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PART 1. COASTAL PELAGIC FISHES
(Report of Working Group 3)

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PART 2. SUBARCTIC GYRE
(Report of Working Group 6)

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1.0 INTRODUCTION

The objective of the Coastal Pelagic Fishes Working Group of PICES (see terms of reference) is to determine the characteristics of the environment, other than fishing, that affect the dynamics of the pelagic fish stocks of the North Pacific. Long term population changes, such as those that may be produced by global climate change, are of particular interest. Consequently, the research and related activities of the Group can be considered to be part of the GLOBEC International program of any PICES country.

The pelagic fishes currently considered by the Working Group are: Pacific herring, (*Clupea pallasi*); sardines (*Sardinops spp*); anchovies (*Engraulis spp*); mackerels (*Scomber spp, and Trachurus spp*); and saury (*Colorabis saira*). The world catch of these pelagic fishes in 1990 was 25 million tons. This catch was 35% of the world catch of marine fishes (Table 1). About 7 million tons of small pelagic fishes are taken annually in the North Pacific (FAO Statistical Areas 61, 67, and 77), with the Japanese sardine accounting for 65% of the total. Only a small portion of the world catch of small pelagic fishes are used directly for human consumption, most of the catch is reduced to fish meal and oil with the meal being an important ingredient of animal feeds. In Japan, where 80-90% of sardine and anchovy catch is used for meal, meal is used to support a rapidly growing fish aquaculture industry. Aquaculture production of fish in Japan, which has tripled between 1970 and 1990, could be seriously affected by a major decline in the Japanese sardine stock.

The general research approach of the Working Group is the comparative method. Our terms of reference state we are "to develop a program for a comparative study of the population dynamics and production of small pelagic fishes in the coastal ecosystem along the western and eastern continental margins of the North Pacific". Comparisons of the dynamics of marine animal populations can be used to test a variety of hypotheses. Comparisons of the same or similar species in different ecosystems can be used to assess effects of population response to different forcing variables (Bakun & Parrish, 1982). Alternatively, comparisons can be made of recruitment success of different species within the same ecosystem to identify specific patterns in the responses to basin-wide environmental change (Hollowed et al., 1987; Koslow, 1984).

Variation in abundance

Great variation in population size is characteristic of the major stocks of small pelagic fishes (Csirke, 1988). Considerable variability exists between species and regions. In Japanese waters, the catch of the sardine fluctuates over a two order of magnitude range while anchovy, mackerel, and saury are less variable (Table 2). In California, the same pattern emerges with the sardine population being much more variable than either anchovy or mackerel. Considering the differences in the data between Japan and California, the variability of the three stocks is remarkably similar in the two systems with the coefficient of variation for sardine about twice that for mackerel and with anchovy being roughly a third as variable as sardine. The most striking difference between the two systems is the much greater productivity of the Japanese stocks. On the average, landings of Japanese sardine, anchovy, and mackerel exceed the biomass of the equivalent California stocks.

The processes affecting the recruitment of year classes, and therefore population growth, have been researched for the last 20 years. This body of information on herring, anchovy and sardine, indicates that the recruitment success depends upon the survival of the early life history stages over the first 6 months of life with survivorship in the egg and larval stages being the most variable. Starvation as well as predation may be an important source of mortality during the first few weeks of life but thereafter survivorship is a function of larval growth and their size specific vulnerability to predators. Starvation and growth of early life history stages is fairly well documented but few quantitative estimates of predation exist.

A succession of strong or weak year classes over a decade or more are needed to realize the large and long fluctuations in population biomass, characteristic of many clupeoid populations. This pattern is also found in the physical oceanographic data where decadal periods of ocean climate exist (often called regimes) in which recruitment is either consistently lower or higher than the mean. In support of this argument authors point out correspondences between successions of strong or weak year classes and periods of lower or higher than average sea surface temperatures. How such temperatures affect recruitment remains obscure, however.

Persistent patterns in the success of year classes suggests to others that a positive feedback loop regulating population growth might exist, instead of the density-dependent negative feedback loop usually postulated as a regulatory mechanism.

A positive feedback loop is possible in Japanese and California sardine since growth, migration, feeding habitats, and spawning habitats change as their populations grow. In the Japanese sardine energy allocation between growth and reproduction, egg and larval transport from spawning grounds to nursery grounds by the Kuroshio Current, may all be linked to population size. Thus, population response to changes in physical forcing variables may be modulated by internal population processes. Consequently, the long term effect of physical forcing variables on populations should be examined within the context of possible density dependent processes.

Lastly, it is important to recognize that these small pelagic fishes may be more closely linked to long term changes in primary and secondary production than are most other major stocks because they are planktivorous throughout their lives.

2.0 DESCRIPTIONS OF STOCKS

2.1 Eastern Pacific

2.1.1 California Sardine (*Sardinops sagax*)

Three stocks of sardine occur in the north eastern Pacific: a Gulf of California stock (Mexico); a southern Baja California stock (Mexico) [Punta Baja, Mexico to Cabo San Lucas]; and a northern stock (Punta Eugenia, Baja California, Mexico to Monterey, Alta California, USA). The northern stock, immortalized in Steinbeck's book, *Cannery Row*, has a summer feeding migration where fish migrate as far north as British Columbia, Canada.

In 1979, about 20 years after its near-total collapse, the northern stock showed the first signs of recovery. The beginning of the recovery is best illustrated by the average number of sardine eggs taken in CalCOFI cruises (Fig. 1, upper panel). The stock was probably less than 10,000 mt in the early 1970s. Currently, the spawning biomass may exceed 100,000 mt, which is still a small fraction of the maximum historic spawning biomass of 3.5 million tons. Some confusion exists regarding the timing of the recovery of the northern stock because FAO combines the landings for the northern and Gulf of California stocks. A new Mexican fishery on the Gulf of California sardine began in the early 70s, reaching a peak catch of over 300,000 tons by 1988 and has declined thereafter. The combined FAO landings give the impression that the northern stock underwent a striking recovery in the 70s and 80s coinciding with the striking recovery of the Japanese Stock (Kawasaki, 1991). The recovery of the northern sardine stock did not occur at the same time as the Japanese sardine; in fact, the northern stock did not exceed 20,000 mt until 1986 (Wolf, et al., 1987). Today (1993) the combined U.S. and Mexican catch of the northern sardine stock is about 60,000 mt. What was interpreted as a recovery was the development of a new Gulf of California fishery for sardine. Ironically, the Gulf of California stock, with catches declining since 1989, collapsed in 1993 with a total catch of less than 20,000 mt. It should be mentioned, however, that genetic analysis indicates that these stocks are part of a common population, but their dynamics are clearly different.

