PICES XIII S2-1934 Oral

Larval stage controls on sardine recruitment variability: Predation or food availability?

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Linear processes have dominated our view of food web energy transfer in marine ecosystems. Fish species are generally modeled by representing trophic energy transfers among adult biomasses, but population dynamics are in many cases determined at non-adult life history stages. Taking into account earlier life stages and the potential non-linearities introduced in the food web by mortalities inflicted at these earlier levels, may present a more complete view of trophic system dynamics, in which control might be exerted by number of mechanisms (top-down, bottom-up *etc.*) each operating at different life history stages. This study focuses on Pacific sardine (*Sardinops Sagax*). Sardines inhabit some of the most highly productive areas of the ocean (upwelling areas). Despite this, they reportedly thrive during warm periods characterized by comparatively lower productivity. Amongst the explanations advanced for the apparent sardine success during warm periods: a) lowered predation pressure on early life history stages; b) access to waters with higher food availability. We examine zooplankton abundance in the sardine larval habitat off the coast of southern California. Our results show that increased food availability (represented here by zooplankton abundance) in the larval habitat cannot alone explain successful sardine year classes. We suggest that zooplankton abundance may also be an index of predation pressure on early life history stages, with decreased predation pressure during warm years being one of the factors allowing for bursts in sardine recruitment.

PICES XIII S2-2109 Oral

Wasp-waist control and beer-belly oscillations: An evaluation of population hypotheses in the Bering Sea and Gulf of Alaska

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Hypothesized controlling factors for highly variable groundfish populations off Alaska include changing climate regimes, benthic and pelagic energy pathways, prey switching by top predators, and exploitation-triggered cascades. As each hypothesis is based on a subset of available species data, each holds a degree of "truth." Yet can a composite controlling hypothesis be synthesized from these individual theories, and will it be useful for predictive ecosystem-based fisheries management? Here, we approach the question with two sets of models. The first are "minimum realistic" multispecies models, each containing the minimum complexity required to duplicate a particular control hypothesis. The second are "ecosystem-level" energy flow models, driven by the output of the minimal models, which will be used to ask two questions: (1) do the embedded minimal models produce ecosystem-level predictions which may be evaluated against supplementary data (for example, does the Oscillating Control Hypothesis for Bering Sea Pollock make verifiable predictions for other forage fish); and (2) do control hypotheses "collide" to produce emergent behavior with negative consequences for predictability? We suggest that, if the controlling factors collide, prediction should be approached in terms of "resonance." Regimes emerge as species life-histories interact with frequencies of variation, and dominant species groups at times control the expansion of resources (the wasp-waist) and at times buffer their collapse (the beer-belly). Under such a world view, "ecosystem-based" fisheries management does not fine-tune ecosystems to maximize productivity, but rather bounds expectations by predicting the long-term frequency and magnitude of booms and busts under alternative management policies.

PICES XIII S2-1852 Oral
Mechanisms of "wasp-waist" control in marine ecosystems

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Contrary to the situation in terrestrial ecosystems where adult and pre-adult stages usually occupy nearly the same trophic level, adults and early life stages in marine systems may operate at quite different trophic levels. This introduces the potential for unstable feedback loops to form between different trophic levels, leading to abrupt populations collapses and explosions, and to massive system reorganizations (*i.e.*, *regime shifts*). Surveys of available *regime shift*-like experiences tend to implicate the populations of small planktivorous pelagic fishes that form the *wasp-waists* of most marine ecosystems as being key actors in the feedback mechanisms that apparently are involved. Several classes of mechanisms potentially involved in initiating and maintaining radical ecosystem shifts are discussed, including: (1) the "simplest loop" wherein *wasp-waist* species prey on the early stages of their larger predators, (2) the effect of geographical shifts in the areas of operation of the mobile wasp-waist populations on less mobile (or slower responding) predators and prey, and (3) changes of dominance among wasp-waist populations that may exchange phytoplanktivores (which may in some cases provide important services in controlling eutrophication, hypoxia. *etc.*), for zooplanktivores (which may be particularly efficient predators on early life stages of desirable fishes). Operation and consequences of such mechanisms will be illustrated, as time allows, by several case histories.

PICES XIII S2-2066 Oral
The natural regulation of long lived fishes and the impact of "longevity over fishing"

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The abundance of long lived fishes such as sablefish is controlled naturally through bottom-up processes that regulate recruitment. However long lived species have not evolved to adapt to top–down controls. Fishing becomes a top-down control that reduces the resiliency of long lived species to extended periods of low food production. The extreme reduction of age classes in a population through fishing is "longevity over fishing". "Longevity over fishing" can cause the collapse of a population during extended periods of poor food production.

