agency responsible for stewardship of coastal and ocean resources, appointed a working group to solicit guidance from within NOAA and from other federal, regional and state organizations on various science-based ecosystem delineation schemes (NOAA, 2004). This group generally supported the use of LMEs to delineate ecosystems in the U.S. EEZ (Fig. 4.2.6), and endorsed use of the main classification criteria that define LMEs (bathymetry, hydrography, productivity and trophodynamics). Ecosystems in the PICES area that result from this delineation approach are: Alaska ecosytem complex (Eastern Bering Sea/Aleutian Islands, and the Gulf of Alaska), the California Current, and portions of the Insular Pacific Islands, which are primarily in the central and eastern tropical Pacific and extend into the Southern Hemisphere. The NOAA working group explicitly recognized that international cooperation would be necessary to achieve an ecosystem approach to management in some of these areas (NOAA, 2004).

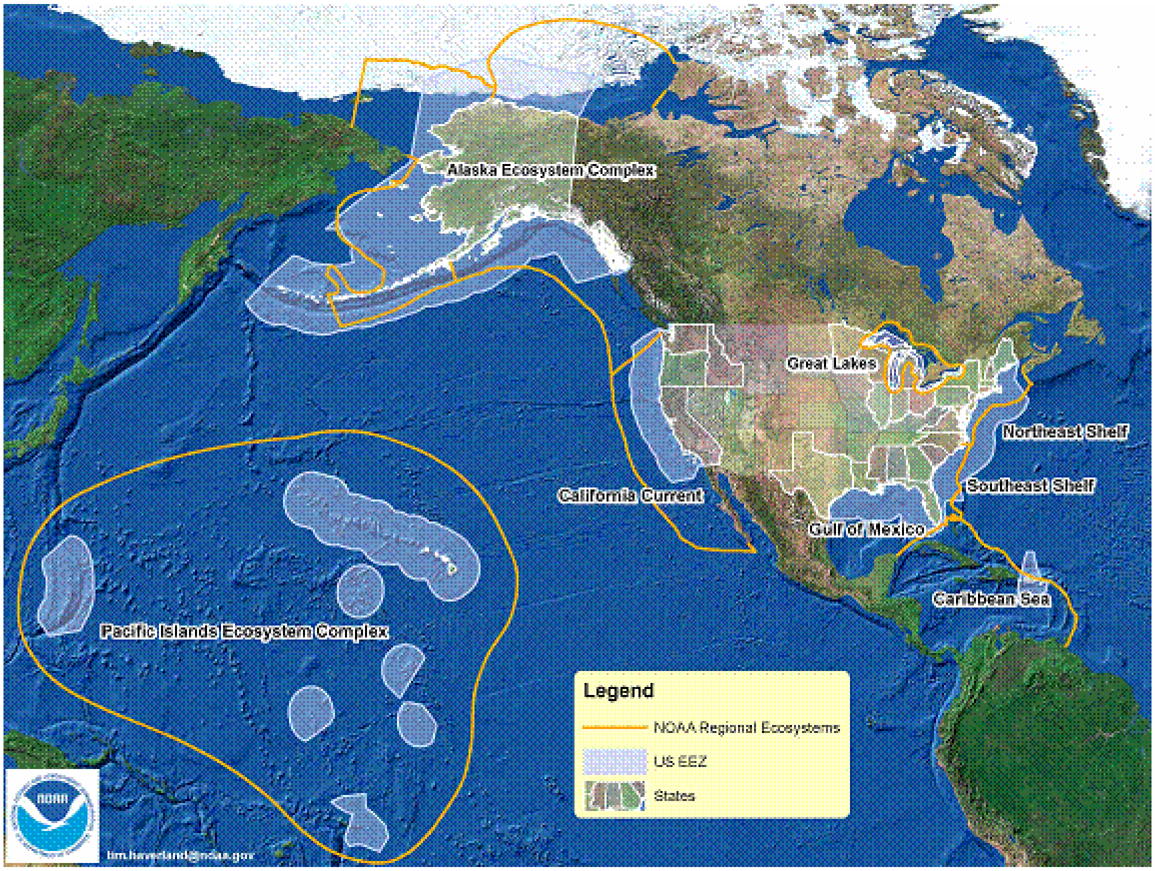

Fig. 4.2.6 U.S. large marine ecosystem (LME) boundaries derived from a regional ecosystem delineation workshop held by the NOAA Regional Ecosystem Delineation Working Group in Charleston, South Carolina, August 31–September 1, 2004 (NOAA, 2004; http://www.nmfs.noaa.gov/pr/sars/improvement/pdfs/ecosystem_delineation.pdf).

The working group also identified the need to delineate subregions in each of the LME-level ecosystems. A workshop convened in 2005 began the process of subregional delineation (Wendy Gabriel, NOAA, Northeast Fisheries Science Center, Woods Hole, MA, pers. comm.). It produced a draft list of four general criteria for defining and describing subregions: bottom topography and physiography; circulation and oceanography; biological characteristics; and characteristics of the coastal area, inland extent, watershed, and marine catchment. These criteria were similar to the LME boundary criteria, but also included the additional criterion of the inland extent of the marine ecosystem. The criteria were proposed to be established at two levels: a national minimum standard, such that a general level of consistency would be used to define subregions throughout U.S. LMEs, regardless of whether they are data-rich or data-poor; and regionally essential criteria that are relevant to specific LMEs. No further action has resulted from the initial workshop. However, there is wide recognition that final delineation will need to occur at the subregional level, and that delineation decision-making will include input from regional stakeholders.