The current interpretation of the collapse of northern stock is that overfishing exacerbated a decline caused by environmental change, a decade of persistently cold sea water temperatures which were unfavorable to sardine recruitment. Recent work by Jacobson and MacCall (ms.) indicates that when sea surface temperatures (as measured at Scripps Pier) average $17.3°C$ the maximum sustainable yield (MSY) of sardine may be about five times the MSY when sea surface temperatures average $16.6°C$. At this time the mechanisms responsible for the relation between sardine recruitment and sea temperature are unknown.

Smith, et al., 1992 estimated rates of California sardine population growth and decline using the scale deposition data from Baumgartner, et al., 1992 changes in standing crop of sardine eggs, and virtual population analysis. Fastest population growth was based on egg abundance of the northern stock of sardine (1975-1991) where annual growth was 70% per year, and fastest declines for the same population were 20-30% per year. Analysis of the effects of life stage specific differences in mortality and growth using Lefkovitch Matrix models indicate that population changes equivalent to those observed in sardine can be produced by altering early or late larval mortality or growth rates within the range of published values (Butler, et al., 1993). Thus, the central question for the California sardine from a climate change perspective is: what are the environmental conditions that persist over a decade or more, affect survival and growth of sardine larvae, and are correlated with three year average sea surface temperatures?

2.1.2 The Northern Anchovy (*Engraulis mordax*)

The northern anchovy population is divided into four stocks, a northern stock that extends from

British Columbia to San Francisco; a central stock which extends from San Francisco to Punta Baja, Mexico; and a southern stock that extends south from Punta Baja to Cabo San Lucas. In 1986 a recent invasion of northern anchovy into the Gulf of California (Mexico) was documented by Hammann (1989) indicating the formation of a new Gulf stock of anchovy. Sedimentary scale evidence indicates anchovy have not been in the Gulf for over 100 years (Baumgartner, pers. comm.). The recent invasion is in rough correlation with a decline in the Gulf sardine stock.

The largest and best known stock is the Central sub-population. The biomass of this stock was low in the 1950's and 60's (200-500,000 mt) grew rapidly in the early 70's, reaching a maximum historic biomass of 1.2 million tons in 1973 (Jacobson and Lo, 1993), and declined thereafter. Over the last 5 years the biomass has stabilized in the 300-400,000 mt range. A 60,000-300,000 mt reduction fishery existed from 1969 through 1989, but landings have been less than 11,000 mt since 1989. Declines in biomass in recent years were probably due to low recruitment rather than high fishing mortalities (Jacobson and Lo, pers. comm.). The most striking feature of the 30 year anchovy time series was an extra-ordinarily large recruitment in 1972, ushering in a decade in which 7 years exceeded the mean. This period of high anchovy abundance coincided with the continuing decline of the sardine.

A pair of clupeoids, a sardine and anchovy, exist as part of the pelagic fish assemblages in many of the worlds oceans. The decline in one member of the pair, usually the sardine, has occurred in rough correlation with an increase in the biomass of the other (Blaxter and Hunter, 1982). This has led to considerable speculation regarding the potential interaction of these two species. Since their food overlap is broad, inter-specific competition for food has often been inferred. The only direct evidence of interaction is provided by Butler (1991). He found that mortality rates of sardine larvae (>20d) increased between 1951-1967 and the increase was positively correlated with the increase in biomass of the northern anchovy. He attributed the correlation to predation by anchovy on sardine eggs and larvae.

Life stage sensitivity analysis for anchovy using Lefkovitch Matrix models indicates that the most sensitive stages were the early larval (4-10 mm) where the fastest growth rate or lowest mortality rate leads to a 270% increase in population size (Butler et al., 1993).

2.1.3 Pacific Mackerel (*Scomber japonicus*)

Two major peaks in the biomass of Pacific mackerel have occurred over historical times, 1925-1935 when the stock exceeded 400 thousand mt and during the early 80's when the stock reached the same level (MacCall, et al., 1985). The paleo-sedimentary record of Pacific mackerel scales indicates the 1925-35 peak and another one around 1830. Thus, three major outbreaks of Pacific mackerel have occurred over the last 162 years. The 1925-35 and 1980s peaks coincided with warm water regimes. Minimum levels of abundance occurred in the late 60s reaching less than 10,000 mt by 1966, and remaining low until the late 70s. The 1976 year class that initiated the recovery of the fishery was in the upper 25% of all year classes, but it was produced by a spawning biomass of less than 10,000 tons. The stock has been declining slowly since the peak biomass in 1982; the estimated 1992 biomass was 124,000 mt.

Unlike sardine and anchovy, no dependable data exists on egg and larval mortality rates nor on larval and juvenile growth in the sea. Accurate estimates of larval mortality may never be practical because of the highly patchy distribution of the spawn. Preliminary work indicates that some mackerel females spawn daily (Dickerson, et al., 1992) but estimates of stock spawning rates would be difficult and costly due to the patchiness in the distribution of spawning and non-spawning fish. For these reasons either anchovy or sardine may be preferable to mackerel as a subject for cooperative research on effects of Climate Change on fish population dynamics.

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2.1.4 Pacific Herring (*Clupea pallasi*) of the Northeastern Pacific Ocean

Distribution & Biology

In the Northeast Pacific herring are distributed along the west coast of North America from California to the Chuckchi Sea with some small stocks in estuarine arctic waters. The greatest abundance is from British Columbia to the Bering Sea. Stocks in California, Oregon, and Washington are small relative to the more northern stocks. Major aggregates of stocks are harvested in San Francisco Bay, Northern Washington-Southeastern Alaska, Prince William Sound, Kodiak Island, Cook Inlet, and eastern Bering Sea in North America.

Pacific herring spawn exclusively in spring, in shallow inter- and subtidal waters. After a 2-3 week incubation, eggs hatch into pelagic larvae and disperse throughout local nearshore coastal waters. After a 1-2 month larval stage the young herring reside mainly in nearshore waters for a 1-2 year juvenile period. They mature sexually in 2-4 years (earlier in south) and spawn once per year for the remainder of their lives. Most herring live for 4-5 years with a few living to 15 years (Grosse & Hay, 1988).

Adults spend summers in a relatively large number of small, dispersed schools and feed mainly on copepods and euphausiids. Movement to summer feeding grounds for larger stocks may require extensive migrations of several hundred kilometers or more, to offshore banks, while migrations to feeding grounds of smaller stocks may be more geographically restricted. In the winter, adult herring form a small number of large aggregations in the same overwintering areas each year. In the spring herring move from these areas to spawning areas, that also are consistently occupied each year.

