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Review

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Contrast in Life Histories of Exploited Fishes and Ecosystem Structures in Coastal Waters off West Canada and East Korea

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Abstract – By reviewing the history of fishery exploitation in the coastal waters of west Canada and east Korea, related with contrasting life history strategies of the dominant species, the fishery management challenges that each country would face in the upcoming decades were outlined. In the ecosystem of the Canadian western coastal waters, the dominant oceanographic feature is the coastal upwelling domain off the west coast of Vancouver Island, the northernmost extent of the California Current System in the eastern North Pacific. In the marine ecosystem of the eastern coasts of Korea (the Japan/East Sea), a major oceanographic feature is the Tsushima Warm Current, a branch of the Kuroshio Current in the western North Pacific. Fishes in the Canadian ecosystem are dominated by demersal, long-lived species such as flatfish, rockfish, sablefish, and halibut. During summer, migratory pelagic species such as Pacific hake, Pacific salmon, and recently Pacific sardine, move into this area to feed. In the late 1970s, Canada declared jurisdiction for 200 miles from their coastline, and major fisheries species in Canadian waters have been managed with a quota system. The overall fishing intensity off the west coast of Vancouver Island has been relatively moderate compared to Korean waters. Fishes in the ecosystem of the eastern Korean waters are dominated by short-lived pelagic and demersal fish. Historically, Korea has shared marine resources in this area with neighbouring countries, but stock assessments and quotas have only recently (since the late-1990s) been implemented for some major species. In the Korean ecosystem, fisheries can be described as intensive, and many stocks have been rated as overfished. The two ecosystems responded differently to climate impacts such as regime shifts under different exploitation histories. In the future, both countries will face the challenge of global warming and subsequent impacts on ecosystems, necessitating developing adaptive fisheries management plans. The challenges will be contrasting for the two countries: Canada will need to conserve fish populations, while Korea will need to focus on rebuilding depleted fish populations.

Key words – Canadian Pacific waters, Japan/East Sea, ecosystem comparison, climate change, life histories of fishes, fisheries management

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1. Introduction

The challenge for fisheries stock assessment and management in the 21st century will be the ever increasing demand for marine resources, and the consequences of potential overexploitation (Zhang et al. 2009). Coupled with this will be the impacts of a changing climate on ecosystem, including community structure and function, with subsequent effects on fish survival, recruitment and distributional ranges. For countries such as Canada, fisheries management processes are currently in place for the provision of stock assessment advice and the implementation of management tools, such as quotas or fishery restrictions (King and McFarlane 2003). Other countries, such as Korea, have recently started the formal process of conducting stock assessments and managing marine resources (MOMAF 2007). In addition, these two countries also have experienced widely different histories of commercial exploitation, and current commercial fisheries are conducted on species with different life history strategies (Jamieson and Zhang, 2005).

As such, these two countries and the ecosystems that they commercially exploit represent different ends of the fisheries science and management spectrum. The purpose of this paper is to establish suitable management advice through the comparison of differences in community structure between major ecosystems off Canada and Korea that currently support large commercial fisheries. To simplify comparisons, we chose one major ecosystem from each country: for Canada, the west coast of Vancouver Island (California Current System in the eastern North Pacific) and for Korea, the Japan/East Sea (Tsushima Warm Current System, a branch of Kuroshio Current System in the western North Pacific). These ecosystems are representative of the community structure and the exploitation history in the two areas of the North Pacific. Both ecosystems account for a considerable portion of the fisheries conducted by either country.

The objectives of this study are to review the ecosystem characteristics, history of exploitation and current fisheries management system off the coasts of west Canada and east Korea, to contrast the life history strategies of the dominant species in these ecosystems, and to outline the fishery management strategies that each country would face in the upcoming decades by considering environmental changes such as global warming.

2. Canadian Pacific Coastal Ecosystems

Geographic extent

Canadian Pacific waters extend from the southern tip of Vancouver Island (48ºN), up to the Dixon Entrance in the north (54ºN). Canadian jurisdiction over marine waters extends offshore to 200 miles, which coincides to approximately 120ºW to 135ºW along the coastlines of Vancouver and Queen Charlotte Islands. Canadian waters include the continental shelf (shelf break at depth of 200 m) and most of the continental slope (Fig. 1).

Oceanographic domains

There are two dominant oceanographic domains within Canadian Pacific waters, excluding nearshore waters: the California Current System, which is dominated by coastal upwelling (Coastal Upwelling Domain), and the Alaska Current System, dominated by coastal downwelling (Coastal Downwelling Domain) (Ware and McFarlane 1989). The bifurcation zone of the Subarctic Current (West Wind Drift) occurs at approximately the northern tip of Vancouver Island, where it splits into the southward flowing California Current and the poleward flowing Alaska Current (Fig. 1).

The California Current System extends southward to Baja California. In winter, southerly winds dominate, causing onshore transport combined with down welling and poleward transport of surface waters. Northwesterly winds dominate in summer, causing surface waters to flow southerly and coastal upwelling results. The annual transition between winter and summer current patterns occurs in spring (March-April) and again in fall (September-October) (PICES 2004). During the upwelling season, surface waters are driven offshore and replaced by intermediate depth, nutrient rich water. Dissolved nutrients and associated phytoplankton production and biomass are on average high throughout this season (PICES 2004). The maximum zooplankton biomass occurs during the spring transition on the continental shelf and later in mid- to late-summer on the seaward of the shelf-break (PICES 2004). The zooplankton community is mainly comprised of euphausiids, herbivorous copepods, chaetognaths and gelatinous zooplankton (PICES 2004).

Major ecosystems

Off Canada, there is one large ecosystem that occurs within the California Current System: the west coast of Vancouver Island. Two large ecosystems are associated with the Alaska Current System: Queen Charlotte Sound and the west coast of Queen Charlotte Islands. In addition, there are two other major ecosystems that are typically considered to be inland seas: the Strait of Georgia and Hecate Strait. The Strait of Georgia is semi-enclosed body of water between Vancouver Island and mainland British Columbia. It is connected to the southwest region of Vancouver Island by the Juan de Fuca Strait and to Queen Charlotte Sound by the Johnstone Strait. Its circulation is dominated by the freshwater runoff of the Fraser River. Hecate Strait is located between Queen Charlotte Islands and the mainland and is open to Queen Charlotte Sound in the south and Dixon Entrance in the north. Its circulation is driven by wind and surface currents from Queen Charlotte Sound and by freshwater runoff from numerous mainland rivers (Fig. 1).

Focus on the west coast of Vancouver Island

Historically, large fisheries have been conducted off the west Coast of Vancouver Island. A number of research programs focusing on understanding the dynamics of key

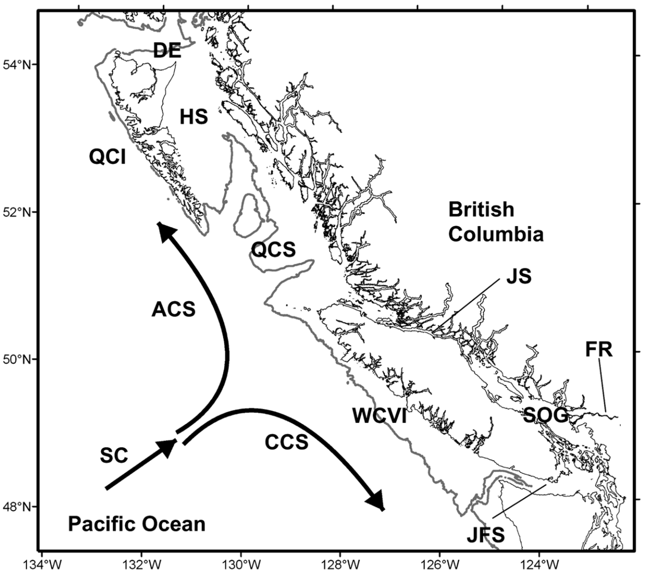

Fig. 1. Geography and current system off the west coast of British Columbia, Canada. Gray line denotes 200 m contour. SC: Subarctic Current; ACS: Alaska Current System; CCS: California Current System. Hecate Strait (HS) and the Strait of Georgia (SOG) are considered inland seas. Hecate Strait is open to Queen Charlotte Sound (QCS) in the south and Dixon Entrance (DE) in the north. The Strait of Georgia connects to the Pacific Ocean by the Juan de Fuca Strait (JFS) in the south and Johnstone Strait (JS) in the north and is dominated by freshwater runoff from the Fraser River (FR). The west coast of Queen Charlotte Islands (QCI) and Queen Charlotte Sound are associated with the Alaska Current System. The west coast of Vancouver Island (WCVI) is associated with the California Current System.

commercial species have occurred in the area. Most recently, programs examining annual and interannual variability of primary and secondary productivity have been conducted. The major fisheries occur from the southern tip of west coast Vancouver Island to Brooks Peninsula near the northern end. Fisheries are conducted in both shelf and slope waters, and account for approximately 80% of the catch off British Columbia.