PICES XIII S2-1846 Invited
Who is controlling whom in marine ecosystems: Observed changes, possible mechanisms and trends in top-down, bottom-up and wasp-waist controls

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The structure and functioning of marine ecosystems can drastically change and affect fisheries in a more or less reversible way. The analysis of controls appears to be a key issue for understanding ecosystem dynamics, particularly in a context of global changes (climate change and overexploitation). Controls can help to predict drastic changes of major living components that occur in marine ecosystems, known as regime shift (a sudden shift in structure and functioning of a marine ecosystem, affecting several living components and resulting in an alternate steady state). This presentation provides an overview of patterns (regime shifts, species replacements and alternations) that have been observed in marine ecosystems. Mechanisms by which regime shifts and ecosystem changes may be initiated and sustained in marine ecosystems are then reviewed. Those changes can be environmentally driven (through bottom-up control of the food web, or via direct effects on recruitment, *etc.*), ecologically driven (*e.g.*, through top-down forces such as predation), mediated behaviourally (*e.g.* behavioural

adaptations to habitat change, mixed species schooling) or driven by human exploitation that selects species or preferential fish sizes (top-down control). Bottom-up control, initiating and sustaining regime shifts or species replacements via environmental forcing, is documented in most ecosystems. However fishing (a case of top-down control) appears to have played an important role in regime shift processes in several ecosystems. Even though we are far from possible generalization regarding the dynamics of the controls, it is suggested that fishing down the food-web may cause worldwide ecosystems to be more sensitive to bottom-up forces, *i.e.* to climate change. We will gain scientific insight by developing models, experiments and observations that will combine bottom-up and top-down controls into the same framework (until now most approaches have been considering them independently). We also need to relate processes to pattern to disentangle the effects of controls on population dynamics, particularly their combined effects. This should help us to move towards 'ecosystem ecology' as a discipline in its own right, and towards an effective Ecosystem Approach to Fisheries.

PICES XIII S2-2145 Oral
The cascading whale predation hypothesis: Testing with existing data

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Springer *et al.* (2003) have hypothesized that the removal of large whales by commercial whaling in the region of the Bering Sea/Aleutian Islands has led to cascading trophic interactions that have caused the sequential decline of populations of harbor seals, northern fur seals, Steller sea lions and northern sea otters. This hypothesis has stirred considerable interest because of its implication regarding ecosystem based management. Based on a review of available data, it appears that the Springer *et al.* hypothesis is not consistent with data on: 1) trends in large whale biomass and pinniped biomass in this area during the last 30 years, 2) trends in marine mammal populations in other areas occupied by killer whales; and 3) the importance of baleen whales as prey for killer whales in high latitudes. Based on this review, it appears that the hypothesis proposed by Springer *et al.* should be modified or rejected. One possible modification of the hypothesis would be to separate the link between commercial whaling in the 1960s and 1970s and the dynamics of the populations of harbor seals, northern fur seals, Steller sea lions, and northern sea otters. Available data are consistent with the hypothesis that predation by killer whales may be an important factor in explaining trends in these four populations of marine mammals in the Bering Sea/Aleutian Islands area.

PICES XIII S2-2085 Oral
Marine ecosystem responses to the warming of 1920s and 1930s in the northern North Atlantic

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During the 1920s and 1930s there was a dramatic warming of the northern North Atlantic Ocean. Warmer-than-normal sea temperatures and reduced ice conditions continued through to the 1950s and 1960s, with the timing of the decline to colder temperatures varying with location. Documented changes to the marine ecosystem off northern Europe, Iceland, Greenland and northern Canada during this warm period will be presented. Ecosystem changes included a general northward movement of fish and benthic fauna and flora. Boreal species of fish such as cod, haddock and herring expanded further north while colder water species such as capelin and polar cod retreated northward. Migration patterns of the "warmer water" species changed with earlier arrivals and later departures. The spawning locations of several fish species also spread northward. Benthos associated with Atlantic waters spread northward along Svalbard and eastward into the eastern Barents Sea. Some tropical species of fish that were unheard of in northern areas prior to the warming event became frequent visitors and many others occasional visitors. These responses will be compared to the ecosystem changes that have accompanied the warming in the 1990s.

PICES XIII S2-2003 Oral

Top-down modeling and bottom-up dynamics: Linking fisheries-based multispecies models with climate hypotheses in the Northern California Current

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We ran a dynamic model of the Northern California Current with historical estimates of fishing mortality, fisheries effort, and climate; fitting to the results of stock assessments, surveys and catch statistics. A key challenge in doing so has been determining whether, and how, to best to incorporate climate impacts and forcing processes into model dynamics, an effort that requires numerous simplifying assumptions in order to accommodate the modeling framework. Climate can affect ecosystem productivity and dynamics both from the bottom-up (through short- and long-term variability in primary and secondary production) as well as from the top-down (through variability in the abundance and spatial distribution of key predators). Although multispecies predator/prey models are generally not intended to account for biophysical processes, we have explored how the incorporation of various means of climate forcing improve the fit of the model dynamics to observed trends and landings for exploited components of the ecosystem. For example, although the model is unable to fully account for the dynamics of migratory species in this system, we can use climate to account for their dynamic role in the NCC in a manner consistent with their known response to environmental variability. We find that the incorporation of climate forcing from both the bottom-up and the top-down has the potential to result in significant improvements in model fits and performance.