Alaska is bounded to the north by the Arctic Ocean, to the south by the Pacific Ocean, and to the west by a large semi-enclosed sea (Fig. 4.2.7); the vast EEZ around Alaska extends into four different LMEs: the Eastern Bering Sea, Gulf of Alaska, Chukchi Sea and Beaufort Sea (Sherman, 2006), the first two of which are in the PICES region. Several major currents and frontal regions influence Alaskan waters, with intensity that varies seasonally, annually and decadally. Its highly complex coastline extends for nearly 10,700 km. In many places, its jurisdiction extends to international boundaries with Russia or Canada. For these and other reasons, defining and delineating subregions in Alaskan waters is particularly challenging.

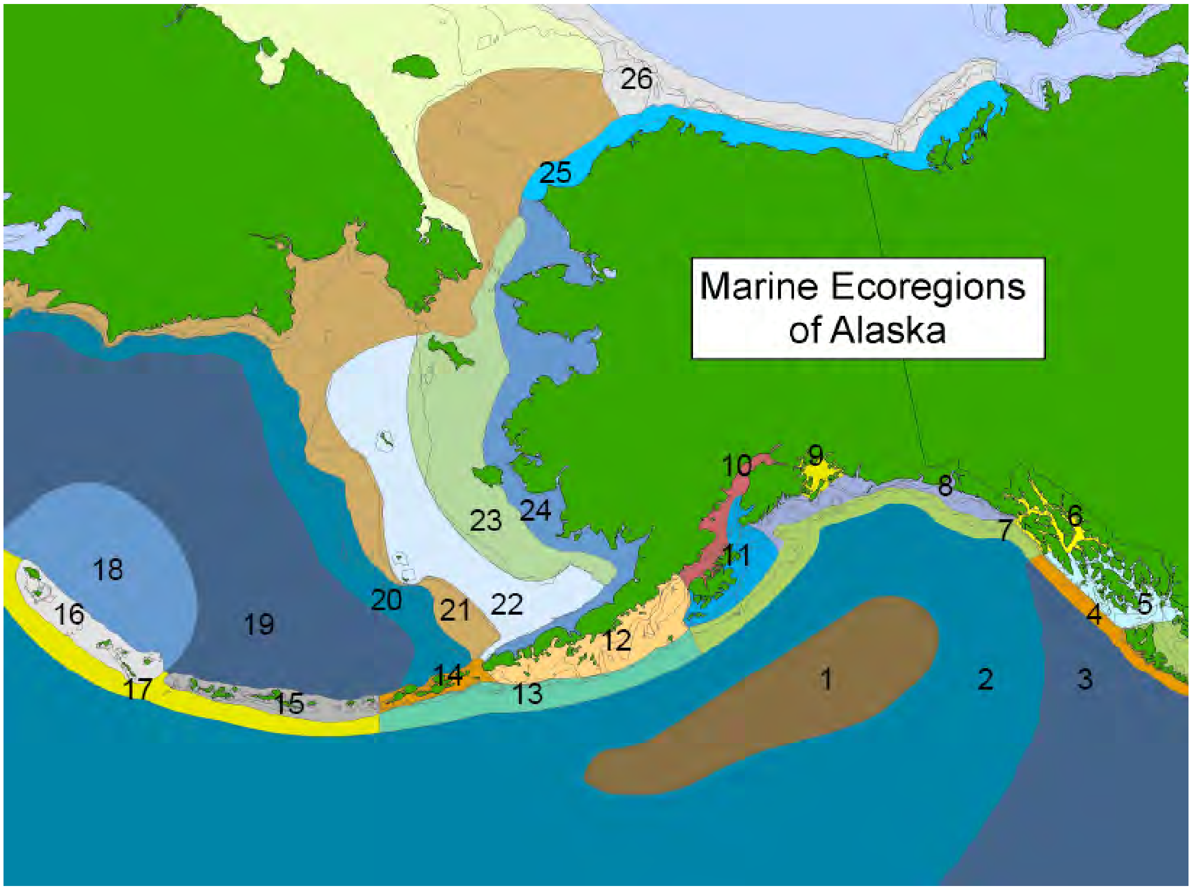

Fig. 4.2.7 Proposed delineation of ecosystem subregions in marine waters around Alaska, based on work by Piatt and Springer (2007).

There have been numerous efforts to define subregional boundaries in Alaska. In 1999, conservation groups (The Nature Conservancy and World Wildlife Fund) hosted a workshop to delineate Bering Sea subregions with a purpose to identify priority areas for conservation. Piatt and Springer (2007) evaluated known information on bathymetry and summer biological features and hydrography to derive 26 subregions for Alaska marine waters (Fig. 4.2.7). They acknowledged that these boundaries are likely variable but are determined mainly by bottom topography and current flow. Alongshelf boundaries were determined primarily from topographically defined fronts while cross-shelf boundaries were determined based on patterns in animal distributions. Piatt and Springer (2007) also concluded that coastal-shelf environments are much more heterogeneous than the open ocean, as is reflected by the finer spatial scale of subregions along the coast of the Gulf of Alaska, the Aleutian Islands, and the Eastern Bering Sea (Fig. 4.2.7).