The west coast of Vancouver Island ecosystem has a broad shelf area in the southern portion (La Perouse bank) and a relatively narrow shelf area north to Brooks Peninsula. This ecosystem is characterized by intense wind-induced upwelling in summer that occurs at the shelf-slope break, and high phytoplankton and euphausiid biomass. High nutrient supply is provided by wind-induced upwelling, augmented by nutrient-rich water from the Juan de Fuca Strait. The highly productive plankton community supports resident pelagic and demersal fish stocks, as well as stocks of Pacific hake and Pacific sardine that migrate from California in summer to feed (Fig. 1) (Beamish et al. 2001).

3. Korean Coastal Ecosystems

Geographic extent

The Korean Peninsula is surrounded by the shallow Yellow Sea (average depth 44 m; maximum depth 103 m) to the west, the East China Sea to the south, and the deep Japan/East Sea to the east (average depth 1.5 km; maximum depth 4.0 km) (Lee 1992). Marine waters for the Republic of Korea extend from the border with the Democratic Peoples Republic of Korea at approximately 38°N down to the island of Jeju at 33°N between 124°E and 132°E. Given the close proximity of other nations, Korean jurisdiction over marine waters extends less that 200 nautical miles from shore (Fig. 2) (MOMAF 2000).

Oceanographic domains

The major oceanographic domain in the Korean side of the East China and Japan/East Sea is the Tsushima Warm Current, a branch of the Kuroshio Current System. The Tsushima Warm Current passes through the East China Sea, and enters the southwestern entrance of the Japan/East Sea. A relatively minor portion of the Tsushima Warm Current

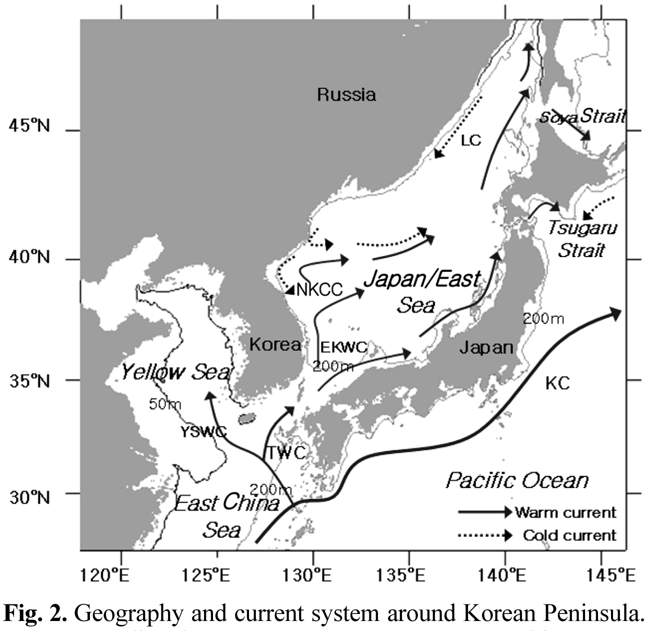

Fig. 2. Geography and current system around Korean Peninsula. Gray line denotes 200 m contour. TWC: Tsushima Warm Current; YSWC: Yellow Sea Warm Current; EKWC: East Korea Warm Current; NKCC: North Korea Coastal Current; and LC: Liman Current.

enters into the Yellow Sea. Most of the Tsushima Warm Current exits eastward to the Pacific Ocean through the Tsugaru Strait and the Soya Strait, south and north of Hokkaido (Japan), respectively. Within the surface layer of the Japan/East Sea, the Tsushima Warm Current meets the sub-arctic coldwater (North Korea Cold Current, a branch of the Liman Current) at about 40ºN, forming a meandering subpolar front, the location of which varies seasonally and interannually (Chang et al. 1999/2000). In the north, ocean circulation along the western portion tends to be southward, producing an overall cyclonic surface circulation pattern (Fig. 2). Severe winters, coupled with the diminishing Tsushima Warm Current, produce cold waters that sink, resulting in deep waters that are very cold (PICES 2004). Given these oceanographic features, the Japan/East Sea is considered to mimic large oceans. The Tsushima Warm Current is predominant in spring and summer, diminishing in fall and winter. The Tsushima Warm Current brings warm water in spring, restricting the vertical circulation in the surface layer which triggers the phytoplankton bloom to develop in the southern Japan/East Sea, resulting in a zooplankton community composed of warm water species, while subarctic species dominate the northern Japan/East Sea (Kim and Kang 1998).

Major ecosystems

The seas around the Korean Peninsula have typical characteristics in terms of geomorphology, oceanography and biota. The Yellow Sea is a shallow water between mainland China and the Korean Peninsula, and exhibits strong tidal forcing near the coast. Overall, the Yellow Sea waters can be described as low in salinity but turbid (Kim and Khang 2000). The East China Sea is off the southern tip of the Korean Peninsula. Eastward, between Korea and Japan is the deep basin Japan/East Sea, which is dominated by the Tsushima Warm Current (Fig. 2). In deeper parts of the Yellow Sea and the East China Sea, several demersal fish species migrate seasonally between the two areas (Kim 2003). Also, in the surface layer of the Tsushima Warm Current, some pelagic fish species including squids show relatively long migration ranges between the East China Sea and the Japan/East Sea (Kim 2003). From the fisheries point of view, three ecosystems can be categorized around the Korean Peninsula: 1-the Yellow Sea demersal ecosystem; 2-the Tsushima Warm Current pelagic ecosystem between the East China Sea and the Japan/East Sea and; 3-the Japan/East Sea demersal ecosystem (Kim 2003).

Focus on the Japan/East Sea

The Japan/East Sea is a semi-enclosed marginal sea. It is bordered by the east coast of Russia, the Korean Peninsula, and the west coast of Japanese islands. The Japan/East Sea covers an area of approximately 1.01×10^6 km^2, and it contains several deep (> 3,000 m) basins. Over 70% of the total catch of marine species in Korean waters occurs in the Tsushima Warm Current System within the Japan/East Sea and the East China Sea ecosystems (Zhang and Lee 2004). Also, some demersal fish such as walleye pollock and Pacific cod have been traditionally important fisheries species in the Japan/East Sea, at least during the past 600 years (http://sillok.history.go.kr).

4. Historical Fisheries

Canada

Catch statistics for the commercial fisheries off the Pacific coast of Canada were first produced in 1889; however, detailed catch statistics were not compiled until 1927 (Beamish 2008). Fisheries off the west coast of Vancouver Island in the 1930s and 1940s were mainly Pacific sardine (*Sardinops sagax*), Pacific herring (*Clupea harengus pallasi*), and Pacific salmon (*Oncorhynchus* spp.) (Figs. 3A, 3B and 3C). Minor catches of groundfish species, such as spiny dogfish (*Squalus acanthias*), lingcod (*Ophiodon elongatus*), and Pacific halibut (*Hippoglossus stenolepis*), were also taken. Catches of all species averaged about 30,000 tonnes annually during the 1930s and 1940s. Pacific sardines and Pacific herring were captured by seine gear, while Pacific salmon commercial fisheries employed trolling. A small, yet consistently valuable, longline fishery for Pacific halibut has always existed off the west coast of Vancouver Island. During this period very little bottom trawl fishing occurred; most of the catch of groundfish species came from hook and line fisheries.

Bottom trawl fishing off the Pacific coast of Canada began in the mid-1940s and expanded rapidly through to the mid-1950s. Off the west coast of Vancouver Island, bottom trawl fisheries for groundfish (Fig. 3E and 3F) captured flatfish species (Pleuronectidae), Pacific cod (*Gadus macrocephalus*), lingcod, Pacific ocean perch (*Sebastes alutus*) and other rockfish species (*Sebastes* spp.), and spiny dogfish. Trawl fisheries for shrimp also began to develop during this time period.