Stocks and fisheries

North American herring fisheries started as food fisheries in the early 1900s producing salt or dried herring. In the late 1920s industrial herring fisheries developed for oil and meal and catches rose rapidly in British Columbia to South-central Alaska where the largest fisheries occurred. Reduction fisheries persisted until the mid-1960s when the fishery closed due to economic competition from Peruvian anchovy and other cheaper meals, and the closure of some fishing areas to preserve herring for salmon forage. In British Columbia a moratorium on herring fishing was established, following a collapse of the herring stock in the mid-1960s (Fig. 2), and maintained until stocks recovered in the early 1970s (Hourston, 1980).

In the absence of fishing, the British Columbia stocks began to increase and in 1972 a roe fishery began which grew to a peak harvest of 80,000 t in 1976-78. In subsequent years the harvest was reduced to about 30-40,000 mt because of concern that high harvests could not be sustained.

Roe herring fisheries also developed in Alaska in the early 1970s, and harvests have been very conservative with exploitation at 10-20% of estimated biomass which has averaged less than 10,000 t annually. In the eastern Bering Sea a distant water fishery was established in the late 1950s by Russian and Japanese vessels. Catches rose rapidly to a peak in the early 1970s, and then declined, and the off-shore foreign fishery was replaced by an inshore roe herring fishery in the late 1970s.

Individual stocks of herring in the northeastern Pacific Ocean have exhibited wide variations in abundance. Sometimes, exceptionally large year classes, such as one in 1977, were synchronous over broad geographical ranges (from Vancouver Island to central Alaska). In other years there may be large differences in cohort strength between reinforcing stocks, such as the Queen Charlotte Island and the mainland of British Columbia. Year-class synchrony in the northeastern Pacific appears to correspond to hydrographic domains with distinctly different recruitment patterns between Alaskan and Canadian stocks (Zebdi and Collie, ms).

In the eastern Bering Sea only about a third of the variation in year class strength can be accounted for by variation in spawning stock size, indicating that environmental factors are important determinants of year-class size (Wespestad and Gunderson, 1991). Climatic effects of wind-driven transport and temperature describe a portion of the residual variation in recruitment, but about 50% of the total variation is left unaccounted. The remaining variation may relate to large-scale physical processes, or local variation in biological processes, for which accurate measures are unavailable.

In the middle part of their range, Washington to central Alaska (Prince William Sound) herring are the most abundant small coastal pelagic fish. They are consumed as principal or secondary prey by many piscivores such as the Pacific cod (*Gadus macrocephalus*), the chinook and coho salmon (*Oncorhynchus tshawytscha* and *O. kisutch*), Pacific hake (*Merluccius productus*), as well as many sea birds and marine mammals (Hay et al., 1992). In this capacity they serve as a principal vehicle for energy transfer from lower to higher trophic levels. Predation has been shown to be a significant source of mortality and may contribute to variation in year-class size (Walters, et al., 1986; Ware 1991). Predation on herring is modified by environment in some cases. Ware and McFarlane (1989) found that in El Niño years hake extended their range into areas occupied by herring resulting in increased herring mortality.

2.2   Western Pacific

2.2.1 Japanese Sardine (*Sardinops melanostictus*)

A major part of this section is based on preliminary results of the BICOCOSMOS project, a ten year research project on Japanese sardine ecology and population dynamics, which began in 1989; results from this project will appear in journals in the near future.

Isozyme analysis for genetic divergence indicates that several stocks of Japanese sardine (*Sardinops melanostictus*) are a single population. The population fluctuated greatly over the last two decades; it began to increase in the mid-70's, reached a peak in the mid-80s, and has been declining since 1989. Total catch of the Japanese sardine was 20,000 mt in 1970. It increased to 2,210,000 mt in 1980 and reached a maximum of 4,490,000 mt in 1988. The catch declined after 1989, falling to about 2,000,000 mt by 1992.

On the Pacific side of Japan, sardine spawn along the Kuroshio Current in February and March. Eggs hatch two days after fertilization at 17-18°C and the larvae start feeding within two days after hatching. Egg and larvae are transported to the east by the Kuroshio Current as fast as 2-3 knots (1.0-1.5 m/sec) and in a few months when the larvae are 20-30 mm, they reach the Kuroshio Extension off the Boso Peninsula east of Honshu Island, Japan. Part of the cohort leaves the Kuroshio Current and enters the coastal waters along the Pacific side of Honshu Island forming shirasu fishing ground for sardine larvae.

While being transported by the Kuroshio Extension, the larvae metamorphose into the juvenile stage and in early summer they start a northward migration through the mixing water between the Kuroshio and the Oyashio fronts. They use warm streams and warm core rings derived from the Kuroshio Extension as migratory paths. They cross the Oyashio front and feed on abundant zooplankton and phytoplankton in the Oyashio water in summer. In autumn they migrate south to the waters off Boso Peninsula. The one year old sardines return to Oyashio waters the following summer.

The sardine mature in 2 or 3 years. Short day length and a decrease in water temperature in autumn induces sexual maturation and southward migration to the spawning grounds. Nutritional conditions of females at the beginning of sexual maturation have a major effect on the reproductive effort during the subsequent

spawning season (Tsuruta, 1985). Batch fecundity varies from 20,000-40,000 eggs depending on nutritional condition (fat reserves) of females, but the number of batches spawned by females per season is not known). Eggs from fat females are of good quality having a larger yolk volume and higher content of poly-unsaturated fatty acids than those from thin females (Morimoto, 1991).

Since 1990 the percentage of the number of landed sardines older than 4 years has increased rapidly (Fig. 3). The percentage was about 30% or less in the years before 1989, but in 1991 and 1992 it increased to more than 90%.

The number of 1 year old sardine caught in waters east of Hokkaido Island is used as a recruitment index in Japan. From 1986 to 1988 the number of recruits ranged from 2,000-5,500 million fish, but decreased to 0-600 million in 1989-1992. Thus, the population has decreased since 1988 because of recruitment failure. Average egg production in the Pacific side of Japan in 1989-1992 was 4,600 trillion. The recruitment failure was assumed to be due to low survival rates in the stages between the egg to juvenile stage.

When the population was in the early phases of growth in the mid 1970's, the recruitment index (mentioned above) was stable as it ranged between, 1,500-2,000 million fish. When the population was in the older growth phase, reaching a peak biomass 1979-1987, the recruitment index was much more variable ranging between 32 million to 5.9 billion fish with a dominant year class occurring every three or four years. The recruitment failed in four successive years after 1988. In summary, three patterns in recruitment were evident during the rise and current fall of the population. Stable recruitment associated with a growing population, fluctuating recruitment associated with sustained high biomass, and recruitment failure associated with population decline. The population growth and decline of the sardine over the last two decades is considered to be caused by a variation of recruitment which might be due to changes in the mortality of early life stages.