In the meantime, a number of subregional boundaries have been defined to implement ecosystem-based protection measures designed to protect Steller sea lion (*Eumetopias jubatus*) foraging areas, corals in the Aleutian Islands, Eastern Bering Sea fish habitat, and a variety of closures to protect specific fish species from harvest during certain seasons (Witherell and Woodby, 2005). These subregions were based on biological information on species distribution and knowledge of fisheries activities in the area. The practical application of subregional boundaries by management authorities, such as the North Pacific Fishery Management Council, exemplifies the conclusion reached by the U.S. working group on regional ecosystem delineation that subregional delineation should be primarily the responsibility of the stakeholders in each region. The U.S.'s fishery management council system incorporates science-based decision making that brings together a cross-section of stakeholders in its design of management actions (see http://www.nmfs.noaa.gov/councils/).

4.2.6 Canada

Classifying marine systems is a main element of marine research and integrative resource management under Canada's national Ocean Strategy (Powles *et al.*, 2004). Thus, of all the PICES member countries, Canada has probably taken the most formal approach toward describing and delineating its marine waters. Their approach has involved dividing marine waters into adjacent 'ecoregions'; based on the hierarchical organization shown in Table 4.2.4 (based on Harper *et al.*, 1993), an ecoregion is an area on the scale of a marginal sea, distinguishable from neighbouring areas by physical and chemical conditions (*e.g.*, temperature, salinity), key systemic rates (*e.g.*, primary production), and community composition. An ecoregion can be a component of an 'ecoprovince' (*e.g.*, a major oceanic surface current), or a collection of several 'ecodistricts' (a localized mixing region). An ecoregion is assumed to be the most complex association of similar, connected areas for which clear, ecosystem-level research and management objectives can be devised and implemented.

Canada defined four ecoregions along its West Coast (Fig. 4.2.8), using nationally developed criteria (Powles *et al.*, 2004) that update earlier ecoregional delineations done by Zacharias *et al.* (1998). The criteria are geological (*e.g.*, degree of enclosure, bathymetry, surficial geology), oceanographic (*e.g.*, temperature, ice cover, freshwater influence, water masses, currents, mixing/stratification) and biological (*e.g.*, primary productivity, species distributions, population structure, community structure). These properties were used to classify an area of ocean only if data were available throughout that area, and they were considered jointly, not hierarchically. Although the ecoregional maps end at the limit of the Canadian EEZ for management purposes, the geological, physical, and biological properties inherent to an ecoregion very likely extend beyond the EEZ into adjacent waters (Powles *et al.*, 2004).

The four Canadian ecoregions are the Strait of Georgia, the Southern Shelf, the Northern Shelf and the Pacific Offshore ecoregion. The Strait of Georgia is primarily defined by its high degree of enclosure; it is bounded between Vancouver Island and the mainland of British Columbia on the west and east, and bordered by archipelagos and shallow depths in the north and in the south (Fig. 4.2.8). Its physical oceanography is characterized by strong tidal fronts to the north and south, along with significant freshwater influence coming from the Fraser River. The freshwater plume in the Strait of Georgia is generally restricted to the upper few centimetres of the water column.

The Southern Shelf ecoregion, located off the West Coast of Vancouver Island, is defined at its northern limit by Brooks Peninsula (northwest coast of Vancouver Island), which extends almost to the 200-m bathymetric contour and thus almost divides the continental shelf. The southern boundary was not defined under the Canadian process, as this ecoregion extends out of the EEZ into U.S. waters. Juan de Fuca Strait, between southern Vancouver Island and the northwest corner of the continental U.S., is a transition zone between the Strait of Georgia and the Southern Shelf. Biologically, the Southern Shelf ecoregion represents the northern distribution limit of many species, including Pacific hake *Merluccius productus*, some pandalid shrimp *Pandalus* spp., and the southern resident stock of killer whale *Orcinus orca*.

Table 4.2.4 Hierarchical levels of spatial organization used by Canada for classifying marine areas. This organizational scheme was originally developed by Harper *et al.* (1993).

Level	Basic descriptive scale
Ecozone	Ocean basins
Ecoprovince	Major oceanic surface currents
Ecoregion	Marginal seas
Ecodistrict	Local mixing processes, eddies, stratifications, small-scale currents
Ecosection	Bathymetric zones, habitat patches