Bottom trawl fisheries during 1950s and 1960s were

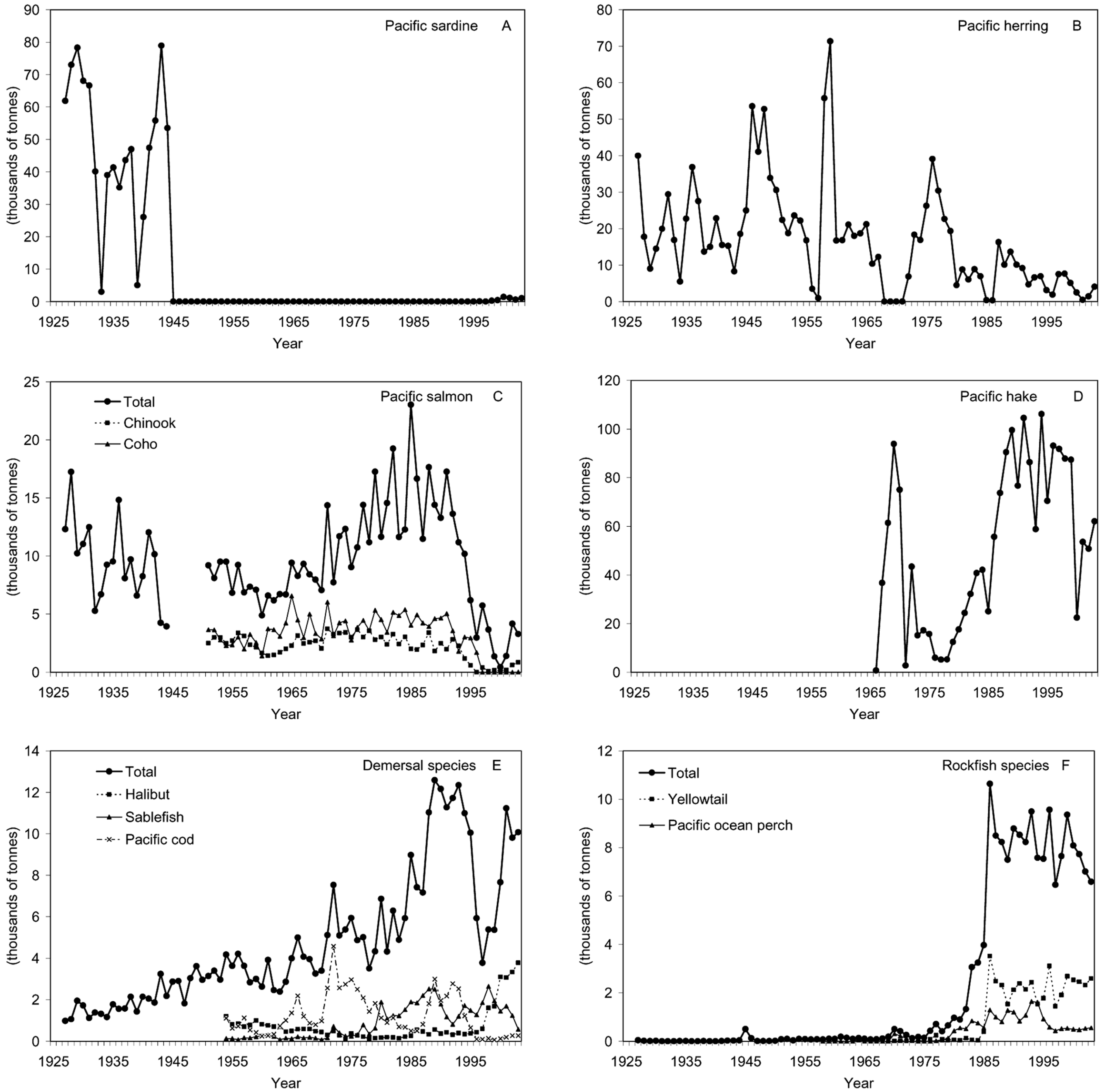

Fig. 3. Commercial landings (thousands of tonnes) of the dominant historical fisheries in Canadian waters off the west coast of Vancouver Island: A) Pacific sardine; there were no landings of Pacific sardine between 1945-1994. The mean annual landings from 1995-2003 is approximately 550 tonnes. B) Pacific herring. C) Pacific salmon; total salmon landings includes the landings for chinook and coho presented along with any landings for sockeye, pink and chum salmon. Catch data are not available by geographic area for 1945-1950, though salmon fisheries were conducted during that period. Catch data by species are available since 1951. D) Pacific hake E) Demersal species; total demersal landings (E) includes the landings for halibut, sablefish and Pacific cod presented along with all other groundfish species excluding rockfish. Catch data by species are available from 1951. Total rockfish landings (F) includes landings for Pacific ocean perch and yellowtail presented (Beamish 2008).

conducted on the continental shelf waters, but in the 1970s, trawl fisheries along the continental slope expanded. The extension of Canada's jurisdiction over offshore resources to 200 nautical miles in 1978 allowed many Canadian fishermen to develop fisheries on slope waters. This included the development of the extensive mid-water fishery for

Pacific hake (*Merluccius productus*) (Fig. 3D), and deeper-water fisheries for slope species such as Pacific ocean perch (Fig. 3F), yellowmouth (*S. reedi*) and rougheye (*S. aleutianus*) rockfish. Other gear fisheries, such as the longline and trap fisheries for sablefish (*Anoplopoma fimbria*) (Fig. 3E), also began to develop in slope waters in the late-1970s. The arrival of mid-water trawl gear also opened up opportunities for mid-water shelf rockfish fisheries, such as canary (*S. pinniger*), yellowtail (*S. flavidus*) (Fig. 3F) and silvergray (*S. brevispinis*) rockfishes.

By the 1980s, trawl fisheries accounted for the majority proportion of the catch of all species off the west coast of Vancouver Island. However, seine and gillnet fisheries for herring and salmon, and troll fisheries for salmon remained an important component of the catch. These fisheries are conducted in coastal waters and inlets.