2.2.2 Japanese Anchovy (*Engraulis japonicus*)

The Japanese anchovy population is divided into four stocks which occur in the following four localities: northern Pacific, southern Pacific including Seto Inland Sea, East China Sea, and Japan Sea. Annual landings were high (350-450,000 mt) in 1950s and 1960s when the Japanese sardine (*Sardinops melanostictus*) population was very low, but landings decreased rapidly after 1975, as the sardine population increased. In the 1980s, the landings remained at a low level (150-200,000 mt). The landings have recovered since 1989 as the sardine began to decline. However, the maximum anchovy catch is only a tenth of that of the sardine, and the stock fluctuations are relatively moderate (see Table 2).

The north Pacific stock of anchovy is the largest and most studied. The spawning habits and demography of the stock change with population size, (Funakoshi, 1987). When the stock is small, almost all spawn at one year old in coastal waters and bays during summer and autumn and die after spawning. Their migration range is restricted to the spawning ground areas. On the other hand, when the stock is large they mature at one year old and spawn in coastal and offshore waters in spring. A large proportion survive after spawning and spawn again in next spring. Their migration range extends to the waters off southern Hokkaido.

Watanabe (1992) mentioned that the stock-recruitment relationship based on the total number of eggs spawned seemed to fluctuate clockwise around a certain equilibrium stock level. Funakoshi (1990) concluded that anchovy in plankton rich coastal waters have a higher fecundity, and spawned more frequently, than those spawning in offshore areas where food was less abundant. Laboratory experiments indicate that when food is reduced, anchovy spawn less frequently and the interval between spawning

increases. The number of eggs spawned per female was reduced at high fish density even when food was held constant indicating density dependent affects on egg production (Tsuruta and Hirose, 1989).

A common belief is that anchovy populations vary inversely with sardine populations, but the long-term landing data of pelagic fishes in Japan seem to indicate a more complex pattern of interactions among pelagic species. These data indicate the following sequence: chub and spotted mackerels (*Scomber japonicus* and *Scomber tapaeinocephalus*, group A) was replaced by the sardine (species B); the sardine was replaced by a group of four species (group C), the anchovy (*Engraulis japonicus*), Pacific saury (*Cololabis saira*), and jack mackerels (*Trachurus japonica* and *Decapterus muroadsi*); and the four species in group C were replaced by the mackerel (Fig. 3). Matsuda, et al. (1991, 1992) proposed an inter-specific competition model for groups A, B, and C as a hypothesis for the species replacement. If species A causes a decline in the population of B, B causes a decline in C; and C causes a decline in A, the model predicts that the abundance of these three groups fluctuate forever and dominate in cyclic order. The kinds of interactions occurring among these three groups are not well understood, however. Improved understanding of their interactions seems to be an essential prerequisite for understanding the dynamics of these populations.

2.2.3 Japanese Common Mackerel (*Scomber japonicus*)

Two mackerel species are fished commercially around Japan, the common mackerel and the spotted mackerel (*Scomber japonicus* and *Scomber tapaeinocephalus*). The Japanese common mackerel is a widely distributed migratory fish, while the spotted mackerel has a much smaller range occurring principally in the southern part of Japan. The range for the common mackerel is even wider than that of the Japanese sardine. The northern limits to their distribution is about the same, but unlike the sardine, the common mackerel occurs in the East China Sea (recent catch is 110,000-250,000 mt).

The range of surface temperature for fishing common mackerel falls between 14-18°C. When the stock is large, common mackerel make large scale north-south migrations. The migration to the north is a feeding migration, while the southern migration is a wintering and spawning migration, similar to the sardine. The common mackerel population around Japan consists of four local stocks: Pacific; South Pacific; East China Sea; and Tushima Current (Japan Sea).

In recent years, the landings of the Pacific stock are 60-70% of the total Japanese landings. The catch from the Pacific stock increased remarkably in the 1970's reaching a peak of 1,300,000 mt in 1978; recent catches fluctuate between 200,000-300,000 mt.

2.2.4 Pacific Saury (*Cololabis saira*)

Pacific saury occurs throughout most of the northern Pacific. In the Western Pacific, saury is one of the major commercial species taken by Japanese, Russian, and Korean fisheries. No estimation of the population size exists because the distribution of the larvae, juveniles and adults is continuous from the Western to the Eastern Pacific.

After World War II, a new fishing gear, the stitch-held dipnet (bouke-ami), was introduced in Japan. Total catch increased remarkably after the introduction and reached a peak during 1955-63 with a maximum catch of 575,000 mt in 1958. Catch decreased in late 60s down to 52,000 mt in 1969. Annual fluctuation of the catch was quite large in 70s ranging between 87,000 to 427,000 mt. In the 80's, the catch stabilized because of landing regulations adopted by the saury fishermen association. Abundances of larvae, juveniles, and adults indicate that the population in the Western Pacific has been increasing since 1988.

Saury spawns off the northern Honshu Islands in autumn and spring, and in the Kuroshio area in winter. Juveniles from different spawning seasons start migrating north in early summer to the Oyashio area where they feed on abundant zooplankton, especially *Neocalanus plumchrus* and euphausiids. Otolith analyses (Watanabe, 1988), rearing experiments (Hotta, 1958, Watanabe and Kuji, 1991), and increase in body length of northward migrating groups (Fukushima, et al., 1990), all indicate that the Western Pacific saury reaches a length of 30 cm in one year. Three length modes occur in fish caught in fishing season from late August to early December. The large fish are assumed to originate from eggs spawned in the autumn, the medium sized fish from winter eggs and small fish from spring spawnings (Fukushima, et al., 1990). The three groups are not thought to be from different stocks because the genetic distances of size groups are too close to be regarded as separate stocks.

Size composition of landed sauries differs annually, and differences in size composition affect price and the total weight of the catch. The length composition of the catch is believed to be related to relative recruitment of autumn, winter and spring spawning cohorts. Pre-season forecasts of size composition of the catch is of great value to fishermen and fish processors. The Tohoku National Fisheries Research Institute provides forecasts of recruitment based on three parameters: larval production at hatching, growth and mortality rates in larval and juvenile stages. Using these parameters, they estimate daily production of 50 mm juvenile for autumn, winter and spring spawnings. Rearing studies indicate that by the time saury juveniles reach 50 mm and begin schooling, they have passed through the high mortality period.