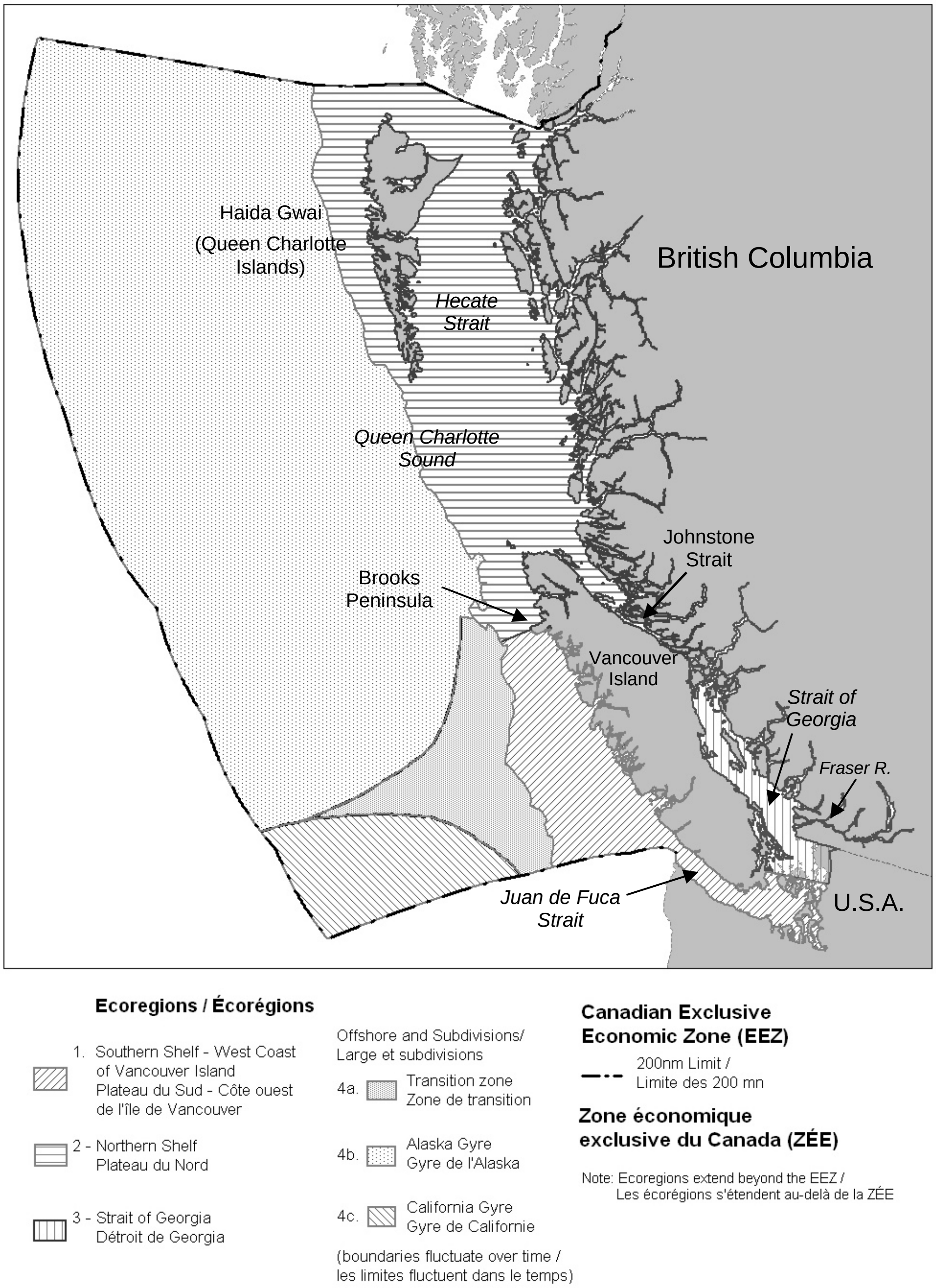

Fig. 4.2.8 Canadian Pacific Coast ecoregions (modified from Powles *et al.*, 2004).

The Northern Shelf ecoregion is bounded on the south by Brooks Peninsula, and extends northward into Alaskan (U.S.) waters. A distinctive geological feature of this ecoregion is the shallow water area located between the Queen Charlotte Islands (Haida Gwai) and the mainland coast. Oceanographically, shallow waters east of the Queen Charlotte Islands create a warm water front and strong mixing. Biologically, this ecoregion is roughly the southern range limit of many species, including the northern resident stock of killer whales. All major seabird colonies (colonies with >10,000 birds) on the West Coast of Canada occur north of Brooks Peninsula.

The Pacific Offshore ecoregion is the area seaward of the 200-m bathymetric contour, past the shelf break and to the west of the Northern and Southern Shelf ecoregions. Circulation patterns effectively divide it into three subregions, defined by the splitting of the easterly flowing North Pacific current as it approaches North America. This splitting results in part of the current going northward towards Alaska, and part turning south towards the continental U.S. This results in a northern subregion, the Alaska Gyre, associated with upwelling; a southern subregion, the California Gyre, characterized by downwelling; and a transition zone near the continental shelf boundary at the fork. The locations of these subregions move northward and southward seasonally and interannually with shifts in the current (Batten and Freeland, 2007). Biologically, the shelf break is an important boundary for seabirds. Species such as Laysan albatross *Phoebastria immutabilis* and many other Procellariiforms are found mostly seaward of the shelf break.

These four ecoregions provide spatial templates in which Canada plans to conduct EBM of marine resources. Canada recently began five ecoregion-scale pilot projects to implement integrated management (IM) plans; three of the pilot IM areas are in Atlantic waters, one in the Arctic and the fifth is the Northern Shelf region described above. The initial focus in the pilot projects is to provide managers and stakeholders with the best available scientific information on the ecoregion in order to support decision-making. To do so, scientists have conducted an Ecosystem Overview and Assessment (EOA; see appendix 4; Lucas *et al*., 2006). An EOA is a two-part document. The first part is a detailed description of the ecoregion's ecological status and trends, in the context of the region's geological, oceanographic and biological properties. The second part is an ecological assessment that reviews significant human activities and threats, links human activities with ecosystem functions, identifies ecologically significant areas and species, and makes recommendations concerning areas and activities that are high priority for management actions. Overall, the EOA also serves to engage stakeholders, and to assist in identifying ecosystem objectives, knowledge gaps, and ways to fill those gaps.