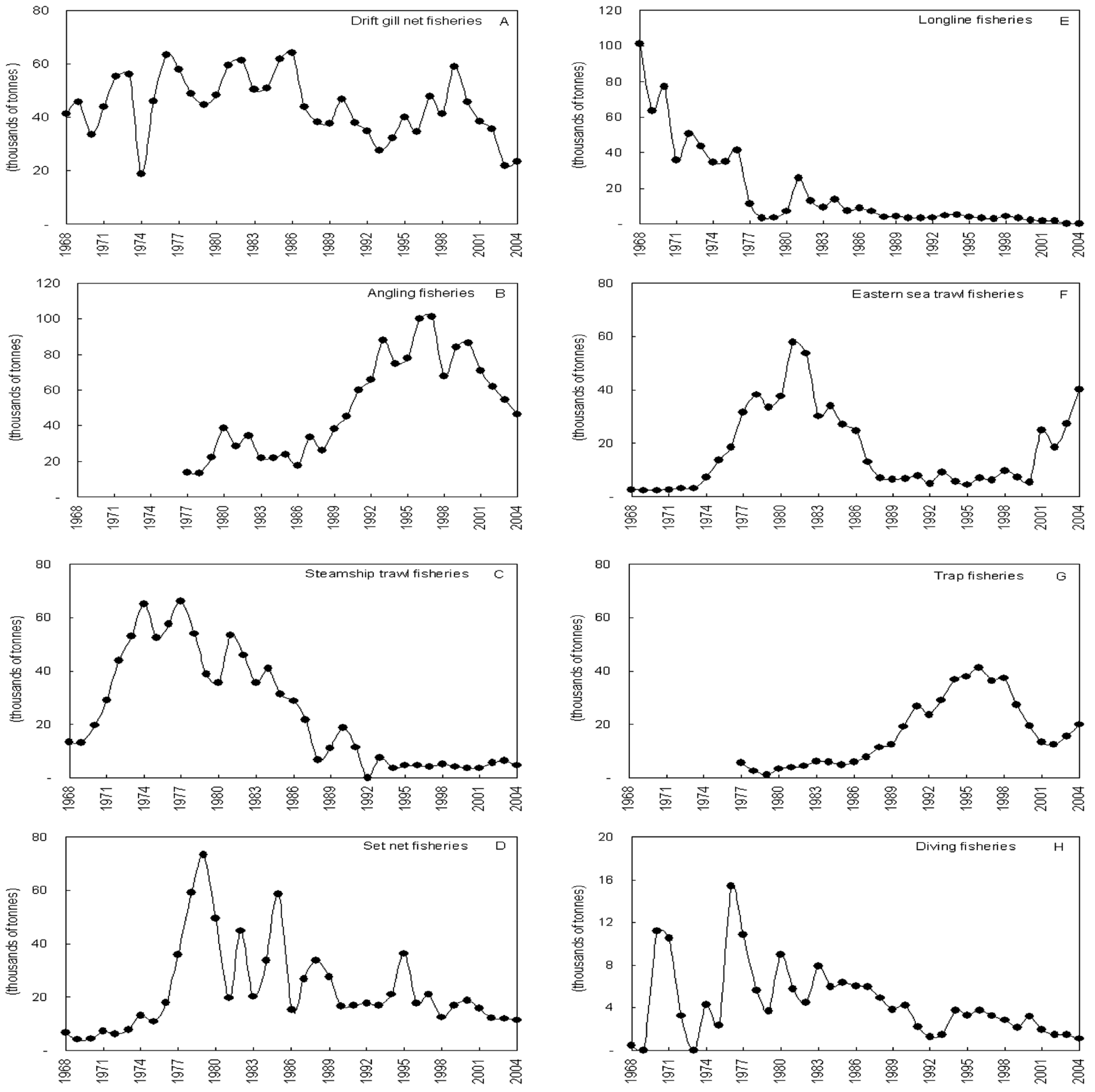

Fig. 4. Commercial landings (thousands of tonnes) of the dominant historical fisheries in the Japan/East Sea from 1968 to 2004: A) drift gill net fisheries. B) angling fisheries. C) steamship trawl fisheries. D) set net fisheries. E) longline fisheries. F) eastern sea trawl fisheries. G) trap fisheries. H) diving fisheries (MOMAF, 2005).

Table 1. Mean annual catch (tonnes), mean proportion (%) of annual catch and coefficient of variation (CV) of mean proportion of main fisheries in the Japan/East Sea, 1968-2004 (MOMAF 2005)

Rank	Fishery	Mean annual catch	Mean proportion	CV
1	Drift gill net	44,271	22.3	26.6
2	Angling	38,341	19.3	84.6
3	Steamship trawl	24,514	12.3	85.1
4	Set net	22,763	11.5	72.3
5	Long line	17,403	8.8	137.5
6	Eastern sea trawl	17,194	8.6	89.3
7	Trap	12,788	6.4	99.8
8	Diving	4,471	2.2	76.8
9	Purse seine	3,606	1.8	97.9
10	Dredge	709	0.4	101.7
	Sub total	186,060	93.6	
	Other fisheries total	12,739	6.4	
	Total	198,799	100.0	

Korea

Fisheries have been conducted in the Japan/East Sea for centuries, and ten types of fisheries are important: (1) drift gill net fisheries, (2) angling fisheries, (3) steamship trawl fisheries, (4) set net fisheries, (5) longline fisheries, (6) eastern sea trawl fisheries, (7) trap fisheries, (8) diving fisheries, (9) purse seine fisheries, and (10) dredge fisheries (Table 1) (Beamish 2008). Among them, fisheries with drift gill net, angling, steamship trawl, and set net occupy two third of total catch in the Japan/East Sea.

Catches in these four major fisheries have declined in recent years (Figs. 4A-4D). Average catch of drift gill net fisheries for the period of 1968 to 2004 was 44 thousand tonnes. Annual catches of drift gill net fisheries recorded a minimum level of 18 thousand tonnes in 1974. They fluctuated between 30-60 thousand tonnes until the late 1990s, and dropped to 21 thousand tonnes in 2003 (Fig. 4A). Angling fisheries showing a mean of 38 thousand tonnes began to increase from 17 thousand tonnes in 1986, and peaked at 101 thousand tonnes in 1997, and then declined gradually (Fig. 4B). Average catches of steamship trawl and set net fisheries were about 20-25 thousand tonnes. Both fisheries were in relatively good condition during the 1970s through mid 1980s, but have much decreased since the 1990s (Fig. 4C and 4D).

5. Important Commercial Species

Canada

Over that past century, over 60 species have been landed in commercial fisheries, some of which are targeted species, most of which are bycatch. We selected key species that have either been important historically or currently dominate landings, and are representative of different life histories. These key species have been the foundation of the various west coast fisheries and they also represent fish captured by the various gear types and captured in the different habitats or geographic locations. In addition, because these species have been important commercially, they have comprised over 90% of the landings, and reliable fishery and biological data are available for them. Overall, commercial species caught off the west coast of Vancouver Island range from demersal, non-migratory slope species (e.g. sablefish and Pacific ocean perch) to highly migratory mid-water and surface pelagics (e.g. Pacific hake and Pacific sardine) (Table 2). Typically, the commercial species are large sized (>70 cm), and with the exception of the pelagics, are long-lived (greater than 20 years) species (King and McFarene 2003).

Korea

The strong oceanic front between the warm water and cold water currents in the Japan/East Sea provides highly productive fishing grounds (Gong et al. 1985). Given the presence of warm and cold water currents, a variety of both subarctic and temperate species are abundant in the Japan/East Sea. In the southern warm water region, Pacific saury (*Cololabis saira*), filefish (*Thamnaconus modestus*), anchovy (*Engraulis japonicus*) and flatfishes (Pleuronectidae) are most abundant, while in the northern cold water region, walleye pollock (*Theragra chalcogramma*) and sandfish (*Arctoscopus japonicus*), Pacific sand lance (*Ammodytes personatus*) and

Table 2. Life history parameters and habitat description of key species captured in the commercial fisheries off of the west coast of Vancouver Island (Canada) and in the Japan/East Sea (Korea). References or data sources. (Beamish 2008; NFRDI 2005)

Species	Habitat	Maximum age	Age at 50% maturity	Maximum size (mm)	Size at 50% maturity (mm)	von Bertalanffy growth curve coefficient(K)	Median fecundity (number of eggs)
West coast Vancouver Island (Canada)							
Pacific sardine (*Sardinops sagax*)	Surface pelagic	13	2	394	210	0.45	115, 000
Pacific herring (*Clupea pallasi*)	Surface pelagic	15	3	330	177	0.45	10, 500
Chinook salmon (*Oncorhynchus tshawytscha*)	Surface pelagic	5	3	1470	755	0.62	9, 500
Coho salmon (*O. kisutch*)	Surface pelagic	4	2	980	550	0.50	35, 000
Pacific hake (*Merluccius productus*)	Epipelagic	23	3	800	370	0.35	1, 147, 000
Pacific cod (*Gadus macrocephalus*)	Demersal	11	2-3	1000	515	0.46	148, 250
Petrale sole (*Eopsetta jordani*)	Demersal	25	5	600	443	0.17	800, 00
Sablefish (*Anoplopoma fimbria*)	Demersal	113	5	1140	587	0.30	700, 000
Yellowtail rockfish (*Sebastes flavidus*)	Epipelagic	64	8	660	435	0.16	341, 000
Pacific ocean perch (*S. alutus*)	Demersal	100	8	510	350	0.11	168, 000
Japan/East Sea (Korea)							
Common squid (*Todarodes pacificus*)	Surface pelagic	1	1	270	200	0.22	400,000
Walleye pollock (*Theragra chalcogramma*)	Epipelagic	10	5	600	340	0.22	267,000
Pacific saury (*Cololabis saira*)	Surface pelagic	3	2	350	220	0.52	5,250
Filefish (*Thamnaconus modestus*)	Surface pelagic	8	5	300	210	0.17	835,000
Anchovy (*Engraulis japonicus*)	Surface pelagic	2	1	150	90	0.57	8,850
Sandfish (*Arctoscopus japonicus*)	Epipelagic	6	5	260	170	0.17	1,600
Pacific sandlance (*Ammodytes personatus*)	Surface pelagic	4	2	250	125	0.69	4,800
Flatfishes (Pleuronectidae)	Demersal	10	4	400	265	0.18	570,000
Pacific herring (*Clupea pallasii*)	Surface pelagic	10	4	460	210	0.66	50,000
Red snow crab (*Chinocetes japonicus*)	Demersal	7	3	90	50	0.27	60,000

Pacific herring (*Clupea pallasii*) are dominant (Kim and Kang 1998). Throughout the Japan/East Sea, dominant invertebrate species which are commercially exploited are common squid (*Todarodes pacificus*), tanner crab (*Chionoecetes bairdi*) and red snow crab (*Chionoecetes japonicus*). Historically, common squid, walleye pollock and Pacific saury have been important commercial fish species for Korea, and have accounted for approximately 60% of the overall annual Korean catch from the Japan/East Sea. For the period of 1998-2008, common squid accounted for 61.39% of catch in weight from the Japan/East Sea; Pacific herring 5.37%, and Pacific saury 3.41% (MOMAF 1997-2006). Typically, the major commercial species caught within the Japan/East Sea are small, short-lived, surface and mid-water pelagics (Table 2).