PICES XIII S2-1858 Oral

Juvenile salmon survival in coastal waters of the Northeast Pacific Ocean: Top-down or bottom-up control?

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Based on the studying the abiotic and biotic relationships of juvenile salmon in the coastal waters of Northeast Pacific Ocean, we developed a mathematical model of the juvenile salmon survival in the nearshore oceanic ecosystem. Our model consists of two components: the dynamics of the number of juvenile salmon, N(t), and the growth of individual fish, W(t). Such an approach allows us to separate the bottom-up and top-down effects in the ecosystem and study the questions: Do these effects have equal influence on salmon survival? If not, what are the conditions under which salmon survival is primarily controlled by a bottom-up (or a top-down) mechanism? Calibrated on a reliable data set, our model provides a theoretical ground for a better understanding of the natural mechanisms controlling juvenile salmon survival, enabling predictions of different scenarios of juvenile salmon dynamics depending on various factors affecting fish.

PICES XIII S2-1904 Oral

The Thompson-Burkenroad debate revisited – What drives fluctuations in Pacific halibut abundance?

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The debate over the relative importance of harvest and environment on the dynamics of natural populations is epitomized by the "Thompson-Burkenroad" debate over Pacific halibut (*Hippoglossus stenolepis*) population fluctuations. The debate emerged in the 1940's and 1950's with the scientific community at that time generally siding with W. F. Thompson's view that fishing mortality was, by far, more important than environmental effects.

In the 50 years since, the debate has remained germane and broadened to many other fisheries in the North Pacific. By the late 1900s, after more years of data collection coupled with new analyses and a new paradigm on climatic regimes, the consensus view had shifted to Martin Burkenroad's original contention that environment was the more important factor, at least in regards to recruitment variability. This year, for the first time, a sex-specific assessment of halibut has allowed for separate population accounting to be made of males and females. This is important in determination of spawning biomass effect on recruitment because males and females have highly differential growth rates, hence differential exploitation rates. Additionally, both sexes both have shown inter-decadal trends in their growth rates. In this paper I revisit the Thompson-Burkenroad debate in light of new data and assessment results. I also illustrate how both fishing and environmental effects are accounted for in devising a robust harvest strategy for Pacific halibut.

PICES XIII S2-2001 Oral
A review of the role of environmental disturbance and resource partitioning as a source of population regulation in marine ecosystems

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We consider the role of spatial partitioning of resources in the context of bottom–up, top-down or wasp-waist trophic pyramid restrictions type systems. We revisit the theories of population regulation based on competition for limited resources and predation and the role of environmental disturbance on these factors. In ocean systems, environmental disturbance influences the spatial distribution of habitat creating spatially and temporally dynamic patterns of resource availability and species interaction. We present evidence for ecological disturbance and its role in mediating competition and predation using field information collected for three different systems: Three winter spawning flatfish in the Bering Sea (probably bottom-up), walleye pollock and capelin interactions on the eastside of Kodiak Island (potentially-top down or bottom-up), and pelagic fish (probably bottom-up or wasp-waist) on the west coast of North America. Our review of oceanographic influences on winter spawning flatfish shows that resource limitation has the highest probability of occurring when cross shelf advection transports reproductive products into favorable nursery grounds. Our review of walleye pollock and capelin spatial partitioning shows that competition for limited resources and spatial overlap of predator and prey is mitigated during summer months by partitioning habitat use. Review of pelagic species demonstrates a similar pattern of resource partitioning by pelagic species. We note that principles of fisheries resource management are based on density dependent regulation of populations. Our review suggests that consideration of environmental influences on resource partitioning should be considered in the formulation of management advice.

PICES XIII S2-1826 Oral
Are the control mechanisms of marine birds and mammals scale-dependent?

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I briefly review evidence for bottom-up control of marine birds and pinnipeds. In marine birds, bottom-up control is the primary mechanism of population control, though the siting of colonies may, in some cases, be determined by where they can be free of terrestrial predators or inaccessible to birds of prey. Similarly, for pinnipeds, while there is evidence for the occurrence of bottom-up control, evidence for top-down control is rare. The relative importance of top-down and bottom-up control is scale dependent, with global patterns in the biomass of marine birds and mammals being bottom-up, the location of breeding sites for seabirds and pinnipeds being at least in part controlled by predation, and the interannual variation in reproductive success or numbers of birds or pinnipeds in a colony or rookery usually being controlled by prey availability. The relative mobility of predator and prey may also affect the likelihood of top-down or bottom-up control.