4.2.7 United States of America – Pacific Coast

Waters off the Pacific Coast of the continental U.S. are entirely within a single large marine ecosystem, the California Current LME (Sherman, 2006). The California Current is an eastern boundary current that crosses the northern and southern borders of the U.S. and extends seaward of the EEZ to roughly 1000 km from the coast. The surface current flows south, parallel to the coastline, from north of the U.S./Canada border until roughly Point Conception (Fig. 4.2.9) where it continues south-southwest to join with equatorial currents (Hickey, 1998). South-southeast of Point Conception and landward of the main body of the California Current is the Southern California Bight, characterized by a counterclockwise gyre that branches off the California Current and either recirculates (the Southern California Eddy) or rejoins the main current. The physical oceanographic features that define the Southern California Bight are most strongly developed in the summer and late fall in a normal year (Hickey, 1998; Hickey *et al.*, 2003).

At present, California Current waters off the Pacific Coast have not been formally subdivided for federal management purposes. However, a panel of federal and state scientists recommended delineating subregions within LMEs for the purpose of more effective resource management (NOAA, 2004). Several bathymetric and coastal features would be logical points for subregional delineation because they mark changes in physical and biological characteristics. Most notably, Point Conception (Fig. 4.2.9) is the point on the coastline where the main body of the California Current diverges, and is also considered the transition point between two biogeographic provinces – the Oregonian Province to the north and the Californian Province to the south (*e.g.*, Burton, 1998). Several other coastal features mark transitions in circulation, ecosystem function and community composition (*e.g.*, the Columbia River plume, Cape Blanco, Cape Mendocino, Point Arena and Monterey Bay). Some coastal areas are marked by strong upwelling, a critical driver of primary and secondary productivity in most years (Barth *et al.*, 2007). The U.S. GLOBEC program long ago recognized three major regions in the California Current. These regions, defined by patterns of circulation, coastal morphology, freshwater inputs and productivity, have break points at Cape Blanco and Point Conception (US-GLOBEC, 1992). One treaty-based international organization, the North American Commission for Environmental Cooperation (CEC), proposes three subregions on the U.S. Pacific Coast, with break points at Cape Mendocino and Point Conception; CEC subregion classification criteria are summarized in NOAA (2004).

Resource management in the California Current LME (especially for commercial species and species of concern) is already done based on subregional delineation in many cases, largely on the basis of distance from shore, depth, zoogeographic breaks and substrate/habitat types. Management responsibility for nearshore (<5.56 km, or 3 nautical miles, from shore) waters largely falls to individual states, and to the federal government from 5.56 km to the edge of the EEZ. Depth zones are a key basis for management of demersal species in federal waters over the relatively narrow continental shelf. This includes limits on the diameter of trawl footrope rollers (to prevent fishing on rocky substrates) and seasonal bottom trawling closures within certain bathymetric contours along the entire coast, in order to conserve depleted stocks of rockfish *Sebastes* spp. (PFMC, 2004). Coastal features mark differences in management strategies for some species; for example, many groundfish are managed more strictly to the