6. Contrast in Management Strategies

Canadian fisheries management

For most of the 20th century, Canada has managed its fisheries resources, initially within a 12 nautical mile zone, the Sovereignty Zone, which was extended in 1977 to 200 nautical miles. Prior to 1977, all management limitations were constricted to gear restrictions and timing and length of fishery openings. In 1977, coinciding with the implementation of the 200 nautical miles, management for all species and species groups became more active and included quotas for the dominant targeted commercial species. Many fisheries (e.g. Pacific herring and Pacific salmon) have in-season management. For many fisheries, the number of licence holders has been limited to curtail excess capacity (Beamish and McFarlane 1999).

Information required to develop and implement quotas was obtained (to varying degrees) through fisher logbooks, onboard observers and dockside monitoring. Since 1927, catch statistics have been compiled for major fisheries and areas. Commercial landings from 1927-1946 were reported in the annual Fisheries Statistics reports compiled by the Dominion Bureau of Statistics for three large geographic areas. For a brief period following World War II (1947-1950) catch landings were combined and reported for the whole west coast of Canada. Since 1951, catch statistics have been recorded by gear type, and by species for at least 8 geographical areas, or in some cases (e.g. Pacific salmon) 28 geographical areas. With the advent of affordable global positioning systems, it is now possible to obtain latitude and longitude data for specific fishing events. In 1996, onboard observers were made mandatory for trawl fishing trips, making reliable discard records available. Partial onboard observer coverage occurs in the line fisheries, and in some Pacific herring and Pacific salmon fisheries.

Since 1979, formal stock assessments with provision of management advice were required to set quotas for all targeted fisheries. These analyses have varied in complexity, from simple catch per unit effort analyses to sophisticated stock dynamic models such as age structured models that now include Bayesian estimates of uncertainty.

Korean fisheries management

Korean management of fisheries resources in the Japan/East Sea has been hindered by the multi-national profile of the fishing activity in this area. Korea shares the marine resources with North Korea, China, Japan and Russia, who are all actively engaged in fishing. However these nations do not coordinate responsibility for assessment and management of the common resources. Korea was re-established as a sovereign nation in 1948, and its management devices for its fisheries have included mesh size restriction, minimum size limits, closed areas and seasons, licence requirements and gear limitations (Zhang and Marasco 2003). In 1994, Korea extended its fisheries jurisdiction. This provided an impetus for implementing a total allowable catch (TAC) based fisheries management system in 1999 (Zhang and Marasco 2003). Currently, three finfish species (common mackerel, jack mackerel, Pacific sardine) and seven shellfish species (queen crab, snow crab, blue crab, common squid, hen cockle, spiny top shell and pen shell) are managed under this TAC system. TACs are determined based on traditional single-species stock assessments (MOMAF 2007). Recently, an ecosystem-based fisheries assessment approach has been developed (Zhang et al. 2009), and an integrated ecosystem-based fisheries management system has been in the process of the implementation.

7. Climate Impacts

A regime is a period of several sequential years (often a decade or more) in which the state, or characteristic behaviour, of the climate, the ocean conditions or an ecosystem is steady (Wooster and Zhang 2004). It does not preclude year-to-year differences, but overall, the state of the system over the decades (i.e. decadal-scale) can be described as persistent, steady, or “locked in.” A regime shift refers to a relatively rapid change (occurring within a year or two) from one decadal-scale period of a persistent state (regime) to another decadal-scale period of a persistent state (regime) (King 2005; Wooster and Zhang 2004). Scientific literature reports that regime shifts occurred in 1925, 1947, 1977, 1989 and 1998 (King 2005; Overland et al. 2008). Regime shifts are not confined to the last 100 years. Paleo-ecological records show that regime shifts have occurred throughout the centuries (Baumgatner et al. 1992).

Ecosystems can respond dramatically to climate regime shifts. For example, the 1977 regime shift resulted in several zooplankton, invertebrate and fish populations throughout the North Pacific undergoing a rapid (within a couple of years) change in distribution, productivity (particularly year class success) and abundance (Hare and Mantua 2000). For many species the change was substantial and unexpected. Most noteworthy was the fact that the changes, or shifts, observed in marine ecosystems were evident on such a large geographic scale, mainly the whole North Pacific, and that the changes were not short-lived, but in fact persisted for a decade (Wooster and Zhang 2004). The post-1977 period is broadly characterized as a period of good fish productivity. The co-occurrence of these shifts in ecosystems (across all trophic levels and including non-exploited fish species) around the North Pacific suggested that the ecosystems were responding to a common factor, namely changes in climate or ocean conditions. In fact, rapid and substantial shifts in climate and ocean systems, such as the Aleutian Low pressure system and sea surface temperatures and salinities, did occur around 1977 (Hare and Mantua 2000).

Numerous studies have illustrated that fish population dynamics are associated with these large-scale changes in climate and ocean conditions, i.e. associated with regimes and regime shifts (PICES 2004; Kim et al. 2007). Fish have evolved life history strategies to cope with variability in their environment. These life history strategies range from short-lived, highly variable stock dynamics which respond immediately to changes in their environment to extremely long-lived species whose population dynamics are mainly stable (King and McFarlane 2003; Zhang et al. 2000). Short-lived species have a shorter generation time which helps to maximize their intrinsic rate of population growth, despite typically having relatively low fecundity. Longevity allows a species to persist through prolonged periods of poor productivity. Long-lived species are typically highly fecund, which allows them to take immediate advantage of changes to more productive regimes, through increased year class success. It is important to note that the intrinsic rate of population growth in long-lived species is lower than in short-lived species, so improved year class success translates into delayed increases in population productivity (King and McFarlane 2006).

Canada

McFarlane et al. (2000) examined the variability in species distribution and abundance in relation to decadal-scale patterns in climate/ocean conditions. They reported a response of most fish species (pelagic and demersal) to both the 1977 and 1989 regime shifts. Changes in abundance of demersal species were directly related to year class success. For example, sablefish year class success improved during the 1977-1988 regime period, and was relatively poor during the 1989-1998 regime periods, with subsequent increase and decrease respectively in the abundance of recruits to the fishery, whereas changes in abundance of major pelagic species off the west coast of Vancouver Island (i.e. Pacific hake, Pacific sardine, Pacific mackerel) were more related to distributional changes in mature fish. For example, the summer distribution of Pacific hake adults, which enter the Canadian zone from California, greatly expanded northward after the 1989 regime shift. In addition, some adults remained in Canadian waters year round and Pacific hake spawned off the west coast of Vancouver Island. The west coast of Vancouver Island is inhabited by a robust mix of pelagic and demersal species, i.e. both short-lived and long-lived species are present. King and McFarlane (2006) discussed the regime impacts on the stock dynamics of both short-lived and long-lived species and noted that differing management responses may be required for the two different life history strategies. Short-lived species exhibit rapid and large abundance responses to regime impacts, whereas long-lived species exhibit prolonged and lower amplitude responses in abundance. King and McFarlane (2006) illustrated that regime impacts on recruitment at the larval stage (i.e. larval survival) result in rapid changes in stock abundance of large amplitudes.

Korea

Climate regime shifts, as detected in changes in relative intensity of the North Pacific High and Aleutian Low pressure systems, have been linked to changes in the physical oceanography of the Japan/East Sea (Zhang et al. 2000). After the 1977 regime shift, there was increased precipitation and increased horizontal advection in this region, resulting in a deepening of the mixed layer depth (Zhang et al. 1999; Zhang et al. 2000). The Tsushima Current strengthened and the thermal front shifted northward (Gong et al. 1985). In the Japan/East Sea these physical oceanographic changes were partnered with a decrease in spring primary production and an increase in autumn primary production (Zhang et al. 2000). Conversely, after the 1989 regime shift, the spring primary production increased, coupled with a drastic increase in zooplankton, while the autumn primary production decreased (Zhang et al. 2000).