PICES XIII S2-2116 Oral

When, where and why Steller sea lions experience physiological stress - Evidence from stress hormones and diet quality

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Following a rapid decline, population counts of the western stock of Steller sea lions leveled off in the mid-1990s. Whether numbers finally stabilized to match the carrying capacity of the ecosystems, or the population has been stripped to the last cohorts prior to disappearance, is not known. One of the basic problems is that we have not been able to determine which breeding populations are currently stressed. We know even less about the severity of physiological stress required to interfere with reproductive function in affected sea lions. Our objectives were to: (A) To determine which rookeries currently experience physiological stress; (B) To examine whether this level of physiological stress might affect reproductive function; (C) To determine whether poor diet quality could be a major factor causing physiological stress (the "nutritional stress" hypothesis). We used fecal samples to assess hormone levels and diet composition. Inter-seasonal and inter-rookery comparisons suggest that physiological stress is contributing to the continuing decline of Steller sea lions, probably via its effects on reproductive function. In support of the nutritional stress hypothesis, we found that the diet quality was lowest in the areas of highest physiological stress and population declines. However, on the scale of specific rookeries this pattern didn't hold. Thus, although physiological stress and its negative effects on reproductive function of individuals in the western stock of the Steller sea lion are evident, the causal factors remain to be shown. The nutritional stress hypothesis can be neither accepted nor rejected based on the results of our study.

PICES XIII S2-2117 Invited

How to test, use and manage sardine-anchovy-chub mackerel cycles

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Although we often generate hypotheses from dichotomies, a trichotomy may give an eye-opening idea. In my analysis of this trichotomy I make the following points: (1) A cyclic advantage hypothesis may explain a permanent stock fluctuation (a May-Leonard orbit) among sardine, anchovy and chub mackerel. The hypothesis is falsifiable because sardine must increase only after chub mackerel are abundant. (2) This hypothesis does not predict when the next species replacement occurs. Species replacement probably depends on temporal and spatial heterogeneity in oceanographic conditions. This is because variance of recruitment strength at a low stock level is much larger than that at a high stock level. (3) Collapse of the sardine population was caused by recruitment failure in the early 1990s. Overexploitation of chub mackerel since 1990s may prevent the stock from recovering forever. (4) Ecosystems are characterized by uncertainty, fluctuations are a permanent feature and ecosystems are complex due to community interactions. Maximum sustainable theory does not work for fisheries management because it ignores these three factors. (5) We propose a new type of multi-species management strategy called "target switching". If fishers focus their fishing effort on a temporally abundant stock, this policy increases the long term total catch and the minimum stock level. (6) If the cyclic advantage hypothesis is true, overexploitation of chub mackerel also prevents the sardine from recovering. Overexploitation of chub mackerel is an experiment for my hypothesis. I also discuss what happens "indeterminacy" by Peter Yodzis if multi-species models include process errors and environmental fluctuation.

PICES XIII S2-2043 Invited

Evaluating the role of top-down versus bottom-up ecosystem regulation from a modeling perspective

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There has been much discussion on the relative roles of top down (*e.g.*, top predators) vs. bottom up (*e.g.*, climate change and resource limitation) regulation of marine ecosystems. However, resolution of the question remains elusive and thus the importance of the impact of variability of physical forcing versus harvesting pressure on the structure and function of marine ecosystems remains unresolved in many instances. Field-based studies to establish the importance of these two processes are a difficult undertaking given the complexity of even the smallest marine ecosystem. Such studies are even more difficult in continental shelf and open ocean domains where the ecosystems under consideration are not generally isolated. Another approach in determining the extent of these controls is through theoretical or comprehensive simulation models. In this paper, we discuss present-day modeling capabilities which could help identify whether a marine ecosystem is controlled top-down or bottom-up. Modeling approaches are discussed in the context of how they relate to the response of marine ecosystems to global climate change, low frequency changes in patterns of climate variability, or fishing pressure.

PICES XIII S2-1948 Poster

Pelagic predatory fishes as consumers of Pacific salmon: Distribution in the Russian exclusive economic zone and adjacent waters, their abundance and some biological features

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Based on data collected in 35 combined surveys, carried out in the economic zone of Russia and north-western Pacific Ocean between 1984 and 2003, several features of distribution, migrations, and biology of blue shark, prickly shark, salmon shark, lancetfish and daggertooth were analyzed. The data from 1984-1996 indicate that all of these pelagic predators together consumed no more than 25-30% of the total pink salmon abundance in fall. Further, during the anadromous migrations of this salmon species, no more than 20% of the abundance was consumed. Salmon shark and daggertooth were the primary predators on pink salmon. In winter, when the distribution of young pink salmon and lancetfish partially coincide, the abundance of the latter species is usually low. In 1997-2003, abundance of pelagic fishes that prey upon Pacific salmon in the north-western Pacific Ocean and Far Eastern seas of Russia decreased significantly. This could probably serve as one of a multiple of factors causing recovery of most Pacific salmon species from Asian stocks in recent years.