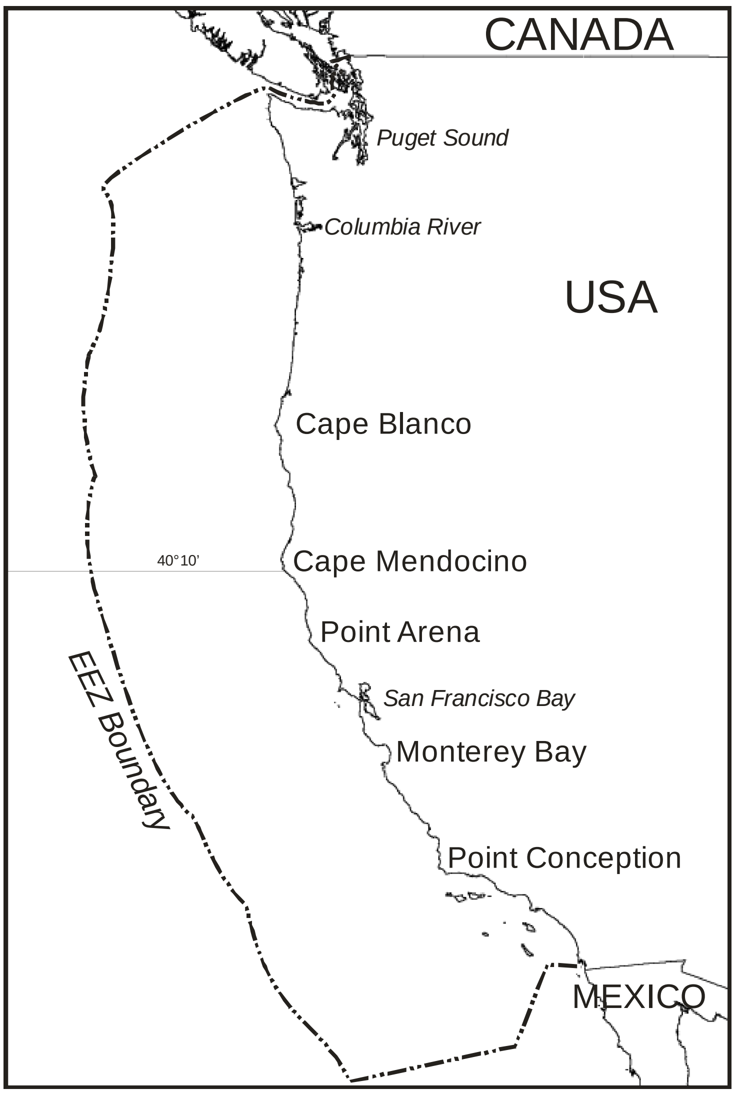

Fig. 4.2.9 Delineation of the Exclusive Economic Zone (EEZ) off the western coast of the continental U.S., along with some major coastal features. No ecoregions have been officially delineated within the EEZ, which lies within the California Current Large Marine Ecosystem (Sherman, 2006).

north of Cape Mendocino (PFMC, 2004). Other restrictions occur in areas where there is high likelihood of incidentally catching depleted or protected species (such as cowcod *Sebastes levis*, Klamath River fall Chinook salmon *Oncorhynchus tshawytscha* or leatherback turtles *Dermochelys coriacea*). Large-scale closures for bottom-contacting fishing gears have been established for unique offshore areas (*e.g.*, seamounts and banks identified by NOAA for groundfish conservation) and for vast areas believed to be rich in deep-sea invertebrates such as cold water corals, sponges, anemones and sea pens (*e.g.*, NOAA, 2005). It is likely that these species are distributed based on subregional differences in geology, oceanography and community structure, which may serve as bases for further spatial delineation as this process evolves.

4.2.8 Discussion

Comparison of National Approaches

In general, the National Summaries from the PICES member countries suggest a broad consistency in the criteria used to define and delineate marine ecosystems in their territories. In nearly all cases, spatial delineations were associated with major ocean currents, depth zones, and continental shelf/slope areas, all of which are obvious sources of spatial structuring. Many of these areas were further validated by statistical identification of distinct, characteristic species assemblages. Coastal features such as capes or peninsulas were frequently identified as key reference points for delineation, often because they represent zoogeographic barriers or points at which large-scale circulation patterns change markedly. Additionally, all member countries acknowledge cases where ecosystems extend beyond their EEZ, either into another country's EEZ or into international waters. Perhaps not surprisingly, the National Summaries contain less information about waters that lie beyond continental slopes and outside of their EEZs, even in cases where those waters are deemed part of the same ecosystem as (and are thus thought to be ecologically linked to) waters lying nearer to shore; this issue has been encountered in other spatial classification efforts (*e.g.*, Spalding *et al.*, 2007).

What is perhaps most interesting about the delineations is that PICES countries approached the issue in several different ways and yet came to comparable conclusions about the levels of ecological organization that constituted ecosystems and subregions. Delineation in some areas has relied primarily on an informal "Delphic" approach (*i.e.*, consensus of expert opinions) while other areas have added quantitative approaches (*e.g.*, neural network analysis or multivariate statistics). It is clear, however, that the PICES member countries vary widely in the formality of their approaches and the extent of their progress with respect to ecosystem delineation and subregionalization. The potential consequences of this are discussed in section on "International Collaborations".

There were several cases where member countries used the LME delineations as coarse-scale guides and defined finer-scale subregions. The coastal and inshore zones around Korea, the proposed conservation subdivisions around Alaska, the Canadian ecoregions, and the biostatistical districts around Russia occur at considerably finer spatial scales than the LMEs. Many countries noted the importance of variability in regional boundaries, such as the seasonal changes in water masses and fish assemblages described in the National Summary of China. That distinction is important because it recognizes that processes near the center of an ecosystem may be very different from processes at the margins, a principle that may help guide future refinements to delineations (*e.g.*, explicitly classifying some areas as transition zones, as was done by Japan and Canada).

Unique among the national approaches was the delineation scheme described by Japan. Acknowledging the inherent variability of the seasonally dynamic boundary and coastal currents, Japan loosely defined four pelagic zones based on three-dimensional oceanographic and biological patchiness relative to surrounding waters. In the demersal zone, however, Japan distinguished six zones, separated by distinct zoogeographic boundaries, such as shallow straits and peninsulas and supporting different benthic fish and invertebrate assemblages. This general notion, that the delineation of the pelagic zone does not necessarily precisely overlie delineations in the demersal zone, is potentially applicable in other parts of the PICES area.

Comparisons with Other Spatial Delineation Frameworks

Many other researchers and organizations have developed regional delineations of the oceans (see summaries in Longhurst, 1998 and Spalding *et al.*, 2007), and our work overlaps considerably with some and departs from others. Here, we draw comparisons and distinctions between our efforts and some prominent work by other individuals or groups.