The climate regime shifts in 1977 and 1989 coincided with shifts in population dynamics of several species in the Japan/East Sea ecosystem, mitigated through either physical processes (such as thermal habitat availability) or biological processes (namely match/mismatch with prey availability) (Zhang et al. 2000). Mid-trophic pelagic species (i.e. cephalopods and pelagic finfishes) showed the greatest response to these shifts, probably as a result of both changes in spawning areas and migration of northern species into or out of the area (Zhang et al. 2004). For example, common squid and walleye pollock appeared to have an oscillatory pattern of dominance in the Japan/East Sea related to water temperatures (Zhang et al. 2004; Minobe 1997). During cool water regimes (e.g. after the 1977 regime shift) the winter spawning areas of common squid contracted and were restricted to the East China Sea (Sakurai et al. 2000; Sakurai et al. 2002). Conversely, during warm water regimes (e.g. after the 1989 shift), the winter spawning areas expanded to include the Japan/East Sea and subsequent adult stocks increased in abundance in that area. In addition, the year-class strength of walleye pollock was positively related to cold water temperatures such that when common squid spawning area was contracting, the distribution of walleye pollock was expanding southward into the Japan/East Sea (MOMAF 2003). Zhang et al. (2000) hypothesized that Pacific saury and Pacific sardine population responses to climate regime shifts were regulated through bottom-up processes, specifically with match/mismatch with primary production. For Pacific saury, the 1977 climate regime shift resulted in warm, oligotrophic waters and a reduction and delay in primary productivity coupled with an earlier than normal arrival of Pacific saury to the summer feeding grounds (Zhang and Gong 2005). Conversely, Pacific sardine distribution during the 1977-1988 regime period matched with the temporal availability of fall blooms resulting in a higher Pacific sardine abundance (Zhang et al. 2000).

8. Global Warming Impacts on Key Species

The most recent assessment of the Intergovernmental Panel on Climate Change (IPCC 2007a) reports on climate projections under various greenhouse gas concentrations. Global General Circulation Models (GCM) use four main scenarios of global population growth and greenhouse gas emission to forecast future global climate variables, such as

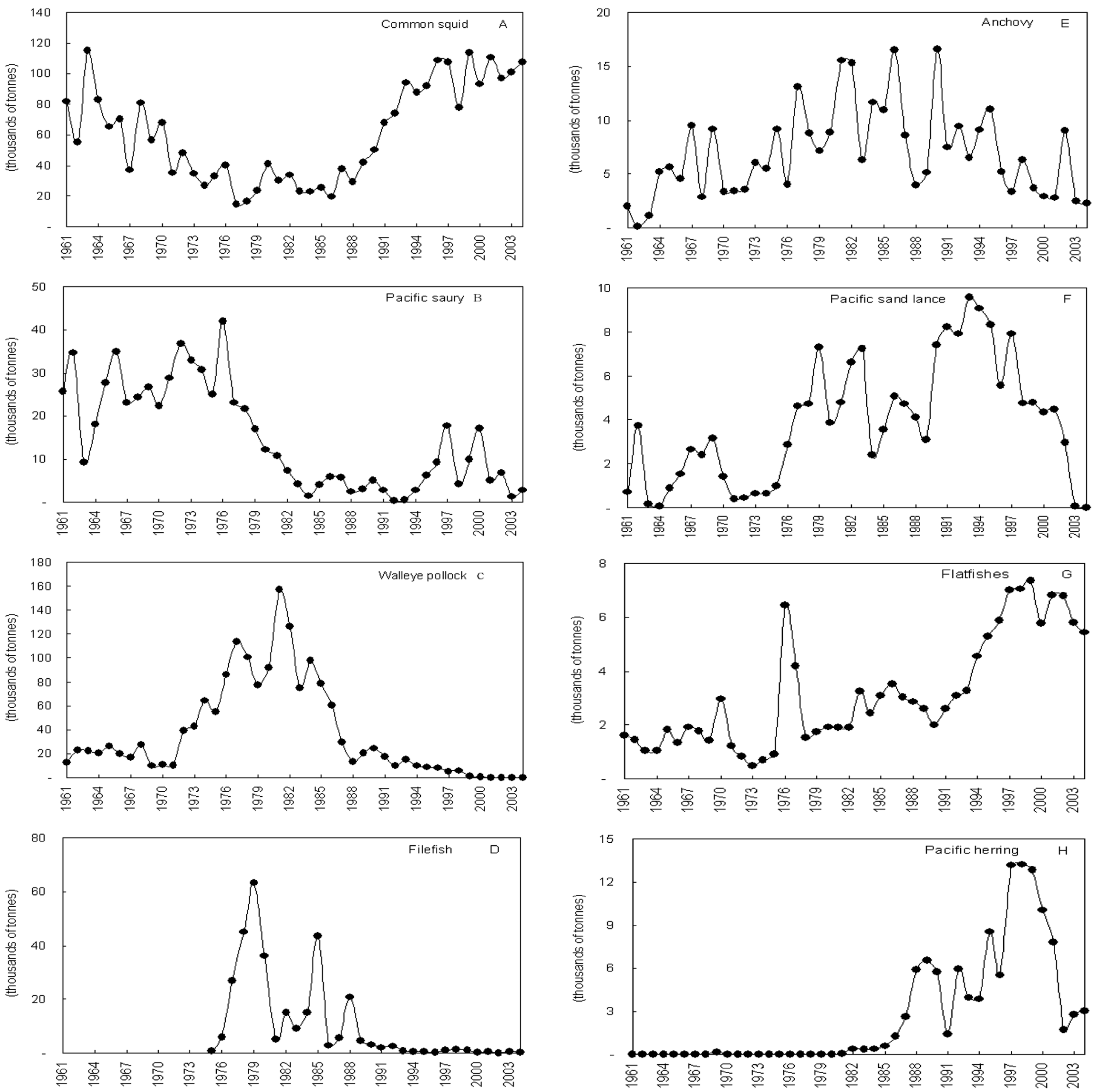

Fig. 5. Commercial landings (thousands of tonnes) of the dominant historical catch by species in the Japan/East Sea from 1961 to 2004: A) common squid. B) Pacific saury. C) walleye pollock. D) filefish. E) anchovy. F) Pacific sand lance. G) flatfishes. H) Pacific herring (MOMAF 2005).

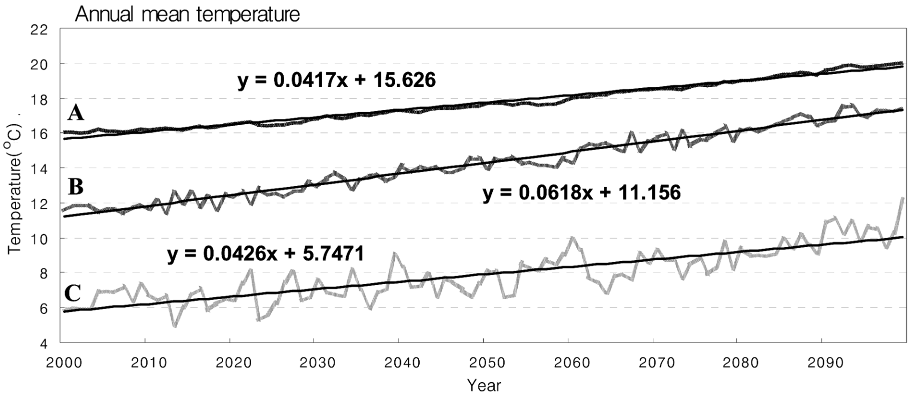

Fig. 6. Annual changes in a) global; b) the Korean Peninsula (East Asia) and; c) the west coast of Vancouver Island (West North America) surface temperature for the next 100 years (2001-2100) predicted by regional climate models based on the SRES A2 greenhouse emission scenario (updated from Oh et al. 2004).

air temperature and precipitation (IPCC 2007a). The projections are usually made for 40-80 years from current, though some are up to 150 years from current. New climate modelling research presented in the IPCC (2007a) report is the development of regional Atmosphere-Ocean General Circulation Models (AOGCM). These AOGCM have a higher resolution for regional areas that are between 10^4 and 10^7 km^2. The west coast of Vancouver Island would fall into the Western North America (WNA) region which encompasses 30ºN to 60ºN west of 110ºW. The Tsushima Warm Current System would fall within Eastern Asia (EAS) region which is between 20ºN and 50ºN east of 100ºE.

Figure 6 compares the predicted annual mean temperature changes for the EAS and the WNA for the future 100 years (2001-2100) by the regional climate simulation (updated from Oh et al. 2004) based on the SRES A2 CO_2 emission scenario (i.e. a doubling by the year 2050). The predicted mean warming rate over the Korean Peninsula and the East Asia is 0.62 ºC/decade for the next century for a total of 5.5 ºC change in annual temperature (Fig. 6). This warming rate is somewhat faster than the global temperature change predicted (3.7 ºC) by the ECHO global climate model simulation of the global mean temperature (Fig. 6). The predicted warming trend for the west coast of Vancouver Island (i.e. WNA) is 0.43 ºC/decade or a total of 3.9 ºC for the whole century (Fig. 6). This is only slightly higher than the predicted global temperature change (0.42 ºC/decade and a total of 3.7 ºC); however, the predicted interannual variability for the WNA is larger compared to both the global and the EAS region warming trends (Fig. 6).