2.2.5 Yellow Sea Herring (*Clupea pallasi*)

The Pacific herring in the Yellow Sea, which is traditionally called Yellow Sea Herring, has a long history of exploitation. The importance of herring is demonstrated by the existence of villages and localities named for their association with it. In this century, the commercial fishery has experienced two peaks (in about 1900 and 1938) followed by a period of little or no catch. In 1967, due to the recovery of the stock, a large number of 1-year old herring began appearing in bottom trawl catches. The catch increased rapidly to a peak of 200,000 mt in 1972. The high catches were due to the very strong 1970 year class and reached a historic maximum abundance estimate of 26.8×10^8 fish (at age 1). Since 1982, the stock has declined apparently due to the occurrence of a series of weak year classes. The catch has declined to below 1,000 mt in 1989-1990.

Obviously, Yellow Sea herring have been characterized by strong fluctuations in abundance. Tang (1981 and 1987) found that there is no strong relationship between spawning stock and recruitment and that environmental conditions such as rainfall, wind, and daylight are the primary causes of fluctuations in recruitment. Long-term changes in biomass may be correlated with the 36 year cycle of dryness/wetness oscillation in eastern China.

3.0   SCIENTIFIC QUESTIONS AND HYPOTHESES

The Working Group discussed the scientific questions and hypotheses required for an understanding of the causes of variability of pelagic fish populations. Four key questions and their associated hypotheses are discussed briefly below.

3.1   What differences exist among Pan-Pacific pelagic stocks in biomass and stage specific vital rates?

Implicit in this question, is the hypothesis that stage specific vital rates determine the variability of fish populations and density dependent processes play a subsidiary role. Pan-Pacific comparisons of vital rates might help answer the questions: 1) why does the western Pacific boundary system support a higher biomass of small pelagic fishes than does the eastern Pacific boundary system? and 2, Why do pelagic fishes show different fluctuation patterns in the same region? The group concluded that detailed descriptions and comparisons of fish biomass and stage specific vital rates, such as growth, mortality and fecundity are the first step in understanding the mechanisms underlying population fluctuations of small pelagic fishes.

3.2   How does physical forcing affect population processes?

Implicit in this question is the hypothesis that variability in population size is determined largely by density-independent factors such as changes in regional oceanographic conditions. A further extension of this hypothesis is that a Pan-Pacific ocean climate influence on fish population dynamics exists and that regional comparisons are necessary to identify the details and modes of actions. Regional comparisons of similar species could lead to identification of the similarities in oceanographic conditions that correspond to population growth or failure, regardless of the validity of the Pan-Pacific hypotheses.

3.3   How do biomass specific changes in life history traits, such as expansion and retraction of spawning habitats or latitudinal extent of feeding migrations, affect population variability?

Implicit in this question is the hypothesis that density-dependent processes play a major role in population growth. In coastal pelagic fishes important population traits seem to vary with population size, including: growth; age or size at maturity; spawning habitat selection; and the tendency to migrate. At high biomass levels, populations may have large migrations, slow growth, and older age at maturity with the opposite pattern at low biomass levels. A more specific hypothesis underlying this question is that density-dependent habitat selection affects reproductive success and population growth through the physical properties of the habitats selected.

3.4   How do the interactions between populations of small pelagic fishes affect their populations?

No doubt exists that coastal populations of sardine, anchovy, and mackerel interact. As they all are pelagic planktivorus, their diets broadly overlap and they may consume each others egg or larval stages. In addition, large mackerel may prey upon adult anchovy and sardine as well as their early life stages. Thus, population interactions should affect the productivity and growth of pelagic fishes in the coastal ecosystem. The tacit assumption underlying this question is that species interactions play a role in population variability and shifts in dominance among pelagic fish.

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4.0 CRITICAL GAPS IN INFORMATION AND KNOWLEDGE

A major challenge for marine science in the twenty-first century will be to forecast how long-term changes in ocean climate will affect our natural marine resources. The obvious first step is to explain past fluctuations in the abundance of stocks. Unfortunately, we lack the information, and the basic level of understanding necessary for a documented and coherent ecological explanation for the history of population growth and decline of North Pacific pelagic fishes. We do not know how physical forcing increased the survival of eggs or larvae to produce the great year classes of the past, nor do we understand the role played by population size and pelagic species interactions in the formation of those year classes. No shortage of plausible mechanisms exists and some have been validated by direct field measurement, but we lack the information needed to test these mechanisms analytically, and we lack the understanding necessary for a synthesis of physical forcing and density dependent mechanisms that would explain stock histories as we have observed them. We believe that the comparative studies we propose will help fill these gaps in understanding.

Initial requirements for a north Pan-Pacific investigation of climate effects on the dynamics of fish stocks are that estimates of abundance, recruitment, and vital population rates are available and that a strong Pan-Pacific communication network exists. Neither of these initial requirements are presently met. We lack data on some of the vital rates of even the best studied stocks, existing data on rates and population statistics are not generally available on a Pan-Pacific basis, and no adequate communication system exists for the development of Pan-Pacific comparative studies.

5.0 POSSIBLE SCIENTIFIC APPROACHES

The group identified various ways critical gaps in data understanding and communication might be filled and key scientific questions might be resolved. All approaches considered by the group are included.

5.1 Assembly of Data

The group placed a high priority on the assembly of time series of available data on annual biomass and recruitment levels, and on stage-specific vital rates for the key pelagic stocks. Such information may include: annual biomass, recruitment and catch; sex, first maturity and fecundity by length or age; spawning habitat characteristics such as temperature and season; egg incubation rates and mortality; and larval and juvenile mortality and growth.

This initial assembly of biological data should be followed by an assembly of time series of relevant oceanographic data for the areas occupied by the stocks. Relevant oceanographic indices could be selected for each area from results of detailed process studies, or by using forcing functions proposed in the literature. Biological data on zooplankton abundance, and the food habits of coastal pelagic fishes would also be desirable.

If fishery data, or data on specific vital rates, are missing for key populations, these data gaps could be filled by a directed program to collect and process such data.

5.2 Expansion of Scientific Knowledge

5.2.1 Pan-Pacific Comparisons of Recruitment

Exploratory comparative time series analyses of the biomass and recruitment for key coastal pelagic stocks need to be conducted to determine common patterns in stock fluctuations (using approaches similar to Hollowed et al.,

1987). These analyses would be most fruitful if they focused on East-West (e.g. California sardine and Japanese sardine) and North-South (e.g. herring) comparisons. The next step may be to couple oceanographic data and models to the fishery analyses, to evaluate hypotheses concerning physical forcing of coastal pelagic stock fluctuations. For example, do similar oceanographic conditions and processes produce similar responses among different coastal pelagic fishes? Fish stock distributions and vital rates could be examined relative to latitude and longitude, seasonal temperature, and current patterns. Analyses of other aspects of the system (e.g. primary or secondary productivity) may also provide information for estimating upper or lower limits of fish production.