PICES XIII S2-2038 Oral

Bottom-up and top-down controls of walleye pollock on the Eastern Bering Sea shelf

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Control of walleye pollock (*Theragra chalcogramma*) recruitment in the Eastern Bering Sea involves complex interactions between bottom-up and top-down processes, although the mechanisms are poorly understood. We used statistical models and stock assessment data to test some of the leading hypotheses linking recruitment variability to biotic and abiotic factors. Recruitment of pollock was on average stronger if larval and juvenile stages coincided with a mild winter and strong northward surface transport during spring. Although these relationships are consistent with the cold-pool hypothesis (Wyllie-Echeverria 1996) and the larval transport hypothesis (Wespestad *et al.* 2000),

respectively, several lines of evidence led us to reject the proposed top-down mechanisms (related to cannibalism) underlying these hypotheses. We found some statistical support for the oscillating control hypothesis (Hunt *et al.* 2002) in the form of significant interactions between ice conditions (reflecting bottom-up processes), and the abundance of adult pollock (reflecting cannibalism) during the larval and early juvenile stages. We also found that recruitment was significantly enhanced when larval or early juvenile stages experienced an early onset of water column stratification. There was no evidence that the latter effect was related to or modified by the abundance of pollock predators. Models based on an index of cannibalism potential, which reflects the spatial overlap between juvenile and adult pollock, explained a similar proportion (30-50%) of the overall variability in recruitment than models based on the best environmental predictors. Clearly, both bottom-up and top-down effects are important in regulating pollock recruitment, but are difficult to separate.

PICES XIII S2-2106 Oral
Who is regulating zooplankton production (or How to resolve issues of control)?

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Who or what controls marine biological production has been a common question for generations of marine scientists. The marine zooplankton community, which contains secondary, tertiary, and quaternary producers, is often cited as pivotal in the transfer of energy from primary production to higher trophic levels which are harvested and/or conserved by humans. On first inspection, the preponderance of writing and research appears to expound the view of control from below (*e.g.* models by G.A. Riley and J.H. Steele). There is also evidence, however, of control from within the zooplankton community (cannibalism of the young and predation by gelatinous zooplankton) as well as evidence of control by higher trophic levels (planktivorous fishes, mammals, and birds).

We will present a brief history of evidence for control of zooplankton populations: what are the leading arguments, what is the strength of the evidence, are the arguments generally applicable or are they unique to certain systems? We will then focus on control of North Pacific Ocean and Bering Sea zooplankton production. High production by the zooplankton community is often cited as a reason for high standing stocks of living and protected marine resources within those regions.

PICES XIII S2-2068 Oral
Top-down and bottom-up linkages among climate, growth, competition, and production of sockeye salmon populations in Bristol Bay, Alaska, 1955-2000

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Bristol Bay supports one of the largest and most valuable salmon fisheries in the world. Bristol Bay populations more than doubled after the 1976/77 marine climate-shift. Salmon production was unexpectedly reduced during a major El Niño event (1997/98). The biological mechanisms leading to survival at sea are poorly understood. We tested several hypotheses linking climate to salmon growth, interspecific and intraspecific competition, and salmon production by measuring seasonal and annual marine scale growth of sockeye salmon. Increase in sockeye salmon abundance during the late 1970s was associated with greater salmon growth during the first and second years at sea, but not with growth during the third year. The 1976/77 climate-shift led to greater prey production, greater early marine growth and survival of sockeye salmon. We found density-dependent growth was not readily apparent until the last year at sea when reduced growth typically has less affect on survival. The 1997/98 El Niño led to significantly smaller size of adult salmon and lower survival, further supporting the hypothesis that growth at sea is strongly associated with climate. We also discovered evidence of interspecific competition between Asian pink salmon and Alaska sockeye salmon in the North Pacific Ocean. This competition effect, influenced by the unique two-year cycle of pink salmon, led to reduced growth, and a 35% reduction in survival with a loss of 59 million

salmon or $310 million (1997-2000). This finding provides the first clear evidence that interspecific competition at sea can lead to reduced growth and survival of salmon.