The IPCC (2007a) identified the incorporation of decadal-scale atmospheric processes, coupled to oceanographic processes, as a key direction for future research in global climate modelling. Currently, GCM and AOGCM do not simulate decadal-scale regime transitions. When developing scenarios of climate change impact on marine ecosystems and resources, the limited range of output variable of GCM and AOGCM (primarily air temperature and precipitation levels), the timeframe of projection (40-80 years) and the lack of decadal-scale atmospheric-oceanic processes is constraining. Air temperature and precipitation levels can not be linked directly to the mechanisms that drive physical and biological changes in marine ecosystems. Agencies responsible for management of marine resources face potentially substantial and immediate changes to resources, which would require shorter term (10-20 years) projections of climate change impacts in order to develop strategic plans and management frameworks (IPCC 2007b, 2007c). Much research has been published on the impacts of climate regime-shifts on marine ecosystems (Seo et al. 2006), and this is likely the area in which climate forcing mechanisms can be determined. We propose that the changes observed in the last 25 years are probably the best source of information for projecting the types of expected climate variability and impacts on marine ecosystems for the upcoming 25 years.

Canada

Over the last three decades, there has been an overall warming of sea surface waters off the west coast of Vancouver Island (McFarlane et al. 2000). The physical oceanography off the west coast of Vancouver Island is influenced by the Aleutian Low in winter. Intense Aleutian Low pressure systems result in increased poleward and onshore transport of southern, warm waters in winter. Warmer upper waters increase water column stability, thereby reducing the depth of the mixed layer. In addition, vertical velocity at depth further pushes up the mixed layer, creating a shallower, warm layer. This shallowing of the mixed layer depth means that the deeper, cold, nutrient rich water is available to the photic zone which translates into increased primary productivity. An intense Aleutian Low also increases onshore transport, which can act to retain larval fish and zooplankton near the productive coastal areas (PICES 2004). In the last 25 years, there has been a decadal-scale pattern to the relative intensity of the Aleutian Low. However, there appears to be an increasing trend in Aleutian Low intensity over the last century. It is unclear if this is a signal of global warming, as suggested by some researchers (Mote et al. 1999; Raible et al. 2005), or if it is a reflection of the recent trend for shorter regime periods and hence shorter periods with weak Aleutian Lows. Using the environmental data of the past years, it is likely that there will be a high occurrence of intense Aleutian Lows, which will translate into shallower mixed layer depths, increase primary productivity and increase shoreward retention of larvae and zooplankton (Zhang et al. 2000). Warming of sea surface waters will likely continue (IPCC 2007a).

The major effects of warming SST on species off the west coast of Vancouver Island will be manifest in two ways: 1) distributional shifts; 2) changes in dominant fish species. The west coast of Vancouver Island is the northern extent of the California Current System. This system is dominated by two migratory pelagics: Pacific hake and Pacific sardine. Pacific hake adults migrate into Canadian waters to feed in summer, and return to offshore spawning grounds off California in winter. Juvenile Pacific hake remain in coastal feeding areas off California until they mature and join the migrating adults (Beamish 2008). Global warming and continued increase in SST could result in a greater proportion of the stock migrating into Canadian waters as well as extending their northern distribution (Fig. 7). In addition, conditions may arise such that spawning grounds will shift northerly, possibly including the west coast of Vancouver Island. These distributional changes could have two impacts: 1) increased prevalence of adults; 2) prevalence of juveniles in coastal areas off of Vancouver Island resulting from northerly spawning. The increased presence of adults will increase predation on fishes such as Pacific herring and will increase competition with fishes for prey items such as euphausiids.

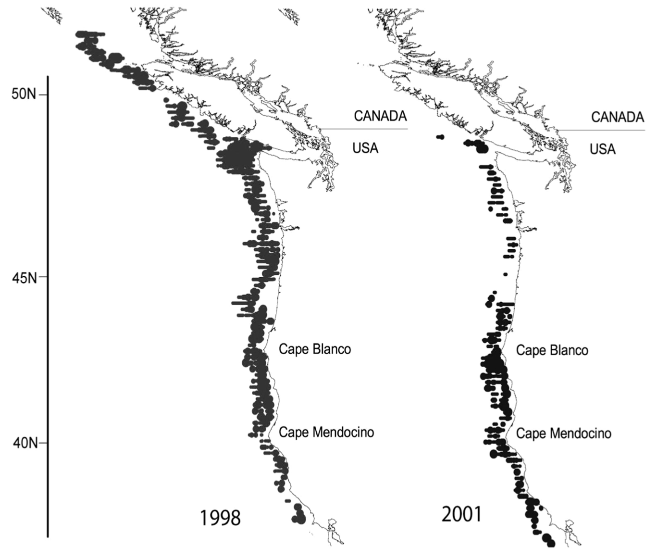

Fig. 7. Temporal comparison in spatial distribution of Pacific hake in 1998 (El Niño year) and 2001 (La Niña year) in the California Current System based on joint Canada-US surveys. Circles along survey transect lines represent relative density of Pacific hake as determined from acoustic backscattering. In the warm year (1998), Pacific hake distribution was at an extreme northward range that included the whole coast of Canada and into the southern Gulf of Alaska. In the cold year (2001), this range was greatly reduced with very few fish in Canadian waters. Figure modified from Wilson et al. (2000) and Guttormsen et al. (2005).

The overlap between adults and juveniles could also result in reduced year class success due to cannibalism. Global warming and continued increase in SST will have similar distributional impacts on Pacific sardine, such that a larger biomass will be present in Canadian waters. In addition, small resident spawning populations and their juveniles may become established. Pacific sardine consume diatoms, copepods and euphausiids; they are both a competitor and predator of copepods and euphausiids. Their increased competition and predation could limit food availability for such fishes as Pacific herring and juvenile coho salmon off the west coast of Vancouver Island. In addition, Pacific hake is a predator of juvenile Pacific herring which could impact recruitment success (Beamish 2008).

The west coast of Vancouver Island is a major rearing area for coho salmon (*Oncorhynchus kisutch*) and chinook salmon (*O. tshawytscha*). They originate from hatcheries and from local rivers on the west coast, including rivers to the south in the United States, from rivers flowing into the Strait of Georgia and into Puget Sound (Beamish et al. 1995, 2000). In recent years virtually all of the approximately 30 million coho salmon produced in hatcheries around the Strait of Georgia and Puget Sound spent their winter off the west coast of Vancouver Island. In recent years approximately 60 million chinook salmon were also produced in these hatcheries and many of these chinook salmon reside off Vancouver Island (Trudel et al. 2004). In addition to these hatchery fish there are large numbers of wild coho and chinook salmon that rear in the area.

The marine survival, and subsequent productivity, of these Pacific salmon is strongly affected by the annual variability in ocean conditions throughout the year (Beamish and Mahnken 2001; Beamish et al. 2004). There also are climate forcing impacts on ocean conditions that result in decadal-scale trends in productivity (Beamish and Bouillon 1993; Beamish et al. 1995, Beamish et al. 1999, Beamish et al. 2000). This interannual and inter-decadal variability in the ocean habitat of coho and chinook salmon translates into variability in the growth and survival of these salmon during the first ocean winter (Beamish and Mahnken 2001; Beamish et al. 2004). If winter conditions are harsh, coho salmon that did not store enough lipids during the summer will perish. The feeding conditions off the west coast of Vancouver Island and in the Strait of Georgia and Puget Sound affect summer growth, but the winter conditions in the waters off the west coast affect survival.

The effects of future climate trends on the productivity of coho and chinook salmon are complex, partially because many fish are produced in hatcheries. During the past 25 years, wild stocks of these two species have not done well off the west coast of Vancouver Island. Marine survival has fluctuated, but overall it has been much lower than in the 1960s and 1970s (Beamish et al. 1995, 2000). However, hatcheries are capable of producing large numbers of smolts and controlling their release times, and hence their release size. During periods of reduced ocean carrying capacity, and subsequent reduced growth and survival for fish, returns of hatchery produced fish could be optimized by actually reducing hatchery releases and thereby reducing competition for food. In addition, by releasing juvenile salmon at appropriate sizes, it may be possible to mitigate the impacts of climate change and compensate for lost wild production. In general, the future does not look bright for wild coho and chinook salmon in this area, but fisheries could be sustained artificially if the appropriate monitoring and research is undertaken.

A conceptual mechanism linking climate forcing to year-class success for sablefish off the west coast of Vancouver Island was proposed by McFarlane and Beamish (1992). Briefly, intense Aleutian Lows in winter increase primary productivity and subsequent copepod production (as outlined above) and years with these conditions correspond to strong sablefish year classes. The recruitment success is partially determined by the increase in copepod production and the match of first feeding sablefish larvae with copepod nauplii at depth. If global warming results in a greater frequency of intense Aleutian Lows, sablefish should experience strong year classes.

Pacific cod is a demersal species that is at the southern extent of its distribution off the west coast of Vancouver Island. Off Vancouver Island, Pacific cod spawn on the bottom, at depth between 60-80 m. Increased warming of waters at these depths could have negative impacts on spawning and recruitment success. The distribution of Pacific cod could be forced further north, with little occurrence off the west coast of Vancouver Island.

Korea

Warming trend in seawater temperature is evident around the Korean Peninsula (Jung 2008). Hahn (1994) revealed that increase of sea surface temperature was more pronounced in winter compared to summer: specifically, the February sea surface temperature had increased 1.8 ℃ during the past one hundred years. Analysis of Korea Ocean Data Center data also indicated that sea surface temperatures increased by 0.93 ℃ and 0.79 ℃ in the East China Sea and Japan/East Sea during the last 35 years, respectively (Hahn 1994).

Assuming a persistent increase in sea surface water temperature in the northeastern coastal areas of Asia during next decades, it is expected that the habitats of warm water species will be expanded toward the north. Based on 50 years SST observation in the northwestern Pacific by Japan Meteorological Agency, Kim (1995) predicted the retreat of cold water species and colonization of warm water species in Korean waters in the 21st century. Actually, due to the increase in seawater temperature, the abundance of warm water species has increased in Korean waters, and the catch distribution of these species has changed to move northward recently. For example, the catches of warm water species such as chub mackerel, common squid, and Jack mackerel, had increased rapidly in Korean waters during the 1990s. Also, the northern limit of the CPUE distribution of mackerels

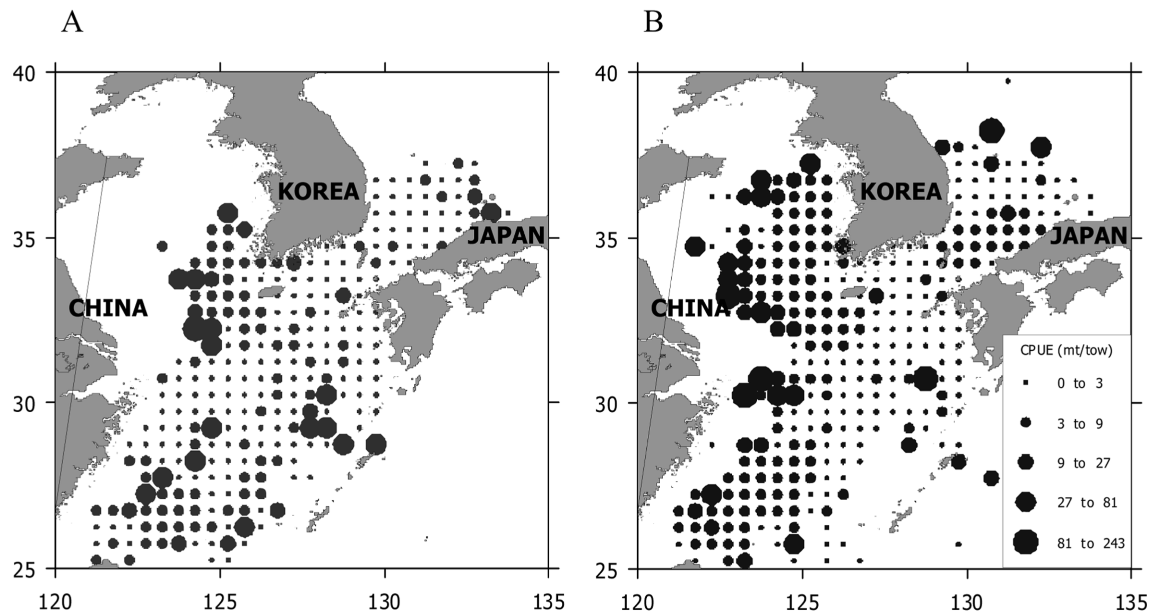

Fig. 8. Temporal comparison in spatial distribution (mean catch per unit effort) of mackerels by Korean and Japanese large purse seine fishery around Korean waters during the periods of (a) 1981-1986 (warm period) and (b) 1991-1996 (cool period) (J.B. Lee, pers. Comm., NFRDI).

(mostly chub mackerel, *Scomber japonicus*) expanded to further north during a cool period in the 1990s (1991-1996) (Fig. 8). The catch proportion of mackerel-like pelagic warm water species, such as spotted mackerel (similar to chub mackerel, *Scomber australasicus*) and whitetip scad (similar to jack mackerel, *Decapterus maruadsi*), and northern bluefin tuna (*Thunnus thynnus*) has been remarkably increasing since 2000 in Korean waters (J.B. Lee, pers. comm., National Fisheries Research and Development Institute of Korea).

The Korean Peninsula is located in southern limit of walleye pollock, Pacific cod and chum salmon distributions. These cold water species might be seriously influenced by the warming trend in seawater temperature. The catch and abundance of walleye pollock still remained at a very low level in Korean waters, and its distribution was limited in northern area since the late 1980s. The growth rates of fingerling salmon in Korean waters were higher in the 1990s than in the 1980s due to favourable growth conditions which seemed to be derived from the increase of zooplankton biomass in the Japan/East Sea (Seo et al. 2006). Despite a relatively good growth rate in 0-age in 1990s, however, marine survivals of chum salmon was very low (< 2%) and sometimes fell to less than 1%. Sporadic events in high seawater temperature (>15 °C) during fry release may cause high mortality of young salmon. Continuous warming trend of seawater temperature in the Japan/East Sea will be detrimental to salmon survival as well as salmon enhancement program of Korea.

The increase in seawater temperature could lower dissolved oxygen concentration, and organisms in confined water mass such as lakes or cages would suffer from hypoxia. Roughly, one third of marine products are currently from marine aquaculture in Korea (MOMAF 2008), and elevated seawater temperature in the near future may influence negatively on aquaculture organisms and industry. Because of short adaptation period, compared to fast warming rate in Korean waters, aquaculture organisms (especially, sessile organisms such as seaweeds and clams) will be expected to experience the upper thermal limit.

9. Challenges for Future Management

The different physical features of the two ecosystems, coupled with different historical fisheries and management approaches, along with composition of the commercial catch have led to two different current ecosystem structures off Canada and Korea. The species assemblage in the Japan/East Sea is predominately short-lived, pelagic species. Conversely the species assemblage off the west coast of Canada is a mixture of short-lived, pelagic species and long-lived, demersal species. Since the Japan/East Sea is a deep basin, bottom trawl fisheries are very limited within the narrow shallow shelf region in the coastal area. Instead, gillnets, set nets, traps and longline fisheries have been actively targeting pelagic species and coastal demersal species. It is unlikely that fisheries management actions could be taken which would result in the re-establishment of robust demersal, long-lived populations. The current ecosystem, which is composed of short-lived, pelagics, requires adaptive management strategies that incorporate rapid actions. Such fast and flexible actions are capable of dealing with the rapid changes in species composition and large amplitude changes in abundance that are likely to occur with regime impacts or potential global climate change. For Canada, this type of adaptive management could be applied to the management of short-lived, pelagics. Adaptive management is also required to accommodate changes in species compositions that may result from irreversible changes in species distribution due to global warming (King and McFarlane 2006). For example, Pacific cod is at the southern extent of its distribution and could in the future be naturally extirpated from the region off the west coast of Vancouver Island. In addition, fishing opportunities may open for other species that expand their range northward. For the management of long-lived, demersal species (e.g. sablefish) frameworks need to encompass the conservation of spawning biomass to ensure that these species can withstand the decadal period of poor oceanic conditions for recruitment. These conservation strategies need not be severe if global warming also increases the frequency of decadal period of good oceanic conditions for recruitment.

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