Inclusion of all possible spawning groups in Pan-Pacific comparisons, would greatly increase the richness of the comparison. Herring, sardine, and anchovy form a mosaic of habitat specific spawning groups, each with unique population dynamics and life table characteristics. Pacific herring are particularly prolific in this regard, with spawning groups associated with specific small intertidal areas, while spawning groups of sardine and anchovy are larger and more regional in character. Comparisons between these groups are useful because they reflect regional habitat differences, even though modern genetic studies often fail to find differences between them. For example, although genetic studies indicate that the sardine population around Japan belongs to one stock, a group of sardines spawn west of Kyushu Island and migrate into the Sea of Japan where oceanographic conditions are considerably different from the Pacific side. One would expect spawning and recruitment and vital rates to differ between the Japanese Sea and Pacific spawning groups.

Recruitment comparisons should not only consider single years of great recruitment success or failure, but should also consider successions

of stronger than average year classes, or periods when year classes consistently failed. It is important to consider in such an analysis not only the environmental conditions that correlate with these periods, but also the affect of such successions of strong or weak year classes on population growth and stability. A number of strong year classes may stabilize the population while a small number of weak year classes may make the population more susceptible to environmental variability.

5.2.2 Life Table Analysis

Life stage matrix models, such as the Lefkovitch model (Lefkovitch, 1965; Caswell, 1989), provide a useful way to begin comparative work. First, they require an inventory of life table data and thereby identify critical gaps in knowledge. Second, they help assess the quality of the information by tests of population stability. Third, they permit assessment of the sensitivity of the population to changes in rates within each life stage. Lastly, they provide a simple standardized way to evaluate effects of physical forcing on population growth. For these reasons, completing a Lefkovitch matrix for each species to be compared would be a useful first step in the development of a PICES comparative study.

An important and recent refinement of life stage matrix models for fishes is to include variance as well as mean duration of stage and mortality (Lo, et al.; ms.). This approach adds new information, and the costs are low because the durations of early life history stages can be obtained from daily growth increment analysis of juveniles (Butler, 1989 and 1991). When variances are included the modeled population is generally less sensitive to changes in vital rates than when only the mean is used, and the results are probably more realistic.

5.2.3 Trophic Ecology

To examine the overall functioning of Pan-Pacific ecosystems an inter-regional comparison of the gross production and biomass at several trophic levels (primary and secondary

levels, and small pelagic fishes) would be useful. This would provide a preliminary idea of the overall functioning of Pan-Pacific ecosystems and might help explain the differences in fish production between systems. A more thorough treatment of trophic relations using trophodynamics modeling is also strongly recommended. Trophodynamics modeling is defined as modeling of the food web linkages that support the production of key pelagic fish species. By trophodynamics modeling, the response of marine production systems to environmental changes can be analyzed, based on the flows and balance of biomass among the trophic levels. This technique will be useful for understanding the biological processes which control population fluctuations and species interactions. Model construction can also reveal the lack of knowledge on relationships among biological components and physical forcing functions. Once the model can generate the average annual cycle of fish production, various hypotheses on the relationships between environmental change and population fluctuations can be examined. This approach becomes more powerful when such models are constructed for several different regions with ecologically similar species.

5.2.4 Comparative Field and Laboratory Studies

The focus of most of the Working Group's discussions were on the analysis of existing data because such work is an appropriate starting point. The Group recognized in the long term, Pan-Pacific field and laboratory work using standardized methods and approaches would have great benefits. One approach might be to focus the field work on accurate interannual measurements of age specific fecundity and life stage specific growth or stage duration and their links to physical forcing. These fish population parameters are among the least expensive to measure, yet they might reveal substantial differences between populations and ecosystems. In contrast, mortality is an expensive parameter to measure directly by sampling larvae and juveniles requiring many more samples and days

at sea. In addition, using modern otolith reading systems one can digitize long chronologies of daily growth records from a single otolith. When such data from a number of juveniles are combined, estimates of mean growth and variance for many life stages can be provided.

It also may be useful to collect larvae from stocks with different growth rates and rear them under identical conditions to determine if such growth rates are genetically or environmentally determined.

5.3   Sharing Knowledge and Technology

PICES has the opportunity for leadership in the Pan-Pacific exchange of knowledge among marine researchers.   Presentations at PICES Annual meetings and workshops are important ways that PICES has opened the avenue of communication by providing a forum for exchange of ideas.   In addition to these approaches, the working group considered several other ways to improve Pan-Pacific communication.

All members believed that informal scientific communication and possible collaboration would increase if a directory of key Pan-Pacific researchers were available.   The Working Group proposed to compile a list of key researchers who study coastal pelagic fishes of the North Pacific within their respective geographic regions.   The directory, would include not only agency or institution, address and FAX, but would include pertinent information such as species of interest, key-words describing broad topics of interest and areas of present research. This final compilation of researchers in all member countries should be made available in a paper copy and also maintained on a computer data base which should be updated annually.

Another way PICES could foster communication and build collaborative efforts is through Pan-Pacific exchange of the researchers. The Group believes that of all the activities sponsored by PICES, few could have as great and immediate benefit as a PICES visiting scientist program. The Group recommended that the Secretariat develop a PICES visiting scientist exchange program.   Such a program might provide 2-4 visiting fellowships per year to the PICES community with a duration of a month or more.   Selection of applicants would be competitive based on a short letter of intent, CV, and references. Applicants would include agency as well as academic scientists and funding would cover only travel and subsistence costs.   If PICES does not have sufficient funds to support the program, some working Group members would be willing to work with the Secretariat to find outside funding. It would be preferable if the Secretariat managed the funds to minimize indirect costs.

6.0   TABLES AND FIGURES

Table 1. Catch statistics of small pelagic fishes in 1990.