PICES XIII S2-2173 Invited
Food webs, fluxes, and flow paths: A fluvial perspective

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Longitudinal (downstream) gradients in productivity, disturbance regimes, and habitat structure exert strong effects on organisms and energy sources to river food webs, but their effects on species interactions are just beginning to be explored. Even less is known about how network structure per se (*e.g*. hierarchical structure, confluence nodes) influences river and riparian food webs and their members. I will discuss research on algal-based food webs in a coastal California river system to illustrate how landscape features and shifts in spatial sources of energy can potentially alter interactions in food webs. In less obviously structured habitats, like the open ocean, discerning features that change regimes in food webs is even more challenging, yet impressive progress is being made. Tracers, increasingly available, can reveal flow paths through space and time of organisms or their elemental or molecular constituents. Concurrently, new mapping technologies based on remote sensing are being used to characterize landscape or seascape features (*e.g.* watershed divides, thermal cells) that contain and constrain these fluxes and the food webs they support. These tools are providing glimpses of spatial and temporal scales linking fluxes and food web interactions in terrestrial, marine, and freshwater habitats, and should greatly advance our understanding of context dependent controls on interaction strengths in webs.

PICES XIII S2-1991 Oral
Possible mechanisms underlying latitudinal abundance changes of Pacific sardine in the California Current system during the last warming regime (1980-1997)

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A recent large-scale long-term analysis of the California Current system (CCS) suggests that climatic regime shifts in the northeast Pacific appear to have forced changing population size associated with major geographical variations in the position of the center of distribution and bulk of the biomass of Pacific sardine. This finding permits explaining the disappearance of the sardine population about 60 years ago at the northern part of the CCS, and also its return after the 1980s. This differs from theories suggesting that environmental regime shifts lead to progressive changes in population growth rates within assumed geo-stationary stocks. To improve the understanding of that large-scale change may require understanding of critical, smaller scale variabilities. The challenge is to determine which of the multiple meso- or small-scale processes is critical, and how to link those pertaining to different temporal scales. We are showing supporting evidence on a meso-scale basis for the last warming period (1980-1997), reinforcing conclusions drawn from that regime scale study. We present a view of seasonal spatial dynamics of Pacific sardine population (with emphasis on the juvenile stages) along the California and Baja California coasts and their interannual variability as a result of environmental changes during 1980 -1997. Sardine relative abundance seems to be related to the ocean front where the California Current (CCal) and the inshore California Countercurrent (CcC) converge alongshore. As a result of the seasonal advection changes, there is a section along the front with favourable feeding conditions for young sardine. Interannual variations in seasonal patterns of sardine distribution and abundance suggest changes in the latitudinal position of the optimal feeding conditions along the front. Recruitment increases where optimal levels are found. Our results suggest a progressive interannual increase of the northward CcC advection after the 1976-1977 regime shift, whereas the CCal southward advection weakened.

PICES XIII S2-1939 Invited
Why do ommastrephid squids increase in abundance during warm regimes?

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Ommastrephid squids are commercially important, however, their annual catches have fluctuated widely, as seen in the decrease in catches of *Todarodes pacificus* and *Illex illecebrosus* in the 1980s, the increase of *T. pacificus* after the late 1980s, and the recent "collapse" of *I. argentinus* fishery. Their recruitment success depends largely on environmental conditions in the spawning and nursery grounds. Ommastrephid squids generally produce gelatinous, nearly neutrally buoyant egg masses that contain large numbers of small eggs. The egg masses are thought to occur within or above the pycnocline at suitable temperatures for egg development (*e.g.* 15-23˚C for *T. pacificus*). The pycnocline region may also provide conditions of reduced predation. After hatching, the paralarvae presumably ascend to the surface layer and are advected into convergent frontal zones. We observed something resembling a *T. pacificus* egg mass within the pycnocline at 70-120 m depth (18-21˚C) in the Tsushima Current using a ROV (Remotely Operated Vehicle). We also estimated from laboratory studies that hatchlings will ascend to the surface at temperatures between about 18-24˚C. A previous study by our laboratory suggested that the increase in annual catch of *T. pacificus* during the mid-1980s to mid-1990s was attributed to increased recruitment when winds were weak and the air temperature was warm (*i.e.* the strength of winter wind stress determines recruitment). Thus the optimum temperature range for survival of *T. pacificus* hatchlings may be more limited than that of the temperature range for normal egg development in other ommastrephid squids.

