Matching Spatial Scales of Ecology, Economy, and Management for Groundfish of the U.S. West Coast Marine Ecosystem: A State of the Science Review

A report to the Lenfest Ocean Program at The Pew Charitable Trust

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EXECUTIVE SUMMARY

This white paper is divided into the following three sections: 1) synthesis of the state of knowledge of scales of organization in the various U.S. west coast groundfish fisheries, 2) identification and prioritization of spatial matches and mismatches between various components of the west coast groundfish fishery, and 3) recommendations for spatial management of west coast groundfish within the context of ecosystem-based fishery management (Field and Francis 2006, Francis et al. 2007, Levin and Lubchenco 2008). In this regard, the paper suggests that spatial management should:

- Consider spatial aspects of interactions between humans and nature (McEvoy 1986, 1996),
- Incorporate the capacity for resilience thinking (Walker and Salt 2006),
- Be "second stream" in its approach to both science (interdisciplinary, holistic, focus on understanding rather than prediction) and management (facilitate existing processes and variability, proactive rather than reactive; Francis et al. 2007, Holling 1993, Holling and Meffe 1996),
- Employ rules which are as simple as possible in achieving the desired results (Berkes and Berkes in review).

SECTION 1 – SCALES OF ORGANIZATION – BIOPHYSICS, SOCIO-ECONOMICS, MANAGEMENT

In this first section, we examine spatial scales of organization for west coast groundfish biophysics, socio-economics, and management.

Spatial structure clearly exists throughout the entire area of the California Current Ecosystem (CCS), where a diverse fishing community pursues an equally dynamic and diverse resource; from northern Washington to southern California, from Cape to Cape, from port to port. It can only, briefly, be viewed through snapshots we take in time. These snapshots all reveal clear spatial structure. Unfortunately the clarity is blurred as we pass from one snapshot to another. Space is an elusive moving target. The ocean is constantly in motion, pushed and pulled by winds and tides, agitating away within a basin with a complex bottom structure, creating spatial patterns that morph from year to year, season to season, month to month, and day to day. That is what both fish and fishers face. As a result, diversity ripples through the fishery – different upwelling zones, some separated by deep canyons; different prevalent groundfish assemblages (north and south, inshore and offshore); different fleet structures by state, county and port; different local, state, federal, non-governmental management jurisdictions – some overlapping and some not, the fishery is a mosaic of diverse activity.

Our analysis reveals how diverse the groundfish fishing communities are as you visit ports dotted from San Diego north to Neah Bay. Fleets have changed over the past several decades, the rise of the offshore domestic Pacific whiting (hake) fleet in the north and of the nearshore live-fish fleet in southern Oregon and California, the declines in overall revenues and the shift in the distribution of revenue between fleets and ports – shifts affected both by changes in the resource and changes in management. So, the picture is blurry but occasionally and briefly clear when taken at certain time scales. What we have reported in this section is based on, at best, annual observations. The following are our major spatial findings:

Biophysics

- **Depth** defines the major axis of west coast groundfish variation (advection and larval transport, metapopulation structure, species assemblages) (Gunderson and Vetter 2006, Gabriel 1982).
- Nearshore demersal habitats tend to be vastly different from deeper offshore areas of the continental shelf and slope. Nearshore regions are typified by "sticky water" with very low alongshore movement (Largier 2003). Offshore regions are generally colder, lower oxygen, and stable ocean environments with much stronger alongshore advective processes coming into play in the pelagic region.
- Metapopulation structures of west coast rocky reef fishes tend to change with depth (Gunderson and Vetter 2006). Broad dispersal and coastwide populations tend to occur offshore (outer shelf and slope). Mesoscale dispersal and populations structured by the capes tend to occur in mid to inner shelf regions. Nearshore populations exhibit very limited dispersal.
- **Latitude** is the second most important factor influencing population and assemblage boundaries (Gabriel 1982). Dynamic atmosphere-ocean processes such as wind stress and current patterns are likely the most important factors controlling these north-south structures. There are two major latitudinal breaks in groundfish biophysics: 1) the turbulent wedge between Capes Blanco and Mendocino – a transition region between north and south which has the strongest upwelling winds and most turbulent coastal flows of the entire CCS (GLOBEC 1994, Peterson et al. 2006, Botsford and Lawrence 2002), and 2) Point Conception - the area south of Conception is very different from the area to the north – much smaller local wind stress, warmer subtropical water, different timing in the upwelling season (Hickey 1998).
- Heavy fishing of rocky reef habitats can cause significant changes in ecosystem structure. Large piscivorous (rockfish) species have been fished out and replaced by smaller faster growing species. This has been demonstrated at the individual reef scale (Yoklavich et al. 2000) and at the coastwide scale (Levin et al. 2006). These spatially explicit ecosystem effects of fishing have not been evenly distributed along the coast and have caused allocation of energy and reproductive potential to shift dramatically and vary from region to region. This has been shown in regional nearshore (O'Farrell and Botsford 2006) and shelf (Harvey et al. 2006) ecosystems.

Socio-Economics

In this section we attempted to describe the spatial scales of organization within the groundfish fishery by using statistics on landings, revenue and number of vessels by sector. In this summary we categorize by trawl (limited entry, whiting), non-trawl (limited entry, directed open access), recreational and tribal. The focus is on how spatial statistics have changed between 1995 and 2006.

- The analysis of Groundfish Fleet Reduction (GFR - Scholz 2003) maps of spatial distribution of 2000 limited-entry (LE) landings revealed that overlap in harvest areas is low between distant ports, and high between adjacent ports. Highest percent overlap occurred between port groups north of Cape Mendocino, but high percent overlap also exists between San Francisco and its adjacent ports. The only high percent overlap across Cape Blanco, Cape Mendocino, or Point Conception was between Coos Bay and Brookings port groups.
- The whiting trawl fishery is the largest volume fishery on the west coast and primarily lands to ports north of Cape Blanco. Although it is a low value species (price-per-pound), it is landed in such high volume that whiting landings generate high revenues (PSMFC 2007).
- Landings by the LE non-whiting trawl fishery previously spanned the coast to Point Conception, but currently are concentrated north of Cape Blanco. Due primarily to severe overfishing of shelf rockfish, landings and revenues have declined across the fishery. Flatfish now comprise the majority of landings (PSMFC 2007).
- The non-trawl fishery (LE fixed gear and open access fleets) has maintained its distribution along the entire coastline. Landings have declined but revenues have not changed due to several spatial factors. High-value sablefish dominate landings and revenue north of Cape Mendocino. South of Cape Mendocino, landings have shifted away from shelf rockfish since 1995. From Cape Mendocino to Point Conception, the shift has been inshore to nearshore rockfish supplying the high value live fish market. South of Point Conception, the shift has been offshore to thornyheads (PSMFC 2007).
- The open access fleet has the most participants of any groundfish sector. Over 50% of the open access fleet landings and revenues are in California. Washington and Oregon directed open access fleets are rapidly expanding; their primary target is sablefish (California Department of Fish and Game (CDFG) 2007).
- The recreational sector is largest in California, north of Point Conception, and appears to be increasing coastwide, aside from southern California. Rockfish are the mainstay of the recreational sector, particularly black and other nearshore rockfish (PFMC and NMFS 2006, PFMC 2007).
- Rapid expansion in the tribal fishery conducted in Washington State waters has potential to continue until harvest reaches the maximum allowable harvest allowable under treaty rights (1/2 of harvestable surplus of groundfish

available in the usual and accustomed tribal fishing grounds)(PFMC and NMFS 2006).

Management

This section of the paper describes the existing suite of spatial management tools currently being applied to the West Coast groundfish fishery by state and federal management agencies.

- **Federal** - The spatial management tools applied to the West Coast groundfish fishery are intended to accomplish a wide range of management objectives. These tools vary greatly in their size, temporal nature and goal. They range from coastwide Rockfish Conservation Areas to species-specific closed areas in the Southern California Bight (cowcod) and off northern Washington (yelloweye rockfish). They also include ecologically important habitat closed areas – 5 off Washington, 9 off Oregon and 20 off California – and bottom trawl footprint closures designed to prevent the seaward expansion of bottom trawling.
- **California** - The commercial and recreational fisheries for nearshore rockfishes in California are currently managed by Pacific Fishery Management Council (PFMC) in conjunction with the state using three adjacent management areas with the boundaries at Cape Mendocino and Point Conception. California Department of Fish and Game (CDFG) is developing a fishery management plan for nearshore fish (NFMP) species. At this time the NFMP Project identifies four management areas, yet to be fully implemented, with separate harvest guidelines. California is also attempting to apply the concepts of spatial management to state waters through implementation of the Marine Life Protection Act (MLPA) – a series of marine protected areas designed to protect and conserve marine life.
- **Oregon** - The Marine Resources Program of the Oregon Department of Fish and Wildlife is authorized by the State Legislature to administer the regulation, harvest and management of commercial and recreational fisheries in Oregon. The agency uses a variety of tools to manage these fisheries include trip and bag limits, area closures and species- specific management zones. Oregon is undergoing an additional spatially oriented management process through the Oregon Department of Fish and Wildlife and the Governor's Ocean Policy Advisory Council (OPAC) to develop a network of marine reserves along the Oregon coast to protect the natural diversity and abundance of species that live in each type of habitat in Oregon's Territorial Sea.
- **Washington** - Washington Department of Fish and Wildlife has jurisdiction over fishery resources within state waters (0-3 miles) as well as the inland fisheries of Puget Sound. WDFW employs a variety of management tools for nearshore groundfish. These tools have evolved over time and include area-based management such as the development and implementation of yelloweye rockfish conservation areas in federal waters through the Council process. In 2000, Washington banned all directed commercial harvest of groundfish in state waters.

SECTION 2 – MATCHES AND MISMATCHES BETWEEN ECOLOGY, ECONOMY AND MANAGEMENT

Almost two decades ago, and based on the history of California fisheries (McEvoy 1986), the environmental historian Arthur McEvoy presented an innovative, broad and comprehensive context for marine fishery science and management, with a strong emphasis on direct interactions and relationships, of which those occurring within the ecosystem are just a part. Ten years later he built on this experience to define a fishery as an interaction between three variables: an ecosystem, a group of people working (economy), and the system of social control within which the work takes place (management) (McEvoy 1996). His key assertion is that management must equally weigh the many social and economic relationships within the fishery and how, in turn, they both influence and are influenced by marine ecosystem processes and dynamics. In fact it is human interrelationships that are of particular concern to decision makers. What McEvoy (1996) says is that a fishery is a classic example of a social-ecological system (Berkes et al. 2003, Berkes 2004): an integrated concept of humans in nature. And the essence of a sustainable fishery is the health of the interactions between the ecosystem, economy and management (Field and Francis 2006).

What we are trying to do in this section is to operationalize McEvoy's concept. Suppose, as proponents of a broader ecosystem-based approach to fishery management seem to agree, preserving biological structure (e.g., age or size structure of a stock, foodweb pathways of an assemblage or community, diversity of an ecosystem) is equally important to management as preserving harvestable biomass. Clearly we manage human activity and not biological entities. And these human activities—fishing—are what create the interactions between a group of people working and an ecosystem. How might management facilitate sustaining these interactions through, in this case, the use of spatial structure? One way is for management to create incentives in the economy to preserve biological structure in the ecosystem, by tying an individual fisher's opportunity to fish with the achievement of broader conservation objectives. Spatial management seems to provide the vehicle for doing this. In the words of O'Farrell and Botsford (2006), "the effects of fishing are not evenly distributed over space." Whatever spatial structure is chosen, resource allocations would be weighted towards those regions with better track records of achieving identified conservation objectives. Management would thus create tight positive feedback between economic incentives (e.g., an individual's opportunity to fish) and conservation objectives. As it stands now and, as the recent rockfish closures show, coastwide management provides no incentives for sustainable interactions between the economy and the ecosystem. Space seems essential to creating a sustainable groundfish fishery.

This section attempts to identify spatially explicit matches and mismatches between regional ecosystems, fleets, and management. Specifically, we ask the question: what are the McEvoy interactions and how are they spatially structured? Section 1 will serve as the basis for this analysis. Perhaps the most important question we could ask is: **Can the west coast groundfish fishery be spatially compartmentalized into modules where feedback is tight (economy and ecosystem highly connected)**

within modules and feedback is loose between modules? Our results are summarized as follows:

- The west coast capes may provide an initial modular framework described by Walker and Salt (2007). For example, one might partition the coast into 3 modules with divisions occurring somewhere in the transition zone between Capes Blanco and Mendocino, and at Point Conception. Evidence for this modular structure is supported by the biophysical and socio-economic summaries.

While the capes serve as a pivot point for our match-mismatch analysis, there are a number of more general matches and mismatches that seem useful in evaluating spatial structure as a groundfish management tool. They can be summarized as follows:

- There is a clear mismatch between the coastwide management of overfished groundfish species and the impact of coastwide closures on coastal fishing communities.

- As coastal communities, such as Morro Bay (CA) and Port Orford (OR), become more engaged in managing adjacent nearshore fisheries, they become more involved in scientific assessment and monitoring of their local resources. Without careful coordination between local and Pacific Fishery Management Council (PFMC) scientific activities, local scientific efforts risk the likelihood of being ignored at the coastwide level, thus creating significant mismatches.

- There are significant mismatches between units on which stock assessment and management are based and those inferred from genetic data (Waples et al. in review). Reasons for the mismatches are that a) assessments are almost always single species whereas most stocks are influenced by multi-species (and ecosystem) effects, b) management is based on political boundaries which do not necessarily reflect biology or actual use patterns, c) management is of multiple species as one putative species and d) local management is implemented on too fine a scale thereby subjecting a single biological population "to independent and perhaps conflicting management regimes in different areas of its range."

- The resilience of coastal fishing communities, particularly those with a predominance of small vessels, tends to be dependent on diversity of fishing opportunities – the potential for fleets to shift among target species. There is concern that fleet-specific rationalization (e.g., proposed trawl Individual Fishing Quota program) could reduce the diversity of the portfolio available to some of these small boat fleets and to individual fishermen, thus fracturing the way some coastal communities currently fish.

- Because of their compressed and extensive depth ranges, many of the continental shelf banks create significant mismatches with the general metapopulation model proposed by Gunderson and Vetter (2006) and used to support the Cape to Cape area stratification discussed above.

- There is a distinct mismatch in terms of management informing decisions based on scientific assessments at the biological community and ecosystem scale. In addition, there is a mismatch between the use of biological and socio-economic assessments in informing the decision making process.

SECTION 3 – MANAGEMENT ALTERNATIVES AND RECOMMENDATIONS

If one looks at the fishery from the "McEvoy" perspective, ecosystem-based fishery management should strive to focus on maintaining or creating healthy interactions between the economy and the ecosystem. As mentioned earlier, sustainability of coastal communities would be enhanced where coastal ecosystems were healthy and the individual opportunities to fish were as high as possible. We feel that since the effects of fishing are not evenly distributed over space, spatial management could help provide incentives for achieving conservation objectives.

This final section starts with the spatially explicit matches and mismatches between regional ecosystems, fleets, and management identified in the previous section (Scales of Organization). We then attempt to answer two critical questions: How to structure management to 1) enhance the matches and 2) reduce the mismatches?

- We think that the three modules, mentioned above, may actually work quite well for all three inshore-offshore components of the coastwide groundfish fishery. The states already manage their nearshore zones separately, and all three seem to be working towards fine scale management. The three modules seem to be ideally suited for the shelf fisheries and their associated social-ecological interactions. And the slope fisheries (Pacific whiting, Dover sole, sablefish – NCC; thornyheads - SCC) tend to partition out along the three module scale.