SPECIES		CATCH IN THOUSAND TONS	
Common	Scientific	World	North Pacific
Atlantic herring	Clupea harengus	1,538	***
Pacific herring	Clupea pallasi	199	199
Japanese sardine	Sardinops melanostictus	4,735	4,735
South American pilchard	Sardinops sagax	4,254	***
European pilchard	Sardina pilchardus	1,540	***
California sardine	Sardinops sagax	399	399
Anchoveta	Engraulis ringens	3,772	***
European anchovy	Engraulis encrasicolus	539	***
Japanese anchovy	Engraulis japonicus	442	442
South African anchovy	Engraulis capensis	201	***
Northern anchovy	Engraulis mordax	6	6
Japanese common mackerel	Scomber japonicus	1,391	751
Atlantic mackerel	Scomber scombrus	657	***
Chilean jack mackerel	Trachurus murphyi	3,828	***
Atlantic horse mackerel	Trachurus trachurus	420	***
Cape horse mackerel	Trachurus capensis	346	***
Japanese jack mackerel	Trachurus japonicus	250	250
Pacific saury	Cololabis saira	416	416
Small Pelagics Total		24,933	7,198
Marine Fishes Total		70,666	***

Source: FAO Yearbook of Fishery Statistics

Table 2. Comparison of the catch or biomass variability of small pelagic fishes from Japan and California.

CHARACTERISTICS OF PELAGIC FISH CATCH OR BIOMASS DATA (Thousands of Tons)	JAPANESE STOCKS[a]				CALIFORNIA STOCKS		
	Sardine	Anchovy	Mackerel	Saury	Sardine	Anchovy	Mackerel
	Catch	Catch	Catch	Catch	Biomass[b]	Spawning Biomass[c]	Biomass[d]
Years data available	1957-87	1957-87	1957-87	1957-87	1935-90	1954-91	1929-91
Mean	878.3	300.7	778.1	274.8	619.	413.	143.
Maximum	4179.4	430.2	1625.9	575.1	3628.	817.	440.
Minimum	9.2	134.6	234.8	63.3	<20.[f]	131.	<20.[f]
Max./Min.	454.3	3.2	6.9	9.1	62.4	6.2	22.
Coef. Var. %	150.	30.	50.	50.	181.	69.	92.

a. Funakoshi, 1990
b. Jacobson and MacCall ms., 1993
c. Jacobson and Lo, 1993
d. Jacobson unpublished data
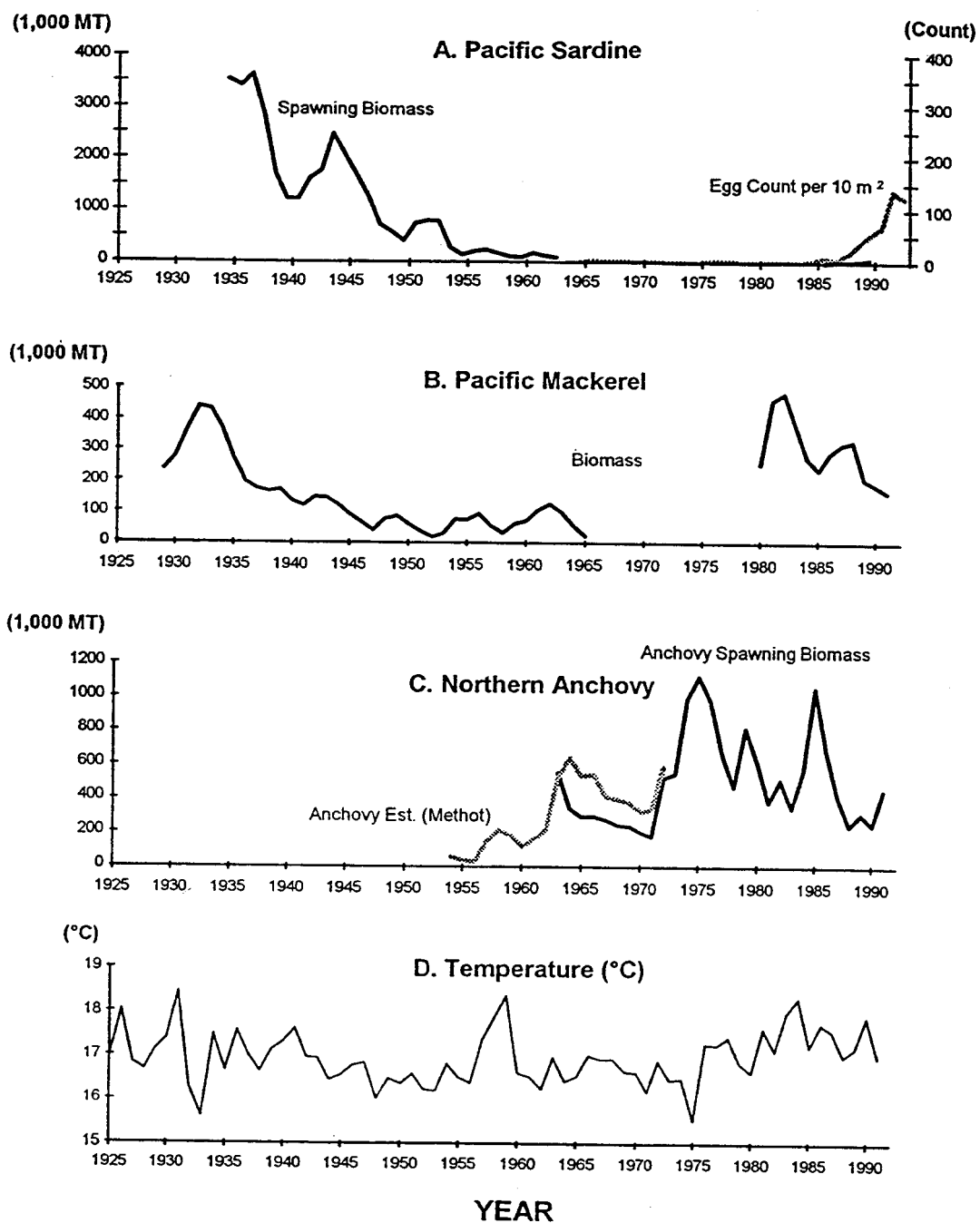f. Biomass uncertain but below 20,000 tons