PICES XIII S2-2023 Poster
Interannual variability in chum salmon (*Oncorhynchus keta*) growth in relation to environmental change during the 1980s-1990s

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Decadal-scale climate change has been reported in the North Pacific, and interannual variability in age-specific growth of chum salmon was investigated in relation to environmental change during the 1980s-1990s. Returning adult salmon were collected along the eastern coast of Korea during 1984-1998, and scales were obtained. Assuming proportionality between scale and fish length, (*i.e.* distance between scale rings indicates growth of the fish at a given age), the absolute distances between scale annuli were converted to relative distances. Age-specific growth patterns were determined, which in turn represented the growth of salmon in coastal and oceanic areas. In brackish and coastal areas, growth of young salmon (age-0 and age-1) was greater in the mid 1990s than in the early 1980s. In Korean waters, the seawater temperature and zooplankton abundance increased from the late 1980s, which might have provided favorable growth condition for young salmon growth. However, in the open ocean, salmon growth from age-2 to age-5 was higher in the 1980s than in the mid 1990s. Also, zooplankton biomass in the eastern Bering Sea was higher in the 1980s than in the 1990s. The increased size of the salmon populations due to the salmon enhancement programs resulted in density-dependent processes that affected salmon growth (*e.g.* reduction in length at age and an increase in recruitment were evident in 1990s). Therefore, the analysis of the distance between scale rings can be a useful technique in interpreting climate/ocean variability in remote oceanic areas.

PICES XIII S2-2148 Oral

Phase relationships and controls of the upwelling-dominated central California Current ecosystem

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Currently there is great interest in physical and biological controls of marine ecosystem structure and function as it applies to fisheries conservation and ocean management. The purpose of this study is to examine the role of "bottom-up" climate forces in structuring the coastal ecosystem, from phytoplankton to top predators, in the upwelling-dominated central California Current System (~35-38° N, ~122-123°W). To accomplish this task, we compiled time series on basin-scale and local climate (SOI, SST, winds, upwelling, *etc.*), nutrients, macrozooplankton (krill), forage fish (juvenile rockfish, herring, anchovy, sardine), and mid and top level predators (salmon, whales, seals and sea lions, marine birds, and white sharks). We created both biomass/abundance and sub-population level life history/demographic biological indices to examine multi-dimensional responses to climate variables. We used de-trended and whitened cross-correlation analyses, complex EOFs, and wavelet analyses to characterize the frequency and amplitude of ecosystem variation and to investigate time lags in bio-physical relationships. We found substantial and more or less simultaneous variation across multi-trophic levels at the ENSO time scale, and some co-variation at lower frequencies, though differences in time series duration and history of animal populations (*e.g.* recovery from exploitation) limited similarities. For long-lived top predators with deferred maturity, life history/demographic parameters were most closely correlated with relatively short-term environmental indices (*e.g.* SOI, at a lag of 6-8 months, SST at 2-3 months). Time lags between environmental variability and population abundance for some species, (*e.g.*, cormorants) indicated climatic controls of upper trophic level species. This portion of the California Current ecosystem, from roughly Monterey Bay to Bodega Bay, is apparently strongly influenced by "bottom-up" forcing mechanisms that reverberate throughout the pelagic food web to apex predators.

PICES XIII S2-1956 Oral

Differential optimal temperatures for growth of larval anchovy and sardine: A potential mechanism for regime shifts?

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An unresolved mystery of the oceans is the out-of-phase stock oscillations of sardine and anchovy. This phenomenon has been explained by climate change (ocean regime shift), however, the biological processes governing regime shifts are unknown. Why do Japanese anchovy, *Engraulis japonicus,* flourish and Japanese sardine, *Sardinops melanostictus,* collapse during the period of presumably lower food availability? The relationships between recent growth rates and environmental factors (water temperature and food availability) were examined for larval Japanese anchovy in different regions through otolith microstructure analysis. The growth-environment relationship for the Japanese anchovy seemed to differ among regions; however, a definite dome-shaped relationship was detected between growth rates and sea surface temperature (SST) when all regions were combined. Overall, growth rates increased with SST until they reached the peak *ca*. 21°C ("the optimal temperature'). They then declined at higher temperatures. A similar analysis suggested that the optimal growth temperature for larval Japanese sardine was lower than that of larval anchovy. Small variations in growth during early life history stages can lead to large recruitment fluctuations. In the western North Pacific, the warm anchovy regime has shifted to a cool sardine regime and back. Here we propose a hypothesis for biological regime shifts

based on optimal temperatures for larval growth. We believe this hypothesis provides a plausible mechanism for regime shifts of small pelagic fishes.

PICES XIII S2-2000 Oral

Long-term changes in fisheries production of the Japan Sea with emphasis on the impacts of fishing and climate regime shifts during the last three decades

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Japanese fisheries production in the Japan Sea increased to a peak in late 1980s (1.76 million tons), and then decreased abruptly with the collapse of Japanese sardine. During the late 1980s the Japanese sardine contributed 60 percent of the total production in the Japan Sea. Production by other small pelagic species was higher during 1970s and 1990s, but lower in 1980s. Large predatory fishes also had higher production during the 1970s and 1980s indicating a possible oceanic regime shift. Production of both demersal fishes and invertebrates showed sharp declines during 1970s and 1980s suggesting impacts of fishing. Mean Trophic Level (MTL) and Simpson's Diversity Index (DI) showed similar patterns ─ higher in 1970s and 1990s, but considerably lower in late 1980s suggesting that dominant species such as sardine have a large effect on the structure of the fish community in the Japan Sea. There was no evidence of "fishing down food webs" in the Japan Sea, however, in addition to the impacts of abrupt shifts in the oceanic conditions occurred in late 1980s, the large predatory and demersal fishes seem to be facing stronger fishing pressure in spite of the declining trend in fishing effort with the collapse of sardine.

PICES XIII S2-1821 Oral

Bottom-up forcing and the decline of Steller sea lions in Alaska: Assessing the ocean climate hypothesis

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Declines of Steller sea lions (*Eumetopias jubatus*) in the Aleutian Islands and Gulf of Alaska could be a consequence of physical oceanographic changes associated with the 1976-77 climate shift. Changes in ocean climate are hypothesized to have affected the quantity, quality and accessibility of prey, which in turn affected the rates of birth and death of sea lions. Recent studies of the spatial and temporal variations in the ocean climate system of the North Pacific are consistent with this hypothesis. Ocean climate appears to have created different adaptive opportunities for species that are preyed upon by Steller sea lions at mid trophic levels. Climate forcing and the details of the mean and eddy oceanic response can explain both the temporal aspect (populations decreased after the late 1970's) and the spatial aspect of the decline (western, but not eastern, populations decreased). The basin-wide climate differences noted in the North Pacific also correspond with regionally sensitive biogeographic structures in the Aleutians and Gulf of Alaska, which include a transition point from coastal to open-ocean conditions at Samalga Pass westward along the Aleutian Islands. Paleological records spanning 4000 years further indicate that sea lion populations have experienced major shifts in abundance in the past. Shifts in ocean climate are the most parsimonious underlying explanation for the broad suite of changes that have been noted in the North Pacific Ocean.

PICES XIII S2-1802 Oral

Changes of net phytoplankton in Sanggou Bay, Northern China: Evidence for consumer regulation of primary producer

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Sanggou Bay is a semi-enclosed shallow bay in the west coast of the Yellow Sea. The bay has a long history of kelp mariculture. Here we report the significant changes in the phytoplankton community after the culturing of filter-feeding shellfish started, using data from three different years of monthly surveys in the bay. Data were collected in 1983/1984 and 1989/1990, which were years immediately before and immediately after introducing scallop-suspension mariculture. Data were collected in 1999/2000, when polyculture of scallops and oysters approached maximum production levels. At the whole ecosystem level, annual average density of 77-µm-mesh retained microalgae and primary productivity decreased, though not statistically significantly, from the first set of surveys to surveys conducted in 1989/1990 and 1999/2000. Further, bay level annual averages of 77-µm-mesh retained flagellates' density and their percentage occurrence in microalgae were significantly lower during 1989/1990 and 1999/2000. By contrast, bay level annual averages of the inorganic nutrients (nitrogen, phosphorus and silicate) increased and average density of 505-µm-mesh harvested zooplankton decreased during 1989/1990 and 1999/2000. During the same survey periods, kelp production remained unchanged while production of shellfish, which feed on microalgae, increased. At the level of culture units (landings with different culture species), annual average density of microalgal decreased only in shellfish culture units during 1989/1990 and 1999/2000. These data indicate that at the observed resource (nutrients) level the 77-µm-mesh retained primary producer is regulated by its consumer, filter-feeding shellfish.

PICES XIII S2-1929 Oral

Recruitment variation of eastern Bering Sea crabs: Density-dependent, "climate-control", or "top-down" effects?

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During the last three decades, population abundances of eastern Bering Sea crab stocks fluctuated greatly, driven by highly variable recruitment. During recent years, abundances of these stocks have been very low compared to historical high levels. Data from bottom trawl and pot surveys and commercial fisheries were used to derive relative recruitment series and effective spawning biomass for seven stocks of red king *(Paralithodes camtschaticus)*, blue king *(P. platypus)*, Tanner *(Chionoecetes bairdi)*, and snow *(C. opilio)* crabs in the eastern Bering Sea. Recruitment to crab stocks is periodic and strongly autocorrelated. Stock-recruitment relationships are generally weak with an exception of Bristol Bay red king crab; however, periods of strong winter Aleutian Lows also coincide with periods of weak recruitment for Bristol Bay red king crab. Spatial distributions of three broadly distributed crab stocks (eastern Bering Sea snow and Tanner crabs and Bristol Bay red king crab) have changed over time, possibly related to the regime shift in climate and physical oceanography that occurred in 1976-1977 and likely affecting recruitment strengths. Relationships among crabs and groundfish are complex; few statistically significant linear relationships between groundfish and crab abundances or recruitments exist in the eastern Bering Sea. In this study, we discussed the causes of crab recruitment variations and generated hypotheses as potential areas for more comprehensive future research.