As is clear from the National Summaries, the North Pacific LME framework (Sherman and Tang, 1999) strongly influenced our efforts. This implies broad acceptance of the LME-related suite of general structuring forces that define large, coastal marine ecosystems (bathymetry, hydrography, productivity and trophodynamics). One member country, the United States, explicitly identified the LME criteria as central to its plans for regional delineations. However, several countries clearly believe that managing marine resources will require finer-scale delineation of ecosystem subregions, as well as accounting for migratory species that move between LMEs (*e.g.*, largehead hairtail and small yellow croaker in the Yellow and East China seas). Two countries, Japan and Canada, also identified transition zones, where boundary current LMEs either converge or diverge, as distinct regions of ecological or management interest.

To a great extent, following the LME paradigm is sensible because the LME network is closely associated with the coastal, continental shelf regions of the world's oceans (Sherman, 2006) and hence is also associated with the EEZs of coastal nations like the PICES member countries. This also may explain why the much larger-scale oceanographic provinces defined by Longhurst (1998) do not correspond as well to the delineations described in the National Summaries. The Longhurst Provinces were developed to partition the entire world oceans, including the open pelagic regions far from continents, and hence processes at very different scales than those within coastal LMEs are being considered.

Recently, Spalding *et al.* (2007) developed a classification scheme known as the Marine Ecoregions of the World (MEOW), which defined 232 coastal marine ecoregions worldwide, based primarily on taxonomic criteria. MEOW ecoregions (areas with high taxonomic homogeneity, particularly at the level of sedentary species) are nested in a hierarchical analytical framework where ecoregions are components of taxonomic provinces and provinces are components of taxonomic realms. This system was designed to provide a basis for analyzing patterns and processes that characterize and influence marine biodiversity, and to inform management and conservation efforts in coastal waters. Its hierarchical framework enables analysis of changes and differences at multiple scales, and its basis in quantifiable taxonomic variables makes its classification criteria somewhat more concrete than qualitative, relative criteria. Spalding *et al.* (2007) described several differences between their network of ecoregions and the currently defined LME network (*e.g.*, Sherman, 2006), in part because the MEOW system covers considerably more coastal regions and, in part, because the criteria for delineation are different. However, Spalding *et al.* (2007) found that roughly half of their ecoregions, alone or in aggregate, were highly congruent with LMEs.

In general, the Northern Pacific Rim ecoregions identified by Spalding *et al.* (2007) were similar to our formally and informally delineated ecosystems. The congruence is highest in the western Pacific, where Spalding *et al.* identified separate ecoregions for the East China Sea, Yellow Sea, Sea of Japan, Sea of Okhotsk, Kuroshio Current and Oyashio Current (Spalding *et al.*, 2007). There were some minor differences; most notably, the MEOW system identified four separate ecoregions along the eastern side of Japanese waters, extending from seaward of the Ryukyu island chain northward to the east coasts of the main islands (Spalding *et al.*, 2007), as compared to the three areas (Kuroshio, Oyashio and Kuroshio-Oyashio Transition) identified in Japan's National Summary. MEOW also did not classify the central part of the Sea of Okhotsk because it lay beyond the MEOW criterion for 'coastal' waters (<370 km from a coastline).

In the Bering Sea and eastern Pacific waters, there was greater (but not insurmountable) incongruence between our approach and MEOW. MEOW delineations of the Western and Eastern Bering Sea ecoregions differed substantially from the Western and Eastern Bering Sea LMEs (Sherman, 2006), and the MEOW system did not include the Bering Sea Donut Hole, again because it lay beyond 370 km from a coastline. In U.S. waters, MEOW ecoregions were, in aggregate, similar to the LMEs of both the Gulf of Alaska (where MEOW defined two ecoregions: the Gulf of Alaska and Aleutian Islands) and the California Current (where MEOW defined three ecoregions, with break points at Cape Mendocino and Point Conception). These differences are related, in part, to the fact that the U.S. has yet to formally define subregions within the LMEs around its coasts. Finally, the four ecoregions defined in the National Summary of Canada were only partly captured by the MEOW process: MEOW did distinguish the Strait of Georgia from other Canadian territorial waters, and also distinguished the north–south break at Brooks Peninsula, but did not identify the Pacific Offshore ecoregion or its subregions as defined in Canada's National Summary. These differences likely reflect specific local knowledge or management priorities identified in the Canadian process that would not have been a part of the global classification criteria of the MEOW effort.

International Collaborations

A key goal of this summary was to identify opportunities for PICES member countries to collaborate in managing marine ecosystems that span international borders. Occurring on both sides of such borders are activities or conditions (*e.g.*, primary productivity, anthropogenic nutrient inputs, fishing pressure, habitat status) that affect resources on the other side. Ecosystem-based management explicitly accounts for the spatial distribution of processes and resources; thus, responsible collaborative management of an ecosystem by two or more countries requires that they share comparable ideas of how ecosystem resources and processes are arrayed in space and time (Juda, 1999; Duda and Sherman, 2002). Ecosystem delineation provides a useful spatial framework for developing national and international research and management plans and activities.