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Fig. 1.   Time series of estimates of the biomass of California coastal pelagic fishes and the average water temperature taken at Scripps Pier (La Jolla, California).
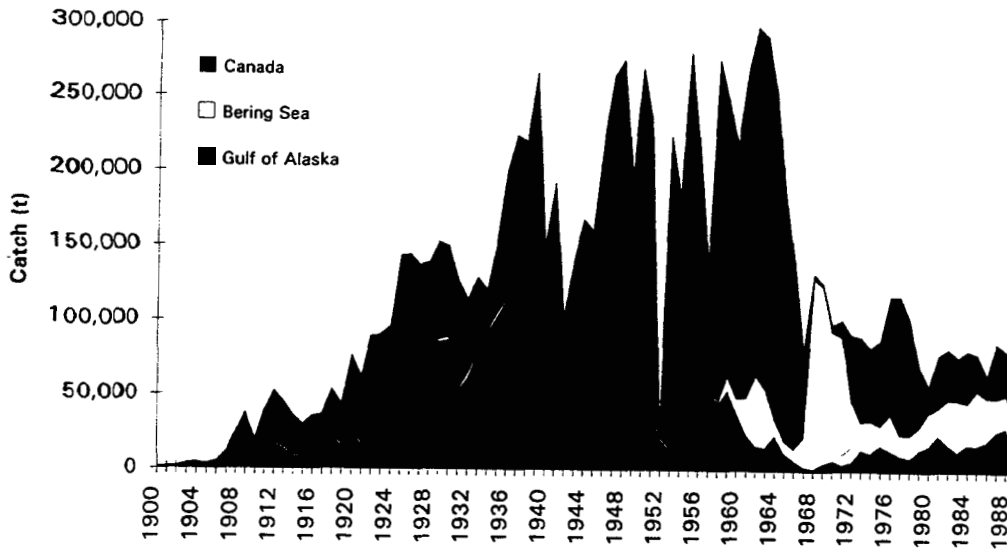
Fig. 2.   Catch of herring off Canada, Gulf of Alaska, and in the eastern Bering Sea, 1900-1990.
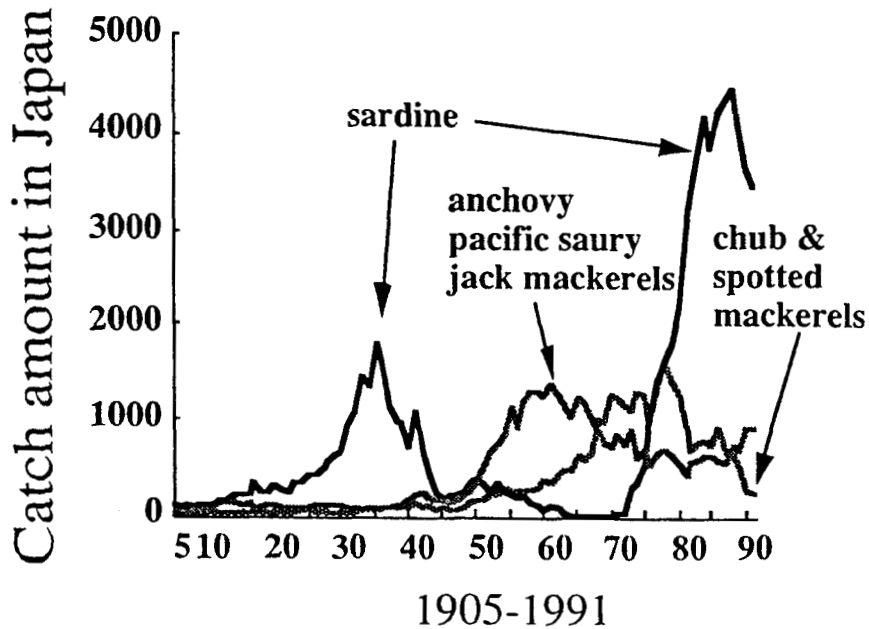

Fig. 3.   The long-term fluctuation of annual catch of several species of pelagic fishes combining three groups: Japanese sardine; Japanese anchovy, Pacific saury, and jack mackerels; chub and spotted mackerels in 1905 to 1991 (after Matsuda et al., 1992).

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8.0 Appendices

Appendix 1

Recommendations and Actions

Science

* Assemble information on Western and Eastern Pacific Coastal pelagic fish populations. Fishery information shall include: stock size, catch, and recruitment estimates per year. Also, life table data containing life stage specific rates of growth, mortality and reproduction shall be required. PICES Working Group 3 agrees to produce a document containing these data for key coastal pelagic species of the Eastern and Western Pacific. The document shall be completed in time for PICES Working Group meeting in 1994.

* Encourage the inclusion of Russian and Korean fish population information data on herring and other northern coastal pelagic species in the data exchange described in item 1.

* Encourage development of relevant oceanographic time series to facilitate the interpretation of Pan-Pacific patterns in recruitment success.

* Apply trophodynamics models in Eastern and Western Pacific ecosystems to understand how the production systems of each region support pelagic fish biomass. This work may require inclusion of pollock and hake.

* In the annual 1994 PICES meeting Working Group 3 shall review the fish population document described in item 1 and establish plans to carry out Pan-Pacific comparisons of life table differences and recruitment.

Communication

* Members of Working Group 3 shall make an inventory of scientists working on key coastal pelagic fishes within their respective geographic area. Working Group 3 will compile a list of key persons, addresses and topics of study and make it available to all interested researchers.

* The PICES COASTAL PELAGIC FISH WORKING GROUP requests PICES Fishery Committee to seek support of the PICES Secretariat in obtaining funds for a visiting scientists program. The working group feels that working visits of PICES scientists to other PICES countries is essential. Recognizing that PICES may not have funds to directly support such an action, the working group stands ready to assist the Secretariat in preparation of proposals to foundations and agencies to support the visiting PICES scientist program.

Administration

* The proposed inventory of fishery time series data and life table information along with the PICES Nemuro Workshop Reports will constitute important working documents for PICES. Such documents need to be organized and archived in some consistent way. For that reason, we recommend to the Fishery Committee of PICES that the Secretariat establish an informal administrative report series. The minimum requirements for such a series are: each working document is assigned a unique administrative report number; a standard cover design is used on each

copy of the report; a standard citation for the reports be established; report date; report number, and names of editors are clearly indicated. To reduce PICES costs, actual production of the report could be assigned to chairpersons, with a certain number of copies to the Secretariat. Of course, a more formal system could be adopted as well.

* Working Group 3 recommends continuation of the Working Group under the existing terms of reference but also recommends a name change to PICES COASTAL PELAGIC FISHES WORKING GROUP.

Appendix 2

Terms of Reference

Working Group 3
Dynamics of Small Pelagics in Coastal Ecosystems (FIS)

- develop a program for a comparative study of the population dynamics and productivity of small pelagics (focusing on herring, sardine, anchovy and mackerel) in the coastal ecosystems along the western and eastern continental margins of the North Pacific;

- review the present state of knowledge, identify the key scientific questions and hypotheses that could be tested, including environmental effects on fish production and ecosystem structure;

- identify who is working in this field, and what data are available for retrospective analyses;

- determine which member countries would be willing to participate in a coastal ecosystems program.

Appendix 3

List of participants

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