We now look at how spatial management might enhance the more general matches and reduce the more general mismatches discussed in the previous (match-mismatch) section.

- We think that the three-area management proposed above could be a strong first step in linking individual access to the resource with the achievement of conservation objectives. The simplest way to start would be to manage the bycatch of all overfished species on this spatial grid. This would greatly reduce the likelihood of coastwide closure of the entire groundfish fishery.

- In order for coastal communities to become fully engaged in the scientific assessment and management of their adjacent nearshore fisheries, there need to be clear performance standards for the data used, assessment methodologies and criteria for community harvest allocations.

- Waples et al. (in review) outline a number of measures that could help to reduce the spatial mismatches between genetic assessments, stock assessments and management. One of the most prevalent uncertainties relates to how many populations exist and what their statuses are. These uncertainties can be reduced through use of a Management Strategy Evaluation (MSE) process to help assess the consequences of ignoring population structure.

- Every effort should be made to evaluate the impact of proposed management measures on coastal community resilience.

- Physical areas of high concentration of nearshore, slope and shelf species (e.g., banks, islands, canyons, headlands) need finer scale management than our three proposed management areas can provide.

- The groundfish management community needs to become more balanced and comprehensive in terms of the nature of its scientific assessments. If we are to move into the realm of ecosystem-based management, then assessments must be conducted at the ecosystem scale. The same can be said for socio-economic assessments. We encourage any EIS analyses of proposed management measures (e.g., trawl Individual Fishing Quotas) to include meaningful socio-economic assessments of potential impacts on coastal fishing communities.

In conclusion, it is clear that space can be a powerful tool in moving towards a more comprehensive and balanced west coast groundfish management. However simply applying the status quo to newly delineated management areas will, in our view, do little to move west coast groundfish policy into the 21st century. Spatial management must be accompanied by clear objectives for what is to be achieved. We think that space can be used as a powerful tool to enhance positive feedbacks between the west coast groundfish economy and ecosystem. The potential is there for management to use space to provide incentives for individual fishers to achieve ecosystem-based conservation objectives. However those objectives must be made explicit and their achievements monitored comprehensively and carefully.

As we state in the introduction to the white paper, "an ecosystem approach to management is management that is adaptive, specified geographically, takes into account ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse social objectives" (Francis et al. 2007). This is a management approach that is proactive and seeks to preserve existing ecological and social processes and variabilities. It is also an approach that requires resilience thinking, and its unifying concept of adaptive capacity, through heterogeneity, modularity and tight feedback. If adaptive capacity is at the heart of ecosystem-based fishery management, then it seems spatial management is a powerful and essential component of ecosystem based fishery management.

The bottom line for sustainability is that any proposal for sustainable development that does not explicitly acknowledge a system's resilience is simply not going to keep delivering the goods (or services). The key to sustainability lies in enhancing the resilience of social-ecological systems, not in optimizing isolated components of the system.(Walker and Salt 2006)

1. INTRODUCTION

WHY THE INTEREST IN SPATIAL MANAGEMENT?

In the year 2000, the U.S. west coast groundfish fishery was declared a federal disaster. This was a salient sign of a regional fisheries crisis. Groundfish, the umbrella term used to describe rockfish (e.g., widow, yellowtail, and canary rockfish; bocaccio, chilipepper, cowcod, thornyheads, Pacific Ocean perch), flatfish (e.g., various soles, starry flounder, turbot, sanddab), and roundfish (e.g., lingcod, cabezon, kelp greenling, Pacific cod, Pacific whiting, sablefish) species, are cornerstones of the U.S. west coast marine food web and the targets of numerous commercial, recreational, and subsistence fisheries. The groundfish fishery reached crisis stages in the late 1990s largely due to gross fleet overcapacity and increasing recognition of the low productivity of the resources, many of which had been severely overharvested and depleted. By 2002, nine groundfish species had been declared overfished. In order to facilitate rebuilding of these populations, the Pacific Fishery Management Council (PFMC), tasked with managing U.S. fisheries in federal waters (3-200 nautical miles - nm) from Mexico to Canada as well as a few species in state waters within 3 nm of the coast, severely restricted fishing activities on the continental shelf and slope. Limited to miniscule bycatch quotas, continued overharvest of several of these species forced closures of virtually the entire west coast continental shelf (e.g., Rockfish Conservation Areas) to groundfish fishing over major periods of the 2003-2006 fishing seasons and shifting substantial effort shoreward. These draconian management measures provided no incentives for individuals to continue fishing by limiting bycatch.

The Washington-Oregon-California coastal region is known for its diversity of biological production, exploited species, associated fishing fleets, and management needs (Figure 1.1). Aside from the overfished species, other groundfish populations are considered abundant (e.g., English sole, starry flounder, Dover sole, longspine thornyhead). Some species such as lingcod have high fidelity to individual reefs, while others such as Pacific whiting traverse waters along the extent of the expansive coast. Given that the groundfish resource is complex and diverse, we expect that some of the problems in the fishery have occurred because management actions have inadequately accounted for spatial variability of the resource. The scientific and fishing communities have long recognized that spatial management, congruent with the spatial and temporal scales of marine ecosystems and human communities, is necessary for healthy marine ecosystems, viable coastal fishing communities, effective policy, and sustainable fisheries (e.g., Bristol Bay sockeye salmon - Jentoft 2000, Perry and Ommer 2003, Berkes 2004, Gunderson and Vetter 2006). And so coast-wide fisheries management lacks the flexibility to protect against local area depletion of stocks, may inadvertently provide disincentives for stewardship, creates economic hardships for local fishing communities, and fails to safeguard the biological structure of fish populations and the ecosystems that support them.

It appears that mismatches exist between the scale of management and those scales naturally found within the west coast marine ecosystem. The existing coast-wide scale of institutional structures for the management of west coast groundfish may not correspond with the spatial and temporal structure of ecological and socioeconomic systems. For example, in 2003 as a result of a coast-wide management approach, activity in the recreational fishery for lingcod in California during a 2-month period shut down fishing over large areas of the coast resulting in prohibited access to historic resources by coastal fishing communities. For example, in 2003, lingcod catch in the California recreational fishery was estimated to be above the coastwide allowance. The high catch estimate, suspected to be due to a very imprecise effort estimate (John DeVore, pers. comm.), resulted in closure of commercial and recreational fishing over large areas of the coast and prohibited access to historic resources by coastal fishing communities. Similarly, generalizations of the status of a stock from one portion of a species range across its entire range may have given misleading inferences (Hutchings 1996). The inability to account for spatial structure can lead to uncertainty about the status of the stocks and the effects of local ecosystems on stock productivity and resilience.

Identification of scale mismatches begins with understanding spatial scales of organization. Spatial structure of U.S. west coast groundfish resources, fisheries that target them, and associated management can be partitioned in at least five ways.

First there is the physical habitat that serves to structure the groundfish resource. This includes dynamic physical oceanographic processes (Agostini et al. 2006) as well as living and nonliving habitat (Benaka 1999).

Second the groundfish resource can be partitioned at the individual species population level. This partitioning or structuring can be measured in a number of different ways: life history (Berkeley et al. 2004), genetic (Cope 2004, Burford and Bernardi 2008); metapopulation (populations self-recruiting with some significant external replenishment - Gunderson and Vetter 2006); population dynamics (Field and Ralston 2005).

Third, along the west coast of North America, there is clear evidence of spatial structure at the level of the ecological community or ecosystem (Allen et al. 2006, Gunderson and Vetter 2006, Blanchette et al. 2008). Nearshore ecosystems exhibit marked regional differences in their habitat structures, species composition, dynamics and productivity (Bennett et al. 2004, Graham et al. 2008). Offshore ecosystems are organized at a slightly larger scale. Over the outer shelf and upper continental slope, abrupt changes in community composition exist in the vicinity of three prominent biogeographic boundaries – Cape Blanco, Cape Mendocino, and Point Conception (Gabriel 1982, Jay 1996, Williams and Ralston 2002, Levin et al. 2006, Tolimieri and Levin 2006).

Fourth, human or community use of the groundfish resource operates at scales that echo spatial patterns of the ecology but are also structured by the socioeconomic setting. As one moves offshore, both the ecosystems and their associated fishing economies become more spatially homogeneous. This spatial structure reflects geographic variation in the physical (e.g., geomorphologic, hydrologic, climatic) and biological (e.g., macro algae communities) attributes of the environment. This regional variation determines the relative role of fisheries in the socioeconomic and cultural composition of local communities. Highly populated regions around major ports such as Newport, Oregon facilitate large-scale, industrialized offshore fisheries; whereas small, remote communities such as Port Orford, Oregon support coastal, small-scale commercial and recreational fisheries (Gilden 1999). Moreover, human impacts on the marine environment vary regionally in relation to the distribution and size of human populations and the magnitude and kinds of human activities (e.g., waste discharges, nutrient influx, cooling water intakes of power plants, likelihood of oil spills, altered riverine and estuarine structure and functions).

Finally there is the fishery management process itself. Most of the responsibility for west coast groundfish management resides within the Pacific Fishery Management Council (PFMC) and the fish and game agencies of Washington, Oregon and California. Because of the heavy federal involvement in the process, west coast groundfish policy has tended to be applied at large, coastwide spatial scales and, has been essentially, “command and control” —controlling or commanding aspects of a system to derive an optimized return (Holling and Meffe 1996, Walker and Salt 2006).

We would like to emphasize that this review is, by intention, not encyclopedic. It is made in an attempt to keep the entire groundfish fishery in focus and within the context of ecosystem based fishery management

SPATIAL MANAGEMENT IN THE CONTEXT OF ECOSYSTEM-BASED FISHERY MANAGEMENT

Much has been written about ecosystem-based fishery management (EBFM) generally (Zabel et al. 2003, Francis et al. 2007, Levin and Lubchenco 2008) and its application to west coast fisheries specifically (Field and Francis 2006, PFMC 2007a). Francis et al. (2007) say that “an ecosystem approach to management is management that is adaptive, specified geographically, takes into account ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse social objectives.” Fisheries policy is clearly science based. Science has a huge influence on west coast groundfish management decisions. Perhaps more importantly, EBFM provides a new context for thinking about the interface between science and policy. That context requires a radical shift in thinking about how fishery science is done, and the kind of advice that it delivers to decision makers. Here, we capture the essence of arguments made by Field and Francis (2006), Francis et al. (2007) and Levin and Lubchenco (2008) as they apply to spatial management of west coast groundfish.

- ***In order to consider the concept of sustainability, a fishery should be considered as an integrated concept of humans in nature.***

Almost two decades ago, and based on the history of California fisheries (McEvoy 1986), the environmental historian Arthur McEvoy presented an innovative, broad and comprehensive context for marine fishery science and management, with a strong emphasis on direct interactions and relationships, of which those occurring within the ecosystem are just a part. Ten years later he built on this experience to define a fishery as an interaction between three variables: an ecosystem, a group of people working (economy), and the system of social control within which the work takes place (management) (McEvoy 1996). His key assertion is that management must equally weigh the many social and economic relationships within the fishery and how, in turn, they both influence and are influenced by marine ecosystem processes and dynamics as it is human interrelationships that are of particular concern to decision makers. What McEvoy (1996) says is that a fishery is a classic example of a social-ecological system (Berkes et al. 2003, Berkes 2004): an integrated concept of humans in nature (Figure 1.2). And the essence of a sustainable fishery is the health of the interactions between the ecosystem, economy and management (Field and Francis 2006).

- ***Resilience thinking provides a framework for viewing a social-ecological system as one system operating over many linked scales of time and space (Walker and Salt 2006)***

Resilience thinking is an alternative way to understand and manage human activities in a social-ecological system. Its major focus is on the whole system and the likelihood that it crosses a threshold and moves into a different regime in response to disturbance. From this broader perspective, resilience has three defining characteristics:

1. The extent to which a system can absorb recurrent natural and human perturbations and continue to function with the same structure, identity and feedbacks.
2. The degree to which a system is capable of self-organization.
3. The ability to build and increase the capacity for learning and adaptation.

Resilience is fundamentally linked to the capacity for biophysical, economic and institutional systems to absorb disturbance without undergoing fundamental changes in their functional characteristics. It also refers to the capacities for multiple components to reorganize (or self-organize) in response to each other. Sustainability thus involves both maintaining functionality of the system when it is perturbed as well as maintaining the elements needed to renew or reorganize if a large perturbation radically alters system structure and function (Walker et al. 2002) – essentially maintaining the adaptive capacity of the system at all levels. Levin and Lubchenco (2008) stress that resilience thinking involves focusing on heterogeneity (e.g., diversity, functional redundancy), modularity (e.g., compartmentalization in space and time), and the tightness of feedback. Of particular importance to this paper, they stress that modularity (e.g., spatial management) tends to tighten feedback loops.

- ***Ecosystem-based fishery science (EBFS) should focus on "second stream" approaches to science (e.g., interdisciplinary, holistic, focus on understanding rather than prediction) which encourage management approaches that facilitate existing processes and variability and are proactive rather than reactive (Holling 1993, Holling and Meffe 1996, Francis et al. 2007).***

The important question to ask here is: why has west coast fishery science and management failed so miserably? Two clues come from writings at the roots of the emerging discipline of sustainability science and management with its focus on the dynamic interactions between nature and society. West coast fishery science has had an almost religious focus on providing scientific advice through quantitative stock assessment. The tendency is to promote the simplification of value to a few quantifiable and marketed variables (e.g., individual population and harvest biomass) and demote the importance of unquantifiable and unmarketed variables (e.g., ecological life support and regenerative services). The focus of modeling is on optimization and economic efficiency in a narrow abstract world of independent parts (e.g., populations or stocks) with strong equilibrium tendencies. Walker and Salt (2006) indicate that this striving to be efficient in the narrow sense leads to elimination of redundancies and drastic losses in overall system resilience.

Holling (1993) and Holling and Meffe (1996) relevantly comes to grips with this issue as it applies to natural resource science and management. They say that science and management are inextricably linked and that there are (at least) two forms, or streams, within which these linkages can take place.

	First Stream	**Second Stream**
Science	• System knowable and predictable • Science of parts and disciplines • Seek prediction	• Ecosystem evolving, has inherent unknowability and unpredictability • Science of integration • Seek understanding
	Command and Control	**Golden Rule**
Policy	• Problem perceived, bounded, solution for control developed • Objective: reduce variability and make system more predictable • Reactive	• Retain and restore critical types and ranges of natural variations • Facilitate existing processes and variability • Proactive • Adaptive

First stream science tends to be disciplinary, reductionist, and detached from people, policies and politics. It is linked with command and control management in which a problem is perceived and a solution for its control is developed and implemented. The focus of management is on controlling or commanding aspects of a system to derive an optimized return (Walker and Salt 2006). The use of independent single species quantitative stock assessments leading to "optimal" harvest biomass quotas based on the concept of maximum sustainable yield (MSY) is a classic example of this linked approach to science and management. When problems arise (e.g., overfishing), rather than questioning the validity of the model being applied, the response is often to exert greater control over the system, thus exacerbating the problem (Walker and Salt 2006).

Second stream science is interdisciplinary, holistic, and focuses on the relationships between nature and society which produce resilience. It tends to be linked with "Golden Rule" management which strives to facilitate existing processes and variability rather than changing or controlling them. Holling (1993) and Holling and Meffe (1996) argue that the key to maintaining resilience in ecosystems is to facilitate existing processes and variability, rather than trying to control them. When some part of a system is held constant in an attempt to derive an optimized return (e.g., MSY, constant harvest rate) the system as a whole adapts and frequently loses resilience in the process (Walker and Salt 2006).

- ***Simple management rules are at the heart of EBFM (Berkes and Berkes in review).***

The need for simple rules when dealing with complex systems is counter-intuitive to both scientists and policy makers. However if one looks at examples of successful EBFM, one will find simple management rules (e.g., Pacific coast sardine management - PFMC 1998, Bristol Bay sockeye salmon - Hilborn et al. 2003, marine protected areas of New Zealand - Warne 2007).

- ***Once management expands its image and embraces the social-ecological context of a fishery, the focus of EBFM can be substantially different depending on the scale of the fishery being managed.***

According to Levin (1992), the issue of scale is "the fundamental conceptual problem in ecology, if not in all of science." Certainly the issue of scale is central to the concept of EBFM. Perry and Ommer (2003) expand on this and say that the issue of scale is central to understanding the reciprocal interactions between humans and marine ecosystems. As Cash et al. (2006) make clear, "closely related to spatial scale are jurisdictional scales defined as clearly bounded and organized political units, e.g., towns, counties, states, or provinces, and nations, with linkages between them created by constitutional and statutory means."

- ***Space is an essential dimension of EBFM (Francis et al. 2007).***

So, as an important component of EBFM, we suggest that spatial management should:

- Consider spatial aspects of interactions between humans and nature,
- Incorporate the capacity for resilience thinking,
- Be "second stream" in its approach to both science and management,
- Employ rules which are as simple as possible in achieving the desired results.

It is, therefore, this critical context that will govern our considerations of spatial management of west coast groundfish in the remainder of this white paper.

APPROACH, SCOPE OF SYNTHESIS AND PRODUCTS

Effective management is crafted from informed decisions. This white paper 1) synthesizes the state of knowledge of scales of organization in the various U.S. west coast groundfish fisheries (in the sense of McEvoy 1996) and 2) identifies and prioritizes spatial matches and mismatches between various components of the west coast groundfish fishery.

In particular we examine spatial scales of organization for west coast groundfish physical habitat, populations (metapopulations), ecological assemblages (ecosystems), fishing communities, and management. We then identify, compare and contrast various spatial matches and mismatches within this social-ecological system. These comparisons range from unique small-scale relationships between local stocks and the fishing communities that depend on them to more general coastwide species distributions and fishery use patterns. Understanding the naturally occurring scales facilitates identification and prioritization of mismatches between the system and its governance. From this point, management can evaluate alternatives in the face of mismatches. Present management measures (e.g., Rockfish Conservation Areas, gear restrictions) may suffice for certain sectors of the fishery. In others, new tools (e.g., area-based allocation, Marine Protected Areas, individual fishing quotas) may be appropriate to enhance proper spatial management, safeguard against localized overfishing, and conserve population and age structure needed to increase the likelihood of successful spawning and recruitment events (Berkeley et al. 2004).

This report includes three components: the written summary included here, an electronic database of all the material used to generate this synthesis, and a compilation of most of this published and gray literature in the form of PDF documents. The literature database was compiled in EndNote (version 7.0), one of the most popular and readily available electronic bibliographic databases. The collection of PDF documents will be available as linked attachments through the Endnote library file as well as on the web at both Dr. Francis' website at University of Washington and the Pacific Marine Conservation Council website www.pmcc.org.

2. REVIEW AND SYNTHESIS OF SPATIAL SCALES OF PHYSICS AND ECOLOGY

This review is, by intention, not encyclopedic. It is made in an attempt to keep the entire groundfish fishery in focus. It is made within the context of ecosystem based fishery management described in the introduction.

PHYSICAL HABITAT

Physical habitat is both static and dynamic. Static physical structure is both nonliving (e.g., geomorphology) and living (e.g., macro-algae, corals). Dynamic physical processes shape the spatial scale of biological production in the California Current Ecosystem (CCE). And it is the interface between static and dynamic processes that creates distinct ocean ecosystems within the CCE. We will discuss these interfaces in two dimensions – latitudinal and cross-shelf (inshore-offshore).

Latitudinal structure

In terms of large scale bathymetric features, the most conspicuous one is the variable relative size of the continental shelf and slope along the west coast of North America (Figure 2.1). Because depth is a major source of spatial variation in population and community structure of fishes and invertebrates (see ***Cross-shelf structure*** below), this latitudinal variation in the on-offshore width of the continental shelf becomes a major source of geographic variation in the composition and relative abundance of fishes and invertebrates along the California Current System (CCS). This geographic variation in the width and depth of the shelf also interacts with geographic patterns of coastal upwelling to drive large-scale patterns of coastal oceanic productivity. Superimposed on this major source of bathymetric variation are regional-scale features, including ridges and canyons. Williams and Ralston (2002) provide an overview for the area of the CCS between Cape Blanco and Point Conception (Figure 2.1). The Mendocino Escarpment (Figure 2.2) is a large fracture zone that forms a huge submarine ridge near Cape Mendocino (Fisk et al. 1993). In the region of Monterey Bay and Point Sur are a number of large submarine canyons. These features result in high diversity of shelf and slope structure, consequent demersal fish habitats and their availability to fishing gear (Yoklavich et al. 2000). North of Cape Blanco, Hickey (1998) describes two major canyons – Astoria and Juan de Fuca - and one major bank – Hecata - which may affect rapid changes in shelf habitat, basic biological production processes and availability to fishing.

The large scale physical oceanography of the CCE is described in detail by Lynn and Simpson (1987), Hickey (1979, 1998), U.S. GLOBEC (1994), Peterson et al. (2006), Agostini et al. (2006). It is essentially a network of latitudinal surface and subsurface flows that vary seasonally (Figure 2.3). The CCS has two (Agostini et al. 2006), three (Peterson et al. 2006), or four (Hickey 1979, 1998) major currents which serve to provide a dynamic mixture of subarctic and subtropical waters in the CCE. The California Current (CC – subarctic, cool, fresh) is a broad (~500 km) slow equatorward flow that extends southward from the trans-Pacific flow of the West Wind Drift

(Figure 2.4). The poleward California Undercurrent (CU – subtropical, warm, saline) is a seasonal (March – September) narrow (10-40 km) sub-surface current, trapped along the continental slope and strongest at depths of 100-300 m. In the winter (October – February) this countercurrent comes to the surface and is referred to as the Davidson Current (DC).

Thus over the shelf and slope, there are biannual transitions between northward and southward flow occurring, on average, during March-April (spring transition) and October-November (fall transition). These shifts are associated with seasonal shifts in atmospheric pressure fields and dominant wind flows (SW in winter, NW in summer). Integrating all of this, one gets a seasonally variable north-south push and pull between cool, nutrient rich subarctic water and warm nutrient poor subtropical water.

This push-pull process is particularly amplified and spatially structured in Northern California Current (NCC - continental shelf off northern California, Oregon and Washington - Field et al. 2006a). Coastal upwelling and surface transport are the dominant physical processes affecting biological production in the entire CCE (Peterson et al. 2006). Upwelling in the NCC occurs primarily from April – September coinciding with the spring (on) and fall (off) transitions mentioned above. Upwelling occurs throughout the year off central and southern California. A combination of upwelling itself along with the advection of subarctic water (and its associated plankton communities) feeds the inshore arm of the NCC creating conditions favorable for the development of a huge biomass of subarctic zooplankton. The subarctic copepod community tends to be dominated by large, abundant, fatty species which greatly enhances pelagic production. The subtropical copepod community, which enters the coastal NCC from the south and offshore, is dominated by small, less abundant, low lipid species which tends to reduce pelagic production.

Peterson et al. (2006) show that the occurrence of these plankton communities in the NCC tend to vary with the dominant North Pacific climate signals – Pacific Decadal Oscillation (PDO) and El Niño Southern Oscillation (ENSO) (Figure 2.5). They conclude that during "cold" PDO regimes, a larger amount of cold subarctic water enters the CCE from the coastal Gulf of Alaska as opposed to the (offshore) West Wind Drift. During "warm" PDO regimes, smaller amounts of subarctic water enter the CCE from the coastal Gulf of Alaska and more transition or subtropical water enters from the offshore West Wind Drift or from the south (Figure 2.6).

In addition, Peterson and Keister (2003) speculate that during El Niño (warm ENSO) events, warm water species are brought into the coastal NCC in winter by a combination of increased northward transport in the Davidson Current and onshore transport of offshore waters. Peterson (Appendix I) further reports that during extreme warm ENSO events (e.g., 1983, 1997-98), massive quantities of subtropical water flood the NCC, disrupting the entire upwelling biological production process for months on end.

Peterson (Appendix I) also indicates that there is considerable latitudinal spatial structure to the physical oceanography of the coastal upwelling zone itself. Off

Washington and northern Oregon, upwelling winds are relatively weak and upwelling is a "linear" process. The circulation more or less tracks the bathymetry, with a southward flowing upwelling jet current (Barth et al. 2000) usually developing in mid-shelf waters. In the region just north of Cape Blanco, the shelf begins to narrow, winds and upwelling intensify, and coastal waters are carried offshore. Moreover, the CC itself begins to change from a simple "laminar flow" system to one dominated by high activity of mesoscale jets and eddies that "wander around seemingly at random." Thus, at or near Cape Blanco, what was once a simple lazy southward current becomes a "maze of swirling eddies." This whole process of strong spring and summer upwelling winds (the strongest in the entire CCS) and turbulent coastal flows continues south to Cape Mendocino (Botsford and Lawrence 2002).

In terms of physical forcing of biological production, there appears to be a large difference between the northern and southern CCS, with the area between Capes Blanco and Mendocino as the boundary between these two regions. This transition region is also the southern boundary of subarctic zooplankton species (U.S. GLOBEC 1994, Peterson et al. 2006).

The area south of Point Conception is substantially different from that to the north. The topography is complex, and the shelf is typically narrower and shallower than to the north, and the coastline suddenly changes from north-south to east-west. In addition, a semi-permanent cyclonic gyre exists in the Southern California Bight. This gyre mixes cooler CC water with warmer waters intruding from the southeast (Hickey and Banas 2003). Most importantly, local wind stress is an order of magnitude smaller near the coast (S. California Bight) during summer to fall than north of Conception, and local upwelling generally occurs in winter and early spring in the Bight (Hickey 1998). Peterson et al. (2006) and Botsford and Lawrence (2002) show that Point Conception is a significant thermal barrier, with much warmer water occurring south of the point. Burton (1998) supports this point based on genetic sampling of pelagic zooplankton, saying:

> *Point Conception's strong impact on species distribution probably derives from its oceanographic position as a boundary between cold and warm water masses..rather than its potential role as a barrier to gene flow.*

U.S. GLOBEC (1994) also addresses the basic physical structure of the CCS and divides the U.S. coastal component into three areas, with the breaks at Cape Blanco and Point Conception:

> *Each is forced by somewhat different physical processes..Each of these regions is characterized by differences in wind stress, intensity of coastal upwelling, coastal morphology, freshwater inflow, large-scale advection and the level of mesoscale activity..As a result, each region harbors a somewhat different ecosystem structure.*

When we asked Bill Peterson (NMFS NWFSC, Newport, OR) what it is about the Capes that creates biogeographic barriers that extend out to sea, he responded:

> *Even a brief visit to Cape Blanco on a summer afternoon will reveal the answer: winds are unbelievably strong there and I believe the answer is related to orography of the coastal mountains and the funneling of air at high speeds from the Klamath Basin to the coast. Orographic effects are also what create a wind-max at Point Arena (which if you have ever been there, you know that it is not really a point at all; and is certainly not a cape). But the high winds there are due to a gap in the coast range that sucks air to the coast from the Sacramento Valley.*

Mueter et al. (2002) examined spatial correlations in three coastal environmental variables (upwelling index, sea surface temperature and sea surface salinity) from California to Alaska and related these to spatial patterns in salmon survival. They conclude that the variability in the coastal marine environment during summer is dominated by regional variability at the scale of several hundred to 1000 km. This is likely due to the complex mesoscale features that develop in response to coastal upwelling jets as well as topography and orography. This is also reflected in regional scale variability in survival rates among salmon stocks.

Cross-shelf structure

Cross-shelf structure is fundamentally defined by substrate and depth. Allen et al. (2006) provide an excellent overview of this (Figure 2.7). Simplifying a bit, substrate can be either hard (e.g., rocky reef, kelp bed rocky reef, bank) or soft. Depth strata include nearshore, shelf, and slope. Gabriel (1982) indicates that several environmental features are strongly related to depth, including bottom temperature, ambient light, pressure, sediment type and bottom topography.

From the biophysical context, nearshore demersal habitats tend to be driven by highly energetic and variable physical processes, are strongly influenced by the coastline itself, and exhibit a broad range of temperatures. Conversely, deep offshore areas of the continental shelf and slope are generally colder, low oxygen demersal habitats with relatively stable and predictable ocean environmental conditions. Largier (2003) and Shanks and Eckert (2005) distinguish the nearshore coastal region from the offshore shelf and slope regions by the relative influences of advection and diffusion as dispersion mechanisms. Talking about larval movement in the plankton, Largier (2003) says "larvae must go offshore to get alongshore." The nearshore is characterized by a coastal boundary layer of weak flow which is, in effect, a retention zone along the shoreline –termed "sticky water." Flow speeds along the coast are typically slow due to the drag of a shallow bottom, the roughness of the coastline and the proximity of the solid coastal boundary. Any cross shelf dispersal near to shore is primarily due to diffusion rather than advection. Off the northern California coast, Largier (2003) reports cross-shore diffusivities in the order of 1-10 m^2/s in nearshore, 100 m^2/s over the wind driven shelf, and 1000 m^2/s or greater in offshore waters.

POPULATION SCALE – GENETIC, METAPOPULATION, POPULATION DYNAMIC/STOCK ASSESSMENT, LIFE HISTORY

> *Broad spatial distribution of spawning and recruitment is at least as important as spawning biomass in maintaining long-term sustainable population levels* (Berkeley et al. 2004).

The groundfish resource can be partitioned at the individual species population level. This partitioning or structuring can be measured in a number of different ways: life history (Berkeley et al. 2004, Shanks and Eckert 2005), genetic (Cope 2004), metapopulation (Gunderson and Vetter 2006), (closed – completely self recruiting) population dynamics (Field and Ralston 2005).

If at all possible, we wish to avoid developing an encyclopedic sense of what is known about spatial structure for each species being exploited, and then somehow asking you, the reader, to synthesize and integrate this information. We wish to use studies which reflect on population structure at the individual species level to synthesize a more general determination of the demographic connections of various groundfish species. Otherwise phrased, how widely and how fast do groundfish disperse as larvae and juveniles, and move as adults?

We begin with the how life histories vary on spatial scales. The classic example of this is the case of Bristol Bay, Alaska, sockeye salmon (Hilborn et al. 2003). They show how individual populations with diverse life history characteristics and local adaptations (summarized conceptually as biocomplexity) has enabled the resource as a whole to sustain its productivity despite major changes in physical climate affecting freshwater and marine habitats during the 20th century. They show how different geographic components have performed well at different times, thus lending relative stability and sustainability to the fishery as a whole. Berkeley et al. (2004) make a similar argument for marine fish species. They show how most marine fish spawners fail to produce surviving offspring because their reproductive activity is not matched in space and time to favorable oceanographic conditions for larval survival. This suggests that the geographic source of successful recruits may differ from year to year, and that “based on these considerations, management should strive to preserve minimal spawning biomass throughout the geographic range of the stock.” Ames (2004) shows the effects of systematic depletions of Atlantic cod geographic spawning components in the Gulf of Maine, and how this spatial erosion may preclude recovery of the resource as a whole.

We now move to specific aspects of spatial patterns of west coast groundfish. Gunderson and Vetter (2006) focus on population structure in their comprehensive and eloquent characterization of metapopulation structure of west coast rocky reef fishes. They evaluate larval dispersion and, essentially, examine how various reproductive strategies and oceanographic conditions are reflected in population genetic structure. They present four scenarios of metapopulation structure (Figure 2.8):

1. Broad dispersal – Larvae are broadly advected away from their natal location and disperse freely among populations along the coast.
2. Mesoscale dispersal – Larvae and pelagic juveniles are advected away from their natal location but are entrained within mesoscale oceanographic features such as upwelling fronts, jets and shadows, or inland basins. Populations are self-recruiting on a regional rather than local or coastwide scale, with limited dispersal between oceanographic domains.
3. Diffusive dispersal – The life history takes place within a domain of "sticky water" where advective processes are limited and alongshore flows are dominated by reversing tidal currents. In these nearshore regions, structures like dense kelp forests, highly structured rocky reefs, bays and estuaries provide the opportunities for swimming larvae to avoid entrainment into bulk offshore flow. This kind of metapopulation structure is reflected in strong correlation between genetic distance and geographical distance.
4. Non-dispersing – Recruitment is local and populations are essentially closed.

Gunderson and Vetter (2006) indicate that depth is perhaps the most significant spatial structuring variable for west coast groundfish. They report genetic studies which indicate that metapopulation structures of west coast rocky reef fishes tend to change with depth. These patterns of genetic structure (lower in deeper offshore waters) coincide with the relative dispersal potential of fish and crustacean assemblages distributed across the onshore-offshore depth gradient (Shanks and Eckert 2005).

- Broad dispersal and coastwide populations tend to occur in the outer shelf and slope. The short- and longspine- thornyheads, *Sebastolobus alsacanus* and *S. altivelus*, are prime examples of this. The only constraints to panmixia over broad environmentally homogeneous geographic areas of the continental slope appear to be due to larval retention in currents and gyres (Stepien 1999, Stepien et al. 2000).
- Mesoscale dispersal has been inferred among deep reef species that can be identified in the ichthyoplankton. Buonaccorsi et al. (2004, 2005) indicate that deep reef rockfish species such as bocaccio (*S. paucispinis*), shortbelly (*S. jordani*) and cowcod (*S. levis*) are often found in offshore ichthyoplankton surveys and appear to exhibit significant alongshore advection and concentrate in oceanographic fronts and gyres – evidence of mesoscale dispersal. Matala et al. (2004) report that the genetic variation of west coast bocaccio partitions into three groups, with breaks at Cape Blanco and Point Conception. They infer that oceanographic influences might restrict larval transport, thereby limiting gene flow or genetic structure. Cope (2004) reports a major break in the population structure of blue rockfish at Cape Mendocino.
- Diffusive dispersal is common among nearshore rocky reef species, particularly those with associated kelp forests. These species show a strong isolation by distance signal over shorter distances within oceanographic regimes (e.g., kelp, grass, copper and brown rockfish - Buonaccorsi et al. 2004, 2005). They may

also show regional differences that suggest oceanographic barriers to dispersal at the larger scale (e.g., grass rockfish - Buonaccorsi et al. 2004). Diffusive dispersal appears not to be limited to nearshore species. Gomez-Uchida and Banks (2005) hypothesize diffusive dispersal for darkblotched rockfish, a deepwater species they sampled in the NCC slope. They estimated a mean (intergeneration) dispersal distance of less than 1 km.

- Non-dispersing species are rare and generally reside in the nearshore.

Of particular importance to this discussion is the role of the three Capes in determining metapopulation structure. In addition, the closer to shore, the more evidence there is for limited "stepping-stone" dispersal reflected in a linear relationship between genetic distance and geographic distance (Figure 2.9). And thus, whereas the capes may provide adequate spatial structure for offshore species, units as small as 10 km may be more appropriate for managing nearshore resources (Gunderson et al. in review).

Field et al. (2006b) review what is known about movement patterns for west coast adult groundfish. They indicate that tagging shows the bulk of adult rockfish are highly sedentary with some gradual ontogenetic movement to greater depths common to most shelf and slope species. In addition, Gunderson (1997) showed that fishing induced changes in abundance and age composition of adult Pacific ocean perch, a slope species, were highly localized, even decades after fisheries impacts. This suggests little to no adult migration of this species between areas of suitable habitat as close as 30 km. Adult lingcod appear to have somewhat greater, albeit still relatively modest, movement rates. Sablefish exhibit even greater latitudinal movements and significant ontogenetic movement towards greater depths as they grow older. Adult flatfish exhibit modest latitudinal and strong seasonal bathymetric movements (Field et al. 2006b). Table 2.1 summarizes known or suspected movement patterns for adults of key west coast groundfish species.

Studies of population dynamics have also been useful in delineating west coast groundfish spatial structure. Field and Ralston (2005) studied spatial patterns of recruitment of three winter spawning and commercially important species of shelf rockfish (e.g., chilipepper, widow and yellowtail) in the California Current System. In all three species, they found substantial spatial synchrony in year-class strength over scales on the order of 500-1000 km, and that "much of the spatial variability in year-class strength that does exist is associated with major geological features such as Cape Mendocino and Cape Blanco." (Figure 2.10) These species would seem to further exemplify the mesoscale dispersal patterns discussed by Gunderson and Vetter (2006).

A summary of recent (2005) PFMC stock and stock complex assessments reveals that a significant number were divided into two or more independent stocks or assessment regions (PFMC and NMFS 2006). Stock assessment breaks occurred at Cape Blanco (lingcod, petrale sole), the Oregon-California border (kelp greenling), Cape Mendocino (English sole, bocaccio and yellowtail rockfish). Yelloweye rockfish was assessed separately by state (Washington, Oregon, California). However due to lack of convergence in the Washington assessment, is currently managed on a coastwide assessment. The SSC did encourage further development of area-specific models given the apparent vulnerability of yelloweye to localized depletions (PFMC March 2006 SSC statement on yelloweye rockfish). Cabezon was divided into two regional assessments with the break at Point Conception. Minor rockfish assemblages were assessed and managed at four depth strata (shallow nearshore, deep nearshore, shelf and slope) with a latitudinal break at Cape Mendocino. In another development, Cope and Punt (in review) are developing a method of stock identification that uses spatially resolved standardized measures of relative abundance (either survey- or fishery-based) and a simple statistical clustering approach to combine areas with similar abundance trends.

O'Farrell and Botsford (2006) address the issue of groundfish stock assessment in a data poor environment, and provide an argument for supporting the spatial distribution of west coast "big old fat female" rockfish (Berkeley et al. 2004). They show that for marine fish, population persistence is best represented by lifetime egg production (LEP), the total number of eggs produced by a female over her lifetime. Using length-frequency data, they present changes in LEP from 1980-2000 for five species of nearshore rockfish. LEP is a similar measure to Spawning Potential Ratio (SPR = spawning per recruit at the current population level relative to that at a stock's unfished condition) used in the PFMC's groundfish management Environmental Impact Statement (PFMC 2005). What is of particular interest here is that O'Farrell and Botsford (2006) show how LEP changed differentially in neighboring geographic regions (Figure 2.11). This indicates that the effects of fishing mortality in truncating size structure and reproductive potential are not evenly distributed over space.

ECOLOGICAL ASSEMBLAGE AND ECOSYSTEM SCALE

Spatial structure of west coast groundfish has been extensively studied at both the assemblage and ecosystem scale. Gabriel (1982) defines an assemblage as a "group of co-occurring species which do not necessarily interact biologically but which are often the object of a common multispecies fishery." Thus, the focus of assemblage analysis is on co-occurrence and not ecological interactions. However, in addition to habitat, food webs create the fundamental organizing relationships in ecosystems (Paine 1980, Francis et al. 2007). So, the focus of fisheries ecosystem analysis is on food webs and how they might be used to form a context for fishery management policy. In this white paper we are looking for evidence of spatial structure in west coast groundfish assemblages and marine ecosystems.

Assemblage analysis

Gabriel (1982) performed the first comprehensive assemblage analysis of west coast groundfish along the continental shelf and upper slope based on data collected during the first triennial NMFS summer trawl survey conducted in 1977 from northern Washington to southern California.

As is the case with all subsequent assemblage analyses, depth is the major factor that determines assemblage boundaries: "The effect on species composition of moving 50 fm (92 m) in depth within a degree of latitude is usually greater than moving 1° in latitude." Gabriel (1982) delineated outer shelf/upper slope from mid to outer shelf assemblages coastwide.

Latitude was second to depth in influencing assemblage boundaries. Reflecting the work of Parrish et al. (1981), Gabriel (1982) indicates that wind stress and current patterns (referred to above) may be the most important factors controlling north-south differences in species assemblage structure. In this regard, she makes particular reference to the area between Capes Blanco and Mendocino, which "incurs the largest annual variation in north-south surface wind stress of any area between Cape Flattery and Point Hueneme," affecting a very simple (i.e., low diversity and standing stock) assemblage structure dominated by Dover sole offshore and Pacific hake at mid-shelf. Gabriel (1982) also found very different rockfish assemblages south of Cape Mendocino (e.g., small size, early maturity, low fecundity, short life – splitnose, chilipepper, bocaccio) than north of Cape Blanco (e.g., larger size, late maturity, high fecundity, long life – canary, Pacific Ocean perch, silvergrey). She attributes this difference to the fact that advective loss of larvae may be more likely in southern regions where Ekman transport (upwelling) is offshore year round and, as a result, a greater proportion of production is likely to be pelagic.

Jay (1996) examined the 1977-1992 NMFS triennial trawl survey data to assess the variability in the summertime spatial distribution of west coast groundfish assemblages. Like Gabriel (1982), Jay also found assemblage discrimination to be primarily a function of depth and latitude. The interesting finding of his analysis is the preponderance of hake-dominated assemblages throughout the study area, inshore-offshore and north-south, and the suggestion that hake may play a large role in the dynamics of west coast demersal fish communities. This finding is supported by a) the massive increase in hake biomass in the mid to late 1980s due to the influx of two enormous year classes (Field and Francis 2006, Figure 2.12), and b) the strong environmentally driven spatial variability in hake summer feeding range in the NCC (Figure 2.13). It is clear that in periods of high hake abundance and a "warm" PDO regime or even El Niño conditions, the NCC could be inundated with hake from the nearshore to the slope. This seems to be a biological analog of Peterson's El Niño "floods" of warm water.

There have been several analyses of west coast rockfish assemblages based on NMFS triennial survey data. Weinberg (1994) analyzed rockfish assemblages from Cape Blanco north, employing the 1977-92 NMFS triennial trawl surveys. Williams and Ralston (2002) analyzed rockfish assemblages from Cape Blanco south, employing the 1977-98 NMFS triennial trawl surveys. Both analyses covered continental shelf and upper slope regions.

North of Cape Blanco, Weinberg (1994) found that rockfish could be broken into two major assemblages – shelf (150 m avg. depth, yellowtail, canary, greenstriped, sharpchin, redstripe, rosethorn) and slope (250 m avg. depth, shortspine thornyhead, Pacific Ocean perch, darkblotched, splitnose). He also found that rockfish species diversity peaked along the outer shelf (~200 m) where centers of abundance of several species overlapped.

South of Cape Blanco, Williams and Ralston (2002) found that rockfish could be broken into four major assemblages: deepwater slope, nearshore, southern shelf and northern shelf. Separation between shelf and slope assemblages was roughly at 200-250 m. Southern shelf assemblage ranged from Cape Mendocino south and northern shelf assemblage ranged from Monterey Canyon north, leaving the area between Monterey Canyon and Cape Mendocino as an area of overlap for these assemblages. The nearshore assemblage resided in waters less than 150 m depth.

It is interesting to examine the species overlap between Weinberg (1994) and Williams and Ralston (2002) as a function of depth. All of Weinberg's slope species appeared in Williams and Ralston's deepwater slope assemblage. All except one of Weinberg's shelf assemblage appeared in Williams and Ralston's northern shelf assemblage. And only one of Weinberg's shelf assemblage appeared in Williams and Ralston's southern shelf assemblage. No comparison of nearshore assemblage could be made since the NMFS survey covers no habitat shallower than 55 m.

Williams and Ralston (2002) found that species richness peaked at around 200-250 m, particularly in the shelf region between Monterey Canyon and Cape Mendocino (Figure 2.14) – essentially the overlap region between the northern shelf, southern shelf, and deepwater slope assemblages.

Tolimieri and Levin (2006) analyzed the NMFS 1999-2002 continental slope trawl surveys to attempt to characterize slope groundfish assemblages. The surveys extended from Cape Flattery, Washington to southern California and ranged in depth from 200-1200 m. Their analysis identified five assemblages which separated primarily on depth and latitude. There was a major shift between deepwater and shallow slope assemblages at 500-600 m, perhaps in response to an oxygen minimum zone at 600-1000 m. Latitudinal variation in assemblage was much more noticeable in shallow slope regions (4 assemblages) than in deepwater slope regions (1 assemblage). Much of the latitudinal variation was correlated with major geographic features – Capes Mendocino and Blanco. The most interesting assemblage group was made up of Dover sole, sablefish, shortspine and longspine thornyheads – all commercially important deep water species. This assemblage had a depth distribution that varied with latitude, being found in a shallower depth range in the north than in the south. These species are known to move into deeper water is they age based, perhaps, on developing the ability to penetrate low-oxygen waters.

All of the above-mentioned analyses were conducted on bottom trawl surveys under a stratified random sample design. Rogers and Pikitch (1992) did a similar analysis based on Oregon trawl observer records collected during 1985-87. They found five assemblages. Two of these were shelf and deepwater rockfish assemblages very similar to those reported off Oregon and Washington by Weinberg (1994). Two others were essentially single species assemblages – pink shrimp and midwater widow rockfish. The other two were deep water Dover (primarily Dover sole and sablefish) and a nearshore mixed species assemblage consisting primarily of flatfish (sand sole, starry flounder, sanddab and English sole). These results clearly show that Oregon trawlers were able to easily target these assemblages, and that the assemblages seemed to persist throughout the year. Lee and Sampson (2000) found four similar assemblages when analyzing Oregon bottom trawl logbooks from 1987-93. Unlike Jay (1996), their results show little effect on assemblage structure of a massive decline in Pacific hake biomass over the study period.

Spatial structure of inshore species assemblages have been examined and identified at smaller spatial scales than those identified in deeper offshore waters. At the extreme inshore, studies of the spatial structure of rocky intertidal communities have detected strong spatial structure throughout the west coast of North America (Blanchette et al. 2008). Some of these patterns reflect large-scale features such as the bifurcation of the central Pacific Gyre (Figure 2.4), others coincide with the major headlands described above (e.g., Point Conception, Pt. Reyes) and at smaller scales as well (e.g., four major community structures within the Southern California Bight). Similarly, the community structure of soft-bottom fishes and invertebrates within the southern California Bight exhibits spatial structure that is both depth and geographically distributed along the coast (Bergen et al. 2001). The fish, invertebrate and algal assemblages associated with kelp forests on shallow (0-30 m depth) rocky reefs also exhibit geographic structure defined my major headlands (e.g., Point Conception), regional oceanographic conditions (e.g., exposure to the California Current, coastal upwelling), local coastal oceanographic conditions (e.g., swell exposure), geologic and biogenic structure (i.e., rock and kelp type) and, nearshore islands (Foster and Scheil 1985, Ebeling and Hixon 1991, Stephens et al. 2006, Springer et al. 2007, M. Carr et al. in prep.).

Ecosystem analysis

Unlike assemblage analysis which focuses on the co-occurrence of species, the focus of fisheries ecosystem analysis is on ecological interactions between co-occurring species – in particular on food webs and how they might be used to form a context for fishery management policy. Due to data requirements, most ecosystem analyses discussed here are conducted at either a semicoastwide or coastwide scale.

In addition, due to data requirements and the nature of scientific investigations of ecosystems, these analyses will not provide the same kinds of direct management advice that stock assessments do, which necessitates that the institution of EBFM requires developing a new context for fishery management (Francis et al. 2007) within the realm of sustainability science (Schellnhuber 1999, Kates et al. 2001). One tenet of this new mindset is to manage to avoid catastrophic outcomes in the system as a whole rather than to optimize isolated components of the system (Walker and Salt 2006). Given this, we examine several ecosystem analyses and see what they can contribute to our understanding of spatial structure in the CCE.

Two of the most important aspects that ecosystem analysis reveals are the structures of ecosystem forcing (i.e., top-down, bottom-up) and production pathways (i.e., benthic, pelagic).

Ecosystem forcing

Field et al. (2006a) used a dynamic ecosystem model to explore the structure and dynamics of the Northern CCE and how that structure may have been influenced by both climate forcing and fishing over the past 40 years. They showed that climate affects 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 – in particular Pacific hake). They also showed that fishing down many predator populations may have caused significant restructuring of the system.

Levin et al. (2006) document these fundamental shifts in the structure of fish assemblages along the continental shelf based on an analysis of 1977-2001 NMFS trawl surveys. They show that over this period, flatfish, cartilaginous fish and small rockfish associated with soft substrate increased, whereas populations of large rockfish associated with hard substrates dramatically declined. They estimate that average fish size, across a diversity of species, has declined 45% from 1977 to 2001.

Scaling down spatially, Yoklavich et al. (2000) and Love and Yoklavich (2006) report dramatic changes in community composition of heavily fished rocky reef habitats (e.g., Hecata Bank, Oregon) where large piscivorous species such as lingcod, bocaccio, yelloweye and cowcod have been substantially depleted and the abundance of smaller faster growing species such as greenstripe, rosethorn, splitnose and pygmy rockfish has increased. Based on observations from submersibles, they also report that rock outcrops of high relief in submarine canyons (e.g., Soquel Canyon, Monterey Bay, California) can provide natural refuge for large piscivorous rockfish. Baskett et al. (2006) provide further supporting evidence that overfishing of deep rocky reefs off California and Oregon has substantially reduced densities of larger rockfish species (e.g., canary, bocaccio, yelloweye), thereby releasing predation and competition pressures and likely causing a subsequent explosion of smaller species' populations (e.g., greenstripe, splitnose, pygmy) in higher quality habitat previously dominated by the larger species. Harvey et al. (2006) examined spatial and temporal trends in the abundance of 16 shelf rockfish species from 1980-2001 between central California and Washington, and found that density changes varied between region and were most often associated with large-bodied rockfish (Figure 2.15).

Reum (2006), in a recent study of the spatial and temporal variability in the Puget Sound, WA food web, indicates that the pervasiveness of piscivory within the fish community can indicate variation in food chain length and the potential for tight predator-prey relationships, and that changes in the prevalence of piscivores at the same site over successive years can indicate degraded ecological integrity.

Finally, Ware and Thomson (2005) address the question of bottom-up versus top-down forcing of the CCE at both the large scale (INPFC areas extending from southern California to western Alaska – mean surface area, 67,157 km^2) and smaller areas for coastal British Columbia (mean surface area 19,000 km^2). They found strong association between alongshore variation in retained primary production (mean annual chlorophyll-a concentrations from 1998-2003) and alongshore variation in resident fish yield (mean annual yields from 1960-1998) at both spatial scales. They conclude that there are strong bottom-up trophic linkages between phytoplankton, zooplankton and resident fish extending from areas as large as 145,000 km^2 to areas as small as 7,200 km^2.

Production pathways

Understanding of the importance of different energy sources is essential to understanding food web dynamics (Reum 2006). Unfortunately, few studies of the CCE have investigated the relative importance of benthic or detrital-based energy pathways as opposed to pelagic or phytoplankton-based pathways.

Field et al. (2006a) give a static view of benthic and pelagic pathways of the NCC (Figure 2.16). They also present a dynamic view of the NCC food web (Figure 2.17), the implications of which are interpreted by Levin et al. (2006), who report that in 1977, rockfish accounted for 60% of the coastwide shelf survey catch and flatfish 34%, whereas in 2001 rockfish comprised 17% and flatfish 80% of the survey catch. In addition, within the rockfish assemblage, there were significant increases in many smaller rockfish species (e.g., greenstriped, splitnose, chilipepper) and declines in most of the larger species (e.g., canary, bocaccio). They then speculate that this shift from large to small bodied rockfish as well as the shift in the flatfish community might alter the balance of benthic and pelagic pathways in the (coastwide) ecosystem. Harvey et al. (2006) take this one step further and show how regional differences in the temporal trends in rockfish density as a function of maximum body size cause highly variable responses in regional rockfish community structures (Figure 2.18). So, they show clear fishing-induced assemblage structural changes which vary at the regional scale.

Inshore on shallow rocky reefs, the productivity of local ecosystems and the reef fishes they support appears to be closely linked to both primary (and detrital) production of kelps (e.g., the giant kelp, *Macrocystis*, and the bull kelp, *Nereocystis*) and the influx of planktonic production (Broitman and Kinlan 2006, Halpern et al. 2006, Springer et al. 2007, Graham et al. 2008). Rates of productivity of these ecosystems varies markedly as a function of geographic variation in coastal upwelling, advection and retention of coastal currents, and width of the nearshore shelf that determines the area of reefs within the photic zone and the delivery of nutrients with upwelled waters. All of these coastal features (geologic, atmospheric, and oceanographic) vary substantially and characteristically among the regions delineated by the major headlands along the coast of North America (Figure 1.1; Strub et al. 1987a,b, Broitman and Kinlan 2006, Graham et al. 2008).

West Coast Marine Ecosystems

Much has been written about west coast marine ecosystems that falls into no reductionist category, other than ecosystems. Most of this research which relates to spatial structure focuses on the nearshore region, in particular on rocky reefs and kelp forests.

In June 2007, 80 concerned citizens and scientists from California, Oregon, Washington, British Columbia and Alaska gathered to consider the management of living resources on nearshore rocky reefs within the region. Their particular focus was on nearshore ecosystems ranging from shoreline to a depth of about 40 m. The following is an excerpt from their draft report in review by *Fisheries* (Gunderson et al. in review):

> *Acoustic and conventional tagging long ago established that many adult fish and shellfish inhabiting these reefs range less than 100 square meters over the course of their lives. For many years, it was assumed that these adults were linked over more extensive scales through their dispersive egg and larval stages. However, recent genetic work has shown that in nearshore areas (less than about 40 meters deep), larval dispersion can be very limited (Gunderson and Vetter 2006), and many species conform to the "stepping stone" model (Figure 2.8). This limited dispersal results from diffusive oceanographic processes that tend to dominate advective processes as one moves shoreward (Largier 2003). Depending on the parameters used in the model, mean larval dispersion over several generations is estimated to range from 1-40 km for the species of rockfish that have been examined to date (Buonaccorsi et al. 2002, 2004). Propagule dispersion distances for kelp, and some species of abalone are even lower than those in Table 1 (Morgan and Shepherd 2006, Reed et al. 2006). These findings present a new challenge to fishery managers accustomed to managing populations which range more widely over the course of their lives.*
>
> *If we are to maintain the function and integrity of these nearshore ecosystems, yet take advantage of the opportunities for consumptive use and environmental services they provide, a new paradigm for management on smaller spatial scales will be required.*

So, from an ecosystem perspective, the nearshore coastal environment presents a challenge to manage on fine spatial scales never before encountered with offshore fisheries.

Much has also been written on the kelp forest ecosystems of the Aleutian Islands, southern California, and the Gulf of Maine. Jackson et al. (2001) and Steneck et al. (2002, 2004) focus on resilience of these ecosystems and removals of apex predators and explosions in herbivores, primarily sea urchins, resulted in kelp deforestation at local to widespread spatial scales. Kelps concentrate biomass and are a significant source of nutrition for coastal marine ecosystems via food webs based on macroalgal detritus (Steneck et al. 2002, Graham et al. 2008), thereby supporting complex food webs and some of the most diverse and productive ecosystems in the world. The key to resilience in these ecosystems is maintaining biodiversity through functional redundancies among predators and herbivores. When comparing the three regions, widespread kelp loss seems rarest in southern California where biodiversity is highest. In all of these systems, a few species seem to be critical to maintaining healthy trophic-level functions and avoiding rapid trophic cascades and ecosystem restructuring.

The major question is: what are the spatial patterns in these west coast nearshore ecosystems? Halpern et al. (2006) report strong spatial variability in primary productivity between sixteen different kelp forest sites around the Channel Islands, California. They attribute this to the complex bathymetry of the region as well as dynamic local oceanographic processes. They report that "this variability in production in turn generates large variations in community structure and dynamics around the islands." Graham et al. (2008) discuss spatial variability in southern and central California kelp forest ecosystems. They indicate that kelp is "an overwhelming source of primary production and detritus that fuels both grazer-dependent and detritus-dependent trophic pathways in these systems." They report that the dynamics and productivity of kelp populations can be highly variable in both space and time. They use examples of out-of-phase dynamics of giant kelp populations on either side of the Monterey Peninsula and across locations south of Point Conception, even at the opposite ends of the same kelp forest (see also Edwards 2004). Finally, they say that "kelp-associated processes may be responsible for much of the food-web dynamics over short spatial scales and a broad range of temporal scales."

BIOPHYSICAL SUMMARY

Physical processes important to coastal fisheries:

- Due to the nature of upwelling winds, shelf and coastline structures, the area between Capes Blanco and Mendocino creates a physical boundary (transition region) between the area to the north and to the south. This transition region has the strongest upwelling winds and turbulent coastal flows of the entire CCS.
- Thus the major north-south division in the CCE occurs between Capes Blanco and Mendocino and serves to define the Northern (NCC) and Southern (SCC) California Current Ecosystems. The NCC is dominated by a seasonally variable north-south push and pull between cool, nutrient rich subarctic water and warm nutrient poor subtropical water.
- The occurrence of two plankton communities (subarctic and subtropical) in the NCC varies interannually according to large scale climate forcing, and has a significant impact on overall pelagic production.
- The area south of Point Conception is very different from the area to the north – much smaller local wind stress, warmer subtropical water, different timing in the upwelling season.
- Nearshore demersal habitats tend to be vastly different from deeper offshore areas of the continental shelf and slope. Nearshore regions are typified by "sticky water" with very low alongshore movement. Offshore regions are generally colder, lower oxygen, and relatively stable ocean environments with much stronger alongshore advective processes coming into play in the pelagic region.

Marine biological processes important to coastal fisheries:

- Both static and dynamic physical processes are key determinants of spatial structure of west coast marine fishery resources. For example, Gunderson and Vetter (2006) discuss this at the metapopulation scale, Gabriel (1982) at the assemblage scale, and Yoklavich et al. (2000) at the ecosystem scale.
- Metapopulation structures of west coast rocky reef fishes tend to change with depth (Gunderson and Vetter 2006). Broad dispersal and coastwide populations tend to occur offshore (outer shelf and slope). Mesoscale dispersal and populations structured by the capes tend to occur in mid to inner shelf regions. Nearshore populations exhibit very limited dispersal.
- Studies of population dynamics tend to support spatial variability associated with major geological features such as the three capes.
- Some stock assessments can be performed at this mesoscale.
- Depth is the major factor that determines assemblage boundaries. In general species richness is highest at transitions between shelf and slope species assemblages (Weinberg 1994, Williams and Ralston 2002).
- Latitude is the second most important factor influencing assemblage boundaries, and dynamic atmosphere-ocean processes such as wind stress and current patterns are likely the most important factors controlling these north-south structures (Gabriel 1982).
- Assemblage analyses based on commercial trawl data show that trawlers are able to target assemblages by adjusting the depth fished (e.g., deepwater Dover sole, shelf rockfish, nearshore mixed species - Rogers and Pikitch 1992).
- Heavy fishing of rocky reef habitats can cause significant changes in ecosystem structure. Large piscivorous (rockfish) species can be fished out and replaced by smaller faster growing species. This has been demonstrated at the very small individual reef scale (Yoklavich et al. 2000, Love and Yoklavich 2006), and at the coastwide scale (Levin et al. 2006), causing allocation of energy and reproductive potential to shift dramatically and vary from region to region (Harvey et al. 2006).
- There are strong associations between mesoscale (Cape to Cape) variation in primary production and mesoscale variability in fish yield (Ware and Thomson 2005).
- From an ecosystem perspective, the nearshore coastal environment presents a challenge to manage on fine spatial scales never before encountered with offshore fisheries (Gunderson et al. in review).
- The key to maintaining resilience in nearshore kelp forest ecosystems is the maintenance of biodiversity through functional redundancies among predators and herbivores (Steneck et al. 2002, Graham et al. 2008).

3. SCALE OF FISHERIES AND FISHING COMMUNITIES

INTRODUCTION

In this section, we describe spatial scales of organization within the groundfish fishery. To do this, we describe each sector of the fishery by presenting spatially explicit information about landings, revenue and number of vessels or permits. These descriptions are primarily based on data summarized from the Pacific Coast Fisheries Information Network (PacFIN, PSMFC 2007), the online clearinghouse for US West Coast fisheries data. Original data analysis was performed when feasible (i.e., when data were publicly available online); these analyses are supplemented with summaries of PacFIN data from existing reports. Spatial data resolution varies from fine (small groupings of ports) to coarse (by state –Washington, Oregon, or California). Year of analysis also varies, depending on data availability.

Overview of main species groups targeted by groundfish fleet

We begin with a brief overview of the recent history of groundfish landings and ex-vessel revenues. The groundfish fishery targets species that can be categorized as rockfish (e.g., widow, yellowtail, and canary rockfish; thornyheads, bocaccio, chilipepper, and Pacific Ocean perch), flatfish (e.g., Dover, petrale and English soles, arrowtooth flounder, and sanddab) or roundfish (e.g., sablefish, lingcod, cabezon, kelp greenling, Pacific cod, and Pacific whiting). Pacific whiting (i.e., whiting or Pacific hake) is considered separately from other roundfish as it is the principal target of a specific fleet and caught in high volume.

Since 1981, rockfish, roundfish, and flatfish landings have declined, while whiting landings have increased (Figure 3.1). Roundfish and flatfish landings declined gradually (-3% and -2% average annual change, respectively) while rockfish declined more rapidly (-11%). Ex-vessel revenues (inflation adjusted to 2005 dollars) mirror the gradual landings decline for flatfish, but less so for the rockfish, roundfish, and whiting. Ex-vessel revenue derived from rockfish landings increased (while landings decreased) until 1995, when revenues plummeted. While roundfish landings have declined, revenues, although highly variable, have remained constant since 1981, which reflects an increase in roundfish value since 1981. Finally, whiting, although landed in high volume, is a low value species. Although landings overshadow all other landings, ex-vessel revenue is of the same magnitude to that of other groups. Additionally, the overall rise in landings since the late 1980s has only resulted in a slight gain in ex-vessel revenue.

Fluctuations in landings and revenues are due to changing regulations, abundance of resources, and markets. A series of overfishing declarations began in 1998, and were accompanied by strict management restrictions to prevent further overfishing and aid in stock rebuilding. By 2002, nine groundfish species were declared overfished (Pacific Ocean perch, lingcod, bocaccio, darkblotched rockfish, canary rockfish, cowcod, widow rockfish, yelloweye rockfish, and whiting). Lingcod and whiting have since been declared recovered.

Sectors of the Groundfish Fishery

The groundfish fishery is comprised of limited-entry (LE), open access, tribal and recreational fleets, each of which has distinct sectors. In 2005, 85% of landed (at-sea or shoreside) groundfish was caught by sectors of the LE trawl fleet (PFMC 2007b). Each of these sectors is described more fully in section 2. The LE fleet consists of trawl and fixed gear (e.g., longlines, traps, pots) vessels. LE trawl vessels are further divided as whiting and non-whiting trawlers. Those that trawl for whiting process landings at sea by integrated catcher-processor vessels and motherships, or land catch for processing at onshore facilities. For whiting, analyses in this report include at-sea (i.e., catcher-processor vessels and motherships) and shore-based sectors. The LE non-whiting trawlers and all other non-tribal sectors deliver their catch to onshore processing facilities. The open access fleet consists of the directed and incidental sectors. Fishermen who directly target groundfish but do not have a LE permit participate in the directed open access fishery, and those who incidentally catch groundfish while targeting non-groundfish species (e.g., California halibut, salmon trollers, shrimp trawl fisheries) are participants in the incidental open access fishery. Trawl gear is prohibited in the directed open access fleet. The tribal fleet of the groundfish fishery consists of members of the Makah, Quileute, Hoh, and Quinault tribes in Washington State. Tribal fisheries exist for commercial, ceremonial and subsistence purposes. The commercial tribal sectors are similar to those of the limited entry fleet: whiting trawl, non-whiting trawl, and fixed gear. The recreational fishery for groundfish includes shore-based angling from docks, beaches, and piers, and vessel-based angling from either charter or private vessels. The majority of recreational harvest has been from vessel-based angling (Karpov et al. 1995, OCZMA 2002).

In 2005, 90% of groundfish fishery landings were whiting (Figure 3.2), taken by the LE and tribal whiting trawl fleets (PFMC 2007b). Of the sectors that did not target whiting in 2005, the highest volume of groundfish was landed by LE non-whiting trawlers – 68% of total non-whiting landings – followed by the LE fixed gear (line and pot gears; 10%), recreational (9%), tribal shoreside (7%) and open access (directed and incidental; 6%) fleets. Since 1995, landings in all whiting sectors have increased, while landings in all other sectors have decreased. The most pronounced decline – 66% – was in the open access (directed and incidental combined) sector, followed by the LE non-whiting trawl sector (61% decline), the LE fixed gear sector (26% decline) and the recreational sector (7% decline). With this brief introduction, we can now present what we know about these fleets and sectors from a spatially explicit perspective.

West Coast Port Groupings

Throughout this section, we have attempted to use PacFIN port groupings. Washington State port groupings, however, were inconsistent between literature sources. At best, Washington ports are characterized as those in southwest Washington, northern Washington, and Puget Sound. However, when data consistency was essential (e.g., to compare port-specific PacFIN landings and revenue data), all Washington ports had to be combined. Unfortunately, by aggregating all Washington ports, we ignore geographically distinct and disproportionate effects of yelloweye and canary bycatch reduction measures.

We did not experience similar issues for Oregon and California, which contain the following port groups: Oregon – Astoria, Tillamook, Newport, Coos Bay, and Brookings; California - Crescent City, Eureka, Fort Bragg, Bodega Bay, San Francisco, Monterey, Morro Bay, Santa Barbara, Los Angeles, and San Diego. Appendix II contains a list of individual ports within each of these port groups.

The PacFIN port groupings contain clusters of ports adjacent to each other and are often grouped by state and county. Ports within a group do not necessarily participate similarly in the groundfish fishery. For example, Depoe Bay and Newport are both in the Newport, Oregon port group, but Depoe Bay is a small community with a relatively large charter fleet, whereas Newport is the opposite[1]. An alternative method to group ports would be to quantitatively characterize type and degree of their participation in the groundfish fishery (Sepez et al. 2005). However, our goal with this work is to identify if spatial swaths of the coast exist that may be good candidates for spatial management, not geographically isolated, yet similarly functioning fishing communities. As such, the PacFIN port groupings are appropriate.

Activity in Non-groundfish Fisheries

A complete description of the groundfish fishery must include mention of activity in west coast non-groundfish fisheries. Vessels in the groundfish fishery adopt a portfolio approach to fishing by participating in several non groundfish fisheries throughout the year (Hanna 1992). Less than half of vessels in any sector of the 2000 Oregon commercial groundfish fishery exclusively landed groundfish. Eighty-seven percent of vessels with LE trawl permits, 97% of LE non-trawl permitted vessels, and 61% of open access permit holders landed non-groundfish species (OCZMA 2002).

Participation in the pot fishery for Dungeness crab is common in all sectors, regardless of whether pot is the vessel's primary gear type (PFMC 2004a). Aside from crab, however, activity in other fisheries is often gear dependent. LE trawl vessels operate in the shrimp and prawn trawl fisheries and whiting trawl vessels (catcher-processors and motherships) venture to Alaska to participate in the pollock fishery (PFMC 2004b, NMFS 2005). LE fixed gear and open access vessels outfitted with hook-and-line gear troll for salmon and albacore and harvest coastal pelagic species (PFMC 2004a). Pots used in the LE fixed gear and open access groundfish fisheries are deployed in crab and crustacean fisheries. Landing of non-groundfish species is also spatially distinct, with more Dungeness crab landings in Washington waters and more coastal pelagic landings in California (PFMC 2004b).

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[1] Detailed descriptions of these and other ports engaged in U.S. west coast commercial fishing were prepared by a team of researchers at NOAA's Northwest and Alaska Fisheries Science Centers and are available at: http://www.nwfsc.noaa.gov/research/divisions/sd/communityprofiles/index.cfm.

LIMITED-ENTRY FLEET

The groundfish limited-entry (LE) program was instituted in 1994 and consists of the following three main sectors: vessels that trawl for whiting, non-whiting trawl vessels, and vessels that use fixed gear (e.g., longlines, traps, pots). In the whiting trawl sector, catch is processed at sea by integrated catcher-processor vessels or motherships, or is landed and processed at facilities onshore. As of May 2007, 10 vessels were permitted in the at-sea catcher-processor whiting trawl fishery, 29 vessels as catcher boats in the whiting trawl fishery that deliver either to shoreside or at-sea mothership processors, an additional 137 vessels in the non-whiting trawl fishery, and 222 in the fixed gear fishery (NMFS 2007).

Spatial Distribution of Year 2000 Limited-entry Landings

To begin, we present a snapshot of the spatial pattern of resource use by the commercial groundfish fishery in year 2000. The analysis was completed in 2003 by Ecotrust as part of the Groundfish Fleet Restructuring Information and Analysis Project (GFR) (Scholz 2003). They created an algorithm to attribute landed catch data from fish ticket records of the commercial trawl (whiting, non-whiting) and non-trawl (fixed gear) sectors to a grid of 9 km x 9 km cells along the west coast. Model results were then summarized by port group to understand where fishing effort might occur for vessels that landed fish in a specific port group. We present maps of segments of the coast from north to south (Figure 3.3 A-F), which are adapted from the GFR maps; when one coastwide map was used, patterns were too difficult to discern.

Qualitative examination of the maps revealed three general patterns. Port groups' modeled harvest area can be described by the alongshore range from port. For some port groups (e.g., Tillamook –3.3B, Southwest Washington –3.3A, B), the harvest areas did not extend substantially north or south of the port groups, whereas other harvest areas extended further alongshore (e.g., Astoria –3.3B, Newport –3.3B, C, Eureka –3.3D). This may be due to fleet characteristics (e.g., far ranging hake fleets are based in Newport and Astoria), biogeographic boundaries (e.g., Columbia River, Cape Blanco), or state boundaries. Second, some harvest areas extended further from shore (e.g., Astoria –3.3B) than others (e.g., Tillamook –3.3B, San Diego –3.3F), which may also be due to fleet characteristics, but also related to state regulations and continental shelf width. Finally, overlap between harvest areas varied. To capture this, we calculated percent spatial overlap (Table 3.1) between the port group harvest areas (i.e., grid cells) shown in Figure 3.3. Overlap is the percent of Port Group$_i$ harvest area grid cells (see Figure 3.3) occupied by Port Group$_j$ harvest area grid cells and overlaps ≥25% are indicated in red. The Oregon port groups of Astoria, Newport, and Coos Bay harvest areas overlapped ≥25% most frequently with other harvest areas. The highest percent overlaps, all >45%, were north of Cape Mendocino: Astoria/SW Washington, Eureka/Crescent City, Coos Bay/Brookings, and Crescent City/Eureka. San Francisco Bay ports also overlapped substantially with ports to the north (Bodega Bay) and south (Monterey). Overall, the following points emerged from the analysis of maps of the spatial distribution of year 2000 LE landings:

- There is a diversity of types of spatial distribution of resource use by port groups.
- Overlap is low between distant ports, and high between adjacent ports.
- Highest percent overlap occurred between port groups north of Cape Mendocino, but high percent overlap also exists between San Francisco and its adjacent ports.
- The only high percent overlap across a Cape (i.e., Blanco, Mendocino, Conception) was between Coos Bay and Brookings port groups.

Limited-entry Trawl Sector

Next, we turn our attention to the LE trawl fleet, which includes the trawl fishery for whiting and non-whiting species. In Figure 3.4A, we show port-specific landings by the trawl fleet[2] in 1995 and 2006. Nominal totals by port are shown for landings of non-whiting and whiting. This distinction was necessary as whiting landings were six times greater than non-whiting landings. Non-whiting landings are shown as proportions by species group of total port landings. The major biogeographic boundaries – Cape Blanco, Cape Mendocino, and Point Conception – are included on the figure for reference.

Total non-whiting landings (outlined white bars) declined 61% from 1995 to 2006. This decline is likely due to fishermen exiting the fleet from the 2003 vessel buyback, severe management restrictions to rebuild overfished stocks, and resource depletion. The decline was not uniform coastwide, resulting in a geographic truncation in the distribution of landings. In 1995, the majority of ports north of Point Conception had substantive amounts of non-whiting landings. Of total 1995 non-whiting landings, 27% came from port groups south of Cape Mendocino, 16% from ports between Capes Mendocino and Blanco, and 57% from ports north of Cape Blanco. However, by 2006, the distribution of landings has been truncated, with only 14% of non-whiting landings occurring south of Cape Mendocino, 17% from ports between Capes Mendocino and Blanco, and 69% from ports north of Cape Blanco. Port groups south of Cape Mendocino saw declines in landings of 80%, 59% decline for those between Capes Mendocino and Blanco and 53% for port groups north of Cape Blanco. The non-whiting LE trawl fleet did not land catch south of Point Conception aside from negligible amounts to Santa Barbara and Los Angeles area ports in 1995.

The decline in landings was accompanied by a shift in composition of non-whiting landings. In 1995, 10 of the 15 port groups[3] received landings of rockfish as the highest proportion of all species groups. By 2006, only Morro Bay received primarily

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[2] Due to the lack of sector specific resolution within the PacFIN trawl fleet online data, Figure 3 contains LE trawl and tribal commercial trawl landings. These landings will likely appear to Washington ports as this is the only state with tribal commercial fisheries and regulations are such that the tribal fishery must occur in "usual and accustomed" fishing areas. See section 4.0 for further description of the tribal fleet.

[3] The at-sea fleet is not considered in this count of port groups as whiting is their primary target and non-whiting landings considered bycatch.

rockfish landings. Flatfish were landed in the highest proportion in the remainder of the ports.

The whiting trawl fisheries – shoreside and at-sea – increased by 52% between 1995 and 2006 due to higher landings to Washington ports and in the at-sea fleets. A portion of this increase is attributable to the tribal fleet, which did not actively pursue whiting in 1995 for shoreside or at-sea processing, but did do so by 2006. From a spatial perspective, the shoreside whiting fleet lands primarily to ports north of Cape Blanco – specifically Washington Coast ports, Astoria, and Newport.

The ex-vessel revenue graph (Figure 3.4C) mirrors patterns described above for the landings data. Total non-whiting revenues declined 64% from 1995 to 2006[4]. Whiting, although caught in volumes six-fold that of non-whiting species, have a low price-per-pound, thus garner comparable amounts of revenue as non-whiting landings.

LE Trawl rockfish landings and revenue data – a subset of data shown in Figure 3.4 – are displayed in Figure 3.5. Between 1995 and 2006, trawl rockfish landings (Figure 3.5A) and revenues (Figure 3.5C) declined precipitously (91% coastwide) in all ports due to restrictions implemented to aid in recovery of overfished rockfish species (see section 4 for further description of these restrictions). The trawl fleets target shelf, slope, and thornyhead rockfish but not those in the nearshore. The change in composition of landings between 1995 and 2006 is dramatic. In 1995, shelf rockfish comprised an average of 52% of individual port group's rockfish landings, with higher proportions in port groups from Newport northwards (71% average) and from Fort Bragg to Monterey (58% average). By 2006, landings of shelf rockfish – although still high (78%) in Washington ports – comprised only 15% on average of individual port group's rockfish landings.

Permit ownership is another metric by which we can gauge participation in the fishery, although it does not inform us about where the fishing on that permit occurs. For example, based on quantitative analysis, Pleasantville, New Jersey, and Seaford, Virginia were determined to be communities with significant involvement in U.S. West Coast commercial fishing (Norman et al.). Similarly, numerous permits in some Alaskan fisheries are held by Seattle residents. Permit ownership can indicate communities that are important participatory hubs for the fishery. Figure 3.6A shows the distribution of 2007 LE trawl permit holders. Newport, Astoria and Puget Sound ports have the highest number of permit holders. Overall, 62% of permits are held north of Cape Blanco, 14% between Capes Blanco and Mendocino, and 19% south of Cape Mendocino. The remaining 4% of permits are held by The Nature Conservancy. No permits are held south of Point Conception.

The final point of analysis for the LE trawl fleet involves impacts of the vessel buyback program, completed in late 2003. In the program, 92 trawl vessels and 240 permits were retired. Those permits included LE trawl permits, but also permits for Dungeness crab and pink shrimp fisheries. Figure 3.7 shows percent change by port group in the count of trawl vessels landing non-whiting groundfish before (2003) and

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[4] 1995 dollars adjusted to 2006 dollars using Implicit Price Deflator for Gross Domestic Product

after (2004) the buyback. Large percent changes occurred in all port groups between Capes Blanco and Mendocino (Crescent City, Eureka, and Brookings). The number of vessels landing to Santa Barbara ports also declined substantially[5]. The smallest change occurred in the Washington Coast, Puget Sound and San Francisco area ports.

Overall, the following points emerged from the spatial analysis of the LE trawl fleet:

- The whiting trawl fishery is the largest volume fishery on the west coast and primarily lands to ports north of Cape Blanco. Although it is a low value species (price-per-pound), it is landed in such high volume that whiting landings generate high revenues.

- Lower landings by the non-whiting trawl sector are primarily due to decline in landings of rockfish, shelf rockfish in particular.

- Since 1995, the distribution of landings has become truncated. Formerly, landings were distributed between ports north of Point Conception but now are concentrated north of Cape Mendocino.

- The majority (62%) of LE trawl permit holders reside north of Cape Blanco.

- The highest proportions of vessels removed in the 2003 LE trawl vessel buyback program were between Capes Blanco and Mendocino, and also vessels south of Point Conception.

Limited-entry Fixed Gear Sector

In the LE fixed gear fishery, longline, traps, and pot gear are used to primarily target sablefish, lingcod and rockfish. Whereas LE trawl permit holders were distributed more northerly along the coast (Figure 3.6A), LE fixed gear permits are more evenly distributed over the entire coast (Figure 3.6B), with the highest numbers in Puget Sound, Los Angeles and Newport area ports.

We cannot present the distribution of LE fixed gear landings, since the data available to us online is not fleet-specific, rather is pooled for all non-trawl commercial fleets. The pooled data is presented in the section entitled, "commercial landings and ex-vessel revenue for non-trawl fleets".

- The LE fixed gear fleet is distributed along the whole coastline, not just to areas north of Point Conception.

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[5] In Figure 3.6, we show that trawl vessels landed to Santa Barbara ports in 2003 and 2004, which strongly implies that, however minimal, some landings are associated with those vessels. Yet in Figure 3.3, there are no trawl landings to the Santa Barbara port group in 2006. No discrepancy exists here – in PacFIN, small amounts of California halibut, other flatfish, sharks, skates, and rays were landed by trawl gear in 2003, less in 2004, and none in 2006.

OPEN ACCESS FLEET

Participants in the open access fishery includes fishermen who both directly target groundfish but do not have a LE permit (directed open access), and those who incidentally catch groundfish while targeting non-groundfish species (incidental open access). Trawl gear is prohibited in the directed open access fishery, but allowed in the incidental fishery, because the incidental groundfish catch may occur when fishermen are trawling for non-groundfish target species (e.g., pink shrimp, California halibut). In the directed open access fishery, hook and line is the most commonly used gear (PFMC 2004b).

Different from the LE sectors, more than half (56%) of open access boats operate from ports south of Cape Mendocino (Figure 3.6C). In 2001, Morro Bay area ports were used as the primary landing port by more vessels (143) than any other port, followed by Santa Barbara, Monterey, and San Francisco. The measure of fleet size is not number of permits as in the LE fleet analysis, but the number of individual vessels landing to specific ports. Also note that a direct comparison between fleets presented in Figure 3.6 is difficult, as the LE data is from 2007, and the open access data from 2001. However, even given this temporal gap, the number of vessels that participate in the open access fishery far outweighs the number of vessels permitted in the LE sectors (1,288 open access vessels, 176 LE trawl permits, 222 LE fixed gear permits).

In Figure 3.8, we show metrics of the directed open access fleet by state for three recent years (2000, 2003, and 2006). Landings (Figure 3.8A) are highest in California, then Oregon and Washington. In the past six years, however, California landings have declined while landings in the other two states have increased; landings of sablefish have increased in all states between 2000 and 2006. The decline in California landings was likely due to lower federal trip-limits to safeguard overfished bocaccio and cowcod populations (PFMC 2004b), and more stringent state management measures enacted in conjunction with passage of the state's Marine Life Management Act. The directed open access fleet in Washington appears to almost solely target sablefish, whereas nearshore rockfish comprise a substantial proportion of landings in the other two states. California open access fishermen also land shelf and slope rockfish.

Nearshore rockfish landings in California and Oregon supply the high-value, live-fish market. Begun in California in the 1980s to supply live fish to restaurants, the live-fish fishery expanded into southern Oregon in the late 1990s. In 1996, only 6% of fish landed coastwide by direct open access fishermen was alive, but by 2001, 20% was landed alive (PFMC 2004b). In California, live-fish landings peaked in 1998 at approximately 450 tons. In 2005, 87% of nearshore finfish landings in California were live-fish (Aseltine-Neilson et al. 2006). The average price paid per pound of live-fish may be two to three times higher than for dead fish. For example, in California in 2004, live cabezon garnered $4.74 per pound, whereas dead cabezon was worth $2.40 (Sweetnam et al. 2005). Accordingly, although only 25% of California 2006 directed open-access landings were nearshore fish, 51% of the revenue is from nearshore landings (Figure 3.8B).

The number of vessels participating in the directed open access fishery (Figure 3.8C) mirrors the patterns of landings. The decrease in number of California participants in the past six years has been quite dramatic – 751 to 430 vessels. Interestingly, the increase in landings in Washington and Oregon (WA: +250% from 2000 to 2006; OR: +105%) has been faster than the increase in participants (WA: +84% from 2000 to 2006; OR: +36%). We can infer then that even with new entrants, per vessel catch is increasing. Finally, of the total open access fleet (directed and incidental), the directed portion has grown in all three states (Figure 3.8D), with most rapid growth in Washington and Oregon.

Summary points:

- The open access fleet has the most participants of any groundfish sector.
- Over 50% of the landings and revenues are in California.
- Washington and Oregon directed open access fleets are rapidly expanding; their primary target is sablefish.
- The live-fish market for nearshore fish in California is stronger than in Oregon and Washington and contributes disproportionately to California ex-vessel revenues.
- With a sharper decline in number of vessels than in landings or revenue, the average California open access fishermen earned more in 2006 than in 2000.

TRIBAL FLEET

The tribal fleet of the groundfish fishery is solely in Washington State, consisting of members of the Makah, Quileute, Hoh, and Quinault tribes. Fisheries exist for commercial, ceremonial and subsistence purposes and are conducted in usual and accustomed fishing grounds. The commercial tribal sectors are similar to those of the limited entry fleet: whiting trawl, non-whiting trawl, and fixed gear. The Makah tribe has the strongest presence in the tribal fishery. They are the only tribe with trawlers, and have the majority of longline vessels. As of 2005, the Makah fleet was 43 boats which included 4 whiting trawlers, 10 non-whiting trawlers, and 29 longliners (NMFS 2005).

The tribal fishery has grown rapidly since treaty rights to groundfish were formalized by the U.S. government in 1994. That ruling granted harvest rights to ½ of harvestable surplus of groundfish available in the usual and accustomed tribal fishing grounds. From 1995 to 1997, landings in the whiting fleet expanded from less than 1,000 metric tons to almost 25,000 metric tons (Figure 3.9). That increase has continued despite a large decline in 2000 and 2001. A sharp increase in rockfish and flatfish landings occurred in 2002. Roundfish landings – the basis of the fishery in 1995 – have not changed much in the last decade.

Summary point:

- Rapid expansion in the tribal fishery conducted in Washington State waters has potential to continue until harvest reaches the maximum allowable harvest allowable under treaty rights.

COMMERCIAL LANDINGS AND EX-VESSEL REVENUE FOR NON-TRAWL FLEETS

The data presented here are pooled from the LE fixed gear, directed and incidental open access, and tribal commercial non-trawl fleets, as fleet-specific data were unavailable. By volume, non-trawl groundfish landings account for 19% (1985), 16% (1995), and 19% (2005) of total non-whiting groundfish landings (Figure 3.10A). However, by ex-vessel revenue, non-trawl landings generated 27 (in 1985), 28 (in 1995), and 44 (in 2005) percent of coastwide non-whiting groundfish ex-vessel revenue (Figure 3.10B).

In Figure 3.4B, we show port-specific landings for the non-trawl fleet in 1995 and 2006. Similar to trawl landings (Figure 3.4A), there has been a substantial decline (48%) in total non-trawl landings between 1995 and 2006. Declines were similar in different regions of the coast. Landings to port groups south of Point Conception decreased 65%, 70% to ports between Point Conception to Cape Mendocino, and 58% to those between Capes Mendocino and Blanco. Landings to port groups north of Cape Blanco only declined 24%. However, when Washington ports are excluded from this analysis, landings in port groups north of Cape Blanco declined 68%. Excluding landings to Washington ports is valid as they are unique in representing the tribal fleet, which experienced substantive growth between 1995 and 2006. By excluding them from the analysis, we examine a suite of comparable fleets.

The portfolio of landings also changed. In 1995, 40% of total non-trawl landings were rockfish. However by 2006 rockfish only accounted for 1%. Roundfish, which comprised 43% of 1995 landings, accounted for 69% by 2006. In both years, rockfish were most prominent in composition of landings of port groups south of Cape Mendocino, and least prominent for port groups between Capes Mendocino and Blanco.

In spite of a 48% decline in non-trawl landings between 1995 and 2006, ex-vessel revenues only decreased 22%[6] (Figure 3.4D). Rockfish appear to contribute successively more to total revenue in southern ports. An examination of the percent of total landings or revenue that is rockfish reveals that from Cape Mendocino south, the percent of total revenue derived from rockfish is more than the actual percent of landings. Although 53% of the rockfish landings occur south of Cape Mendocino, 75% of the non-trawl revenue from rockfish is attributable to ports south of Cape Mendocino. The rockfish are worth more south of Cape Mendocino. This is due to a market for live-fish, described previously, where higher price-per-pounds are paid for fish than in other markets.

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[6] 1995 dollars adjusted to 2006 dollars using Implicit Price Deflator for Gross Domestic Product

Non-trawl rockfish landings decreased 84% between 1995 and 2006 (Figure 3.5B). The largest decrease was to port groups between Point Conception and Cape Mendocino (89%), and the smallest to port groups between Capes Mendocino and Blanco (6%). In 1995, landings from non-trawl fleets to ports between Cape Blanco and Point Conception were comprised of nearshore and shelf rockfish species. Landings to ports north of Cape Blanco were more representative of all rockfish categories (i.e., nearshore, shelf, slope, and miscellaneous rockfish), while landings to ports south of Point Conception included more slope rockfish species than in several other ports. By 2006, the majority of rockfish landings to ports south of Point Conception were thornyheads. Shelf rockfish were absent from landings in several ports, with port landing proportions – especially between Capes Blanco and Mendocino – dominated by landings of nearshore rockfish species.

Accompanying the decline in rockfish landings was a 57% loss of ex-vessel revenue (Figure 3.5D). The largest decrease was to port groups north of Cape Blanco (87%), and the smallest to port groups between Capes Mendocino and Blanco (31%).

Summary points:

- Non-trawl landings generate more ex-vessel revenue per landed ton than trawl landings. Although non-trawl landings accounted for only 19% of average 2005 coastwide non-whiting landings, non-trawl landings generated 44% of the total coastwide ex-vessel revenue.
- Non-trawl landings have declined between 1995 and 2006, primarily rockfish landings (shelf rockfish in particular), thereby disproportionately adversely affecting southern ports that had landed higher amounts of rockfish.
- Landings have declined but revenues have not changed due to several spatial factors. High-value sablefish dominate landings and revenue north of Cape Mendocino. South of Cape Mendocino, landings have shifted away from shelf rockfish since 1995. From Cape Mendocino to Point Conception, there has been a shift inshore in landings to nearshore rockfish, which supply the high value live fish market. South of Point Conception, the shift has been offshore to thornyheads (PSMFC 2007).
- Value of rockfish is higher in central and southern California ports than elsewhere along the coast (live-fish market).

RECREATIONAL FLEET

The recreational fishery for groundfish includes shore-based angling from docks, beaches, and piers, and vessel-based angling from either charter or private vessels. The majority of recreational harvest is from vessel-based angling (OCZMA 2002). The following description is restricted to the groundfish component of the recreational fishery, although the fishery targets numerous other species (e.g., salmon, Pacific bonito, Pacific mackerel) not discussed here. The recreational groundfish sector is largest in California, where in 2005 the sector accounted for 60% of total coastwide mortality (harvest plus observed discarded dead fish) (Figure 3.11) and 80% of all fishing trips (Figure 3.12). Washington's recreational groundfish sector is the smallest with 16% of total 2005 mortality and 6% of all fishing trips.

Rockfish species are the primary catch in the recreational groundfish sector, and account for over 65% of 2005 catch in each state. In the Washington and Oregon recreational sectors, black rockfish comprised 72 and 55% of total 2005 catch, respectively (Figure 3.11). In northern California (north of Point Conception, 34° 27' N. latitude), rockfish catches are more equally proportioned between a broader range of species and species groups. The top three rockfish species or species groups caught in 2005 were nearshore minor rockfish[7] (34% of total catch), black rockfish (16%), and shelf minor rockfish[8] (13%). The southern California recreational groundfish sector primarily targets shelf minor rockfish, but also other species, such as bocaccio and California scorpionfish, which are not caught elsewhere along the coast. Lingcod was second to rockfish in all regions for highest 2005 catch. In Washington, Oregon, northern and southern California, lingcod catch was 15, 24, 24 and 10% of total regional catch.

Between 1995 and 2005, total catch declined 7%. Higher catch of nearshore minor rockfish, lingcod and black rockfish was offset by lower catches of other rockfish, other fish, shelf minor rockfish and California scorpionfish. Catch in southern California declined by 44% and by 4% in northern California. In Washington and Oregon, catches increased by 32 and 2%, respectively. Between 2004 and 2005, participation increased in all port groups aside from the south coast of California.

Summary points:

- Rockfish are the mainstay of the sector, particularly black and other nearshore rockfish.
- The recreational groundfish sector appears to be increasing coastwide, aside from southern California.

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[7] nearshore minor rockfish complex includes the following species: black and yellow rockfish *(S. chrysomelas);* blue rockfish *(S. mystinus);* brown rockfish *(S. auriculatus);* calico rockfish *(S. dalli);* China rockfish *(S. nebulosus);* copper rockfish *(S. caurinus);* gopher rockfish *(S. carnatus);* grass rockfish *(S. rastrelliger);* kelp rockfish *(S. atrovirens);* olive rockfish *(S. serranoides);* quillback rockfish *(S. maliger);* and treefish *(S. serriceps).*

[8] shelf minor rockfish complex includes the following species: bronzespotted rockfish *(S. gilli);* bocaccio *(Sebastes paucispinis);* chameleon rockfish *(S. phillipsi);* chilipepper rockfish *(S. goodei);* cowcod *(S. levis);* dusky rockfish *(S. ciliatus);* dwarf-red rockfish *(S. rufianus);* flag rockfish *(S. rubrivinctus);* freckled rockfish *(S. lentiginosus);* greenblotched rockfish *(S. rosenblatti);* greenspotted rockfish *(S. chlorostictus);* greenstriped rockfish *(S. elongatus);* halfbanded rockfish *(S. semicinctus);* harlequin rockfish *(S. variegatus);* honeycomb rockfish *(S. umbrosus);* Mexican rockfish *(S. macdonaldi);* pink rockfish *(S. eos);* pinkrose rockfish *(S. simulator);* pygmy rockfish *(S. wilsoni);* redstripe rockfish *(S. proriger);* rosethorn rockfish *(S. helvomaculatus);* rosy rockfish *(S. rosaceus);* silvergray rockfish *(S. brevispinis);* speckled rockfish *(S. ovalis);* squarespot rockfish *(S. hopkinsi);* starry rockfish *(S. constellatus);* stripetail rockfish *(S. saxicola);* swordspine rockfish *(S. ensifer);* tiger rockfish *(S. nigrocinctus);* and vermilion rockfish *(S. miniatus).*

FISHERIES AND FISHING COMMUNITIES SUMMARY

In this section we attempted to describe the spatial scales of organization within the groundfish fishery by presenting spatially explicit information about landings, revenue and number of vessels or permits by sector. In this summary we categorize by trawl (limited entry, whiting), non-trawl (limited entry, directed open access), recreational and tribal.

- The analysis of GFR maps of spatial distribution of 2000 LE landings revealed that overlap in harvest areas is low between distant ports, and high between adjacent ports. Highest percent overlap occurred between port groups north of Cape Mendocino, but high percent overlap also exists between San Francisco and its adjacent ports. The only high percent overlap across Cape Blanco, Cape Mendocino, or Point Conception was between Coos Bay and Brookings port groups.
- The whiting trawl fishery is the largest volume fishery on the west coast and primarily lands to ports north of Cape Blanco. Although it is a low value species (price-per-pound), it is landed in such high volume that whiting landings generate high revenues (PSMFC 2007).
- Landings by the limited-entry (LE) non-whiting trawl fishery previously (year 1995) spanned the coast to Point Conception, but currently (year 2006) are concentrated north of Cape Blanco. Due primarily to severe overfishing of shelf rockfish, landings and revenues have declined across the fishery. Flatfish now comprise the majority of landings (PSMFC 2007).
- The non-trawl fishery (LE fixed gear and open access fleets) has maintained – from 1995 to 2006 - its distribution along the entire coastline. Landings have declined but revenues have not changed due to several spatial factors. High-value sablefish dominate landings and revenue north of Cape Mendocino. South of Cape Mendocino, landings have shifted away from shelf rockfish since 1995. From Cape Mendocino to Point Conception, the shift has been inshore to nearshore rockfish supplying the high value live fish market. South of Point Conception, the shift has been offshore to thornyheads (PSMFC 2007).
- The open access fleet has the most participants of any groundfish sector. Over 50% of the open access fleet landings and revenues are in California. Washington and Oregon directed open access fleets are rapidly expanding; their primary target is sablefish (CDFG 2007).
- The recreational sector is largest in California, north of Point Conception, and appears to be increasing coastwide, aside from southern California. Rockfish are the mainstay of the recreational sector, particularly black and other nearshore rockfish (PFMC and NMFS 2006, PFMC 2007).
- Rapid expansion in the tribal fishery conducted in Washington State waters has potential to continue until harvest reaches the maximum allowable harvest allowable under treaty rights (1/2 of harvestable surplus of groundfish available in the usual and accustomed tribal fishing grounds)(PFMC and NMFS 2006).

4. SCALE OF FEDERAL AND STATE MANAGEMENT

INTRODUCTION

The spatial structure of the management system for West Coast groundfish species is evolving and becoming increasingly complex over time. Six International North Pacific Fisheries Commission (INPFC) areas and at least twenty-two other management lines can be found within the existing management system for this fishery (PFMC 2007c). Space is one tool in the management tool-box, which like others, has been applied within a multifaceted management structure that is required by law to balance biological, socioeconomic, and conservation concerns. The use of spatially-explicit management tools has become more important over time as a tool of balancing the rebuilding of overfished stocks with providing access to healthy stocks (PFMC 2007c). The spatial management tools currently being applied to the West Coast groundfish fishery vary greatly in their size, temporal nature and goal. On one end of the spectrum, the Pacific Fishery Management Council (PFMC) manages areas that encompass the entire West Coast, while on the other end, discrete, species-specific closed areas are found in the Southern California Bight and the northern Washington coast. For the purposes of this paper, the term "spatial" refers to how fisheries are managed over a geographic area. West Coast groundfish species are managed through the setting of catch limits based on calculations of Optimum Yield (OY), and allocation of OY ranges from year-round and area-wide to relatively small spatial and temporal scales. The vulnerability of the stocks to fishing pressure, the bycatch of non-target species, socioeconomic concerns, as well as the degree of available scientific information about an individual stock have all played a role in determining the scale at which the TAC for individual stocks are managed and can be applied spatially. This section of the paper describes the existing suite of spatial management tools currently being applied to the West Coast groundfish fishery by state and federal management agencies.

MANAGEMENT WITHIN FEDERAL WATERS

Prior to the 1976 passage of the Magnuson Fishery Conservation and Management Act (MFCMA), the management of domestic groundfish fisheries was under jurisdiction of the states of Washington, Oregon, and California. By 1983, an Exclusive Economic Zone (EEZ) in ocean waters from three to 200 miles surrounding the United States was put into place by proclamation. To manage this zone, seven regional councils were established, including the Pacific Fishery Management Council (PFMC or Council) which is responsible for managing west coast fisheries. These Councils were created with the primary role of developing, monitoring, and revising management plans for fisheries. Total groundfish landings reached an all-time high during 1982 due to large increases in catches of rockfish species such as widow rockfish. From 1982 through 1990 the total catch of groundfish declined as stock assessments were completed and, for the most part, indicated a reduction in catch (ODFW 2000).

Identification of overfished groundfish stocks in the mid to late 1990s resulted in an additional reduction in available harvest and the implementation of rebuilding plans.

First yellowtail rockfish, lingcod and canary rockfish were identified as approaching being overfished. "Overfished" is defined by the Pacific Coast Groundfish Fishery Management Plan (FMP) as a decline in spawning stock abundance of a species to 25% of its estimated virgin biomass, which is the size of the spawning population if the stock had never been fished (PFMC 2006). By the end of 2000, bocaccio, canary rockfish, cowcod, darkblotched rockfish, lingcod, Pacific Ocean perch and widow rockfish were all identified as overfished and fell under the new federal requirement to implement formal rebuilding plans. In January of 2000 a groundfish fishery disaster was declared by the Secretary of Commerce (ODFW 2000). To address the challenge of rebuilding overfished stocks while maintaining a fishery on healthy stocks the Council began applying the spatial management tool of depth and area closures. These closures, most notably Rockfish Conservation Areas (RCAs), have constrained fishing activity to smaller areas of state and federal waters. Though these closures are considered to be effective tools in limiting fishing interactions with depleted species, they are also responsible for shifting additional fishing pressure into other areas and onto other species. The most extensive of these are the RCAs, which have been in place off of all three states since 2002 to prohibit vessels from fishing in depths where overfished groundfish species (currently Pacific ocean perch, bocaccio, darkblotched rockfish, canary rockfish, cowcod, widow rockfish, and yelloweye rockfish) are more abundant (PFMC 2006).

PFMC Management Areas

The broad area the PFMC manages, and where groundfish stocks are fished, can be described as the U.S. EEZ of the northeast Pacific Ocean that lies between the U.S.-Canada border and the U.S.-Mexico border. Within this area the primary spatial management structure for groundfish is based on the INPFC statistical areas (Figure 4.1). These areas were developed using information on stock distribution and domestic and foreign historical catch statistics (PFMC and NMFS 2006). The areas from south to north are (PFMC 2006):

- **Vancouver**: U.S.-Canada border to 47°30' N. latitude
- **Columbia**: 47°30' to 43°00' N. latitude
- **Eureka**: 43°00 to 40°30' N. latitude
- **Monterey**: 40°30' to 36°00' N. latitude
- **Conception**: 36°00' N. latitude to the U.S.-Mexican border

Rockfish species, except for thornyheads, are divided into categories north and south of 40°10' N. latitude, depending on the depth where they are often caught and the amount of information available for that species. Depth ranges are categorized as nearshore, shelf, or slope. "Nearshore" is defined (by the California Nearshore Fishery Management Plan) as the area from the high-tide line offshore to a depth of 120 ft (37 m). "Shelf" refers to the continental shelf, while "slope" refers to the continental slope (Figure 4.1, PFMC and NMFS 2006). Information level is categorized from a level one to a level three. Level one stocks have their allowable biological catch (ABC) levels based on information from quantitative assessments. Level two stocks have their ABC levels set with information from nonquantitative assessments. Level three stocks have no ABC levels, catch levels are set based on qualitative information (PFMC and NMFS 2006).

In addition to the primary INPFC areas the following subareas are sometimes utilized (PFMC):

- **Cape Falcon, OR** (south of Cannon Beach, OR): 45°46' N. latitude
- **Cape Lookout, OR** (about 10 miles south of Tillamook, OR) 45°20'15" N. latitude
- **Cape Blanco, OR** (north of Port Orford) 42°50' N. latitude
- **Cape Mendocino, CA** (slightly north of 40°10') 40°30' N. latitude
- **North/South management line** (south of Cape Mendocino) 40°10' N. latitude
- **Point Arena, CA** (about 100 miles south of Mendocino) 38°57'30" N. latitude
- **Point Reyes, CA** (about 35 miles north of San Francisco) 38° N. latitude
- **Point Conception, CA** (north of Santa Barbara near Buellton) 34°27' N. latitude

Time and area closures

Within its area of management jurisdiction, the Council uses a variety of time/area closures which vary in their level of permanency and size. These spatial management tools are intended to accomplish a wide range of management objectives such as controlling the catch of targeted species, reducing the incidental catch of non-target, protected (including overfished) species and preventing fishing in specified areas in order to mitigate the adverse effects of such activities on groundfish Essential Fish Habitat (EFH) (PFMC 2007c).

These tools include:

Rockfish Conservation Areas (RCAs): RCAs are west-coast wide fishing area closures bounded on the east and west by lines connecting a series of coordinates approximating a particular depth contour. RCAs are gear-specific and their eastern and western boundaries may vary during the year (Figure 4.1, PFMC and NMFS 2006). Since January 2003, the Council has used coastwide RCAs to reduce the incidental catch of overfished species in waters where they are more abundant. Of the seven currently overfished species, six are continental shelf species, and RCAs have primarily been designed to close continental shelf waters. Although both the eastern and western RCA boundaries have changed over time for all of the gear groups, the area between the trawl RCA boundary lines approximating the 100 fm and 150 fm depth contours has remained closed since January 2003, to protect overfished rockfish stocks (PFMC 2007c).

Groundfish fishing areas (GFAs): These are areas where fishing for groundfish is allowed. For example, fishing for schooling species, such as petrale sole or chilipepper rockfish, could be allowed within GFAs for those species, but not permitted outside of the GFAs, where fisheries for those species might have higher incidental catches of overfished species (PFMC and NMFS 2006). West Coast groundfish managers are also using tools like "hotspot" and coldspot" analyses to balance the need to reduce encounters with overfished species while maintaining access to healthy stocks. These spatial analyses are helping to identify areas where target species can be accessed and overfished species avoided (PFMC 2007c).

Ecologically important habitat closed areas and the bottom trawl footprint closure: These ecologically important habitat closed areas are intended to mitigate the adverse effects of fishing on groundfish EFH (Figure 4.1). They may be categorized as bottom trawl closed areas (BTCAs) and bottom contact closed areas (BCCAs). There are five BTCA areas off of Washington, nine off of Oregon, and twenty areas off of California. There are two BCCA areas off of Oregon and fourteen off of California (PFMC 2006).

Bottom Trawl Footprint Closure: This area is intended to mitigate the adverse effects of fishing on groundfish EFH by prohibiting trawling seaward of the 700 fm (1280 m) isobath. The closure is intended to prevent the expansion of bottom trawling into areas where groundfish EFH has not historically been adversely affected by bottom trawling (PFMC and NMFS 2006).

Other time/area closures (considered long-term bycatch mitigation closed areas) are used by the PFMC to reduce incidental catch of protected species in fisheries targeting groundfish, and include areas such as the Western and Eastern Cowcod Conservation Areas (CCA; Figure 4.1), and the Yelloweye Rockfish Conservation Area (YRCA) (PFMC and NMFS 2006).

The PFMC is also currently involved in developing three new amendments to the Groundfish Fishery Management Plan that could benefit from the type of area-based management described in this paper. Flexibility could be built into these amendments to allow for the development and application of area-based information in the management of the fishery. Amendment 20 addresses rationalization of the trawl fishery through a limited access privilege program, with submission of a plan to the Secretary of Commerce scheduled for as early as January 2009, and possible implementation in 2011. An area-based component has been proposed as part of this program to address potential issues of spatial concentration of fishing effort resulting in localized depletion of stocks and inequities in allocation. There is a delicate balance to consider in the process of constructing an area-based quota program. The program should be developed to addresses the issues identified above but not so complex that it is not flexible enough to respond to changing conditions in the environment and the fishery (PFMC 2007c). Amendment 21 would define long-term allocations of selected species between the trawl fleet and all other sectors of the groundfish fishery. Refinement of alternatives for this Amendment is set for early 2009. Amendment 22 will address open access fishery limitation, with the intent to transition those currently fishing for groundfish who don't hold federal permits (considered "open access") into the limited entry program for the fishery.

MANAGEMENT WITHIN STATE WATERS

Washington, Oregon, and California have jurisdiction over fisheries taking place in state waters (0-3 miles). Currently, species under state management are managed statewide for all three states, with few exceptions. Several State Parks within the California Current system as well as the National Marine Sanctuaries in California and Washington also utilize spatially explicit management schemes and should be reviewed and analyzed for their potential impact on West Coast groundfish species.

The Pacific Fishery Management Council works cooperatively with the state resource agencies (Washington Department of Fish and Wildlife - WDFW, Oregon Department of Fish and Wildlife - ODFW, California Department of Fish and Game - CDFG). As a result some of the management for state species takes place within the federal management process such as setting the overall OY for some nearshore species and commercial regulatory measures (ODFW 2000). By law, state management may be more restrictive or precautionary than federal management, but not less so.

Recreational fishery management is implemented principally at the state level, since most recreational fishing occurs in state waters. The Council coordinates management and the states conform their management regulations to Council recommendations implemented at the Federal level (PFMC and NMFS 2006).

Primary recreational management measures utilized for West Coast groundfish:

- Seasonal closures can be implemented according to state recreational management zones.
- Depth-based area closures under which retention of different groundfish species is prohibited. Area closures can vary by month or fishing season (PFMC and NMFS 2006).
- Bag limits.

California

The commercial and recreational fisheries for nearshore rockfishes in California are currently managed by the Council in conjunction with the state using three adjacent management areas with the boundaries at Cape Mendocino and Point Conception. There are 19 finfish species taken in California's nearshore fisheries. These include many rockfishes as well as species such as cabezon, greenling, and lingcod (CDFG 2002).

In 2002 the California Department of Fish and Game (CDFG) developed a fishery management plan for nearshore fish (NFMP) species. One focus of the plan was the development of a regional system for managing the California nearshore finfish fishery to protect nearshore fish species and promote sustainable fisheries. CDFG sees regional management of the nearshore finfish fishery as a way to formally recognize geographic differences of species distribution and human use and to more closely match regulations to prevailing conditions (CDFG 2002). Ultimately, the intention is to have a California nearshore regional system formed by regional management areas each with separate harvest guidelines to match harvest to conditions within that region and prevent localized overfishing. The nearshore management areas will be selected based on the criteria of jurisdictional boundaries, oceanographic characteristics, genetics, species distributions, species assemblages, historical landings, and social and economic patterns (CDFG 2002).

At this time the NFMP Project identifies four management areas (Figure 4.1, CDFG 2002):

- North Coast Region - from the Oregon border to Cape Mendocino (Humboldt County)
- North-Central Coast Region - from Cape Mendocino to Point Año Nuevo (San Mateo County)
- South-Central Coast Region - from Point Año Nuevo to Point Conception (Santa Barbara County)
- South Coast Region - from Point Conception to the Mexican border

Although implementation of the four California nearshore management areas has yet to be fully implemented, management of California's nearshore recreational groundfish fishery