WG 19 identified several examples of international resource management (particularly of fisheries) in the PICES area. The U.S. and Canada have shared treaty-based cooperative management of several transboundary species, including Pacific halibut *Hippoglossus stenolepis* since 1923; sockeye salmon *Oncorhynchus nerka* and pink salmon *O. gorbuscha* bound for the Fraser River since 1985; and the abundant, highly migratory Pacific hake *Merluccius productus* since 2003. Japan and Korea share jointly fished zones in shared seas, and China and Korea share jointly fished zones in the East China Sea and Yellow Sea. The Convention on Conservation and Management of Pollock in the Bering Sea, signed in 1994, established a means for international management and conservation of walleye pollock in international Bering Sea waters; signatories include China, Japan, Korea, Russia and the U.S. China, Japan, Korea and the U.S. are also included in the membership of the Asia Pacific Fisheries Commission, established through the FAO in 1948. It has a broad agenda related to sustainable fisheries development, research, coordination and communication (see http://www.apfic.org). The United Nations and World Bank-funded Global Environmental Fund (GEF) recently endorsed a proposal entitled "Reducing Environmental Stress in the Yellow Sea Large Marine Ecosystem" that will support the governments of China and Korea in cooperative efforts to sustainably manage fisheries and mariculture, reduce pollution, and promote responsible oil, shipping and tourism industries in the Yellow Sea LME (Duda and Sherman, 2002; GEF, 2004). The outcome of this project may provide a model for other international collaborations in the PICES region.

Ecosystem-based management will require more collaboration by PICES member countries in the multinational LMEs typical of the North Pacific. We suspect that international collaboration will be most complicated in the western North Pacific, owing to ecological structuring forces as well as socio-economic and governance issues. In the eastern North Pacific, where Canadian and U.S. waters intersect in two places, the borders cross a continental shelf that is very narrow relative to the longshore extent of the boundary current ecosystems. Thus, these cases involve two nations with comparable governance and socio-economic structures, similar marine resources, and small geographic areas that require co-management. This is not to say that the U.S. and Canada always practice cooperative, transparent management of transboundary marine resources. It does, however, represent a simpler condition than that of the western North Pacific, where several semi-enclosed ecosystems are shared by three or four member countries, often with profound differences in governance structure, economic development, levels of scientific involvement, and degrees of dependence on marine resources. Their EEZs often meet over continental shelf waters, which tend to be the most heavily exploited and stressed marine systems in this densely populated area. The political boundaries themselves may be uncertain due to territorial disputes. These complications further underscore the value of the generally similar science-based approaches to ecosystem definition and delineation used by China, Japan, Korea and Russia.

Several institutions and frameworks can support additional international collaboration. Clearly, PICES is a forum for scientists to exchange information, to identify critical data gaps, and to discuss elements of possible cooperative monitoring programs (*e.g.*, useful ecosystem and fishery indicators, optimal spatio-temporal allocation of monitoring effort, data reporting formats, *etc.*). Another significant resource is the experience gained from the 'five-module approach' to LME assessment (Sherman, 1995; Sherman and Duda, 1999; Duda and Sherman, 2002). In this process, variables and indicators in three focal science-based modules (productivity; fish and fisheries; pollution and ecosystem health) are monitored in support of gathering basic information, assessing risk, and making decisions. A socio-economic module links ecological dynamics and resource management to economic principles that might operate under various management regimes. A governance module considers national and international institutions, activities and mores that determine how resources are used, how constraints and opportunities are assessed, what behaviors are acceptable, and who is responsible for implementing policies and programs (Juda, 1999; Duda and Sherman, 2002). Finally, management strategy evaluation (MSE) provides an analytical framework for assessing the outcomes of potential management actions. MSE involves defining a set ecological and economic objectives, selecting management strategies that can achieve those objectives, quantitatively analyzing the trade-offs among management alternatives, and specifying performance measures that indicate management success (Sainsbury *et al.*, 2000). Spatially explicit ecosystem models, such as Atlantis (*e.g.*, Fulton *et al.*, 2005) or Ecospace (Christensen and Walters, 2004) which feature management routines, are often used in MSE, and may prove vital tools for synthesizing available information and developing holistic management plans for marine ecosystems that span international borders. International research organizations like PICES are ideally suited to develop, refine and distribute these types of large-scale, data-intensive modeling tools.

4.2.9 Conclusions

As PICES member countries move toward ecosystem-based management of marine resources at a national and international scope, they are undergoing the crucial step of partitioning marine waters into ecologically cohesive, manageable spatial units. Although some member countries have taken more formal approaches than others, all members seem to have embraced similar criteria for delineating ecosystems and ecosystem subregions. The outcomes described in the National Summaries are also encouragingly similar to widely accepted classification schemes such as the LME network (Sherman, 2006) and the MEOW network (Spalding *et al.*, 2007). At least two major challenges remain, however, for formal delineation of ecosystems and subregions in the PICES area. First, the member countries need to determine the priority of developing, defining and implementing a standardized template for ecosystem delineation. Currently, such a template does not exist and its priority, both within individual countries and within PICES, remains unclear. Second, the delineation schemes described above were largely prepared by fisheries ecologists and likely reflect biases of the authors. The limitations and consequences of those biases would need to be addressed, likely through inclusion of a broader family of disciplines. As these two challenges are addressed, PICES experts and member countries should carefully consider the advantages and disadvantages of existing delineation schemes and identify criteria (abiotic, biotic, economic, *etc.*) and structural frameworks (qualitative, quantitative, hierarchical) that will facilitate national and international marine resource management.

4.2.10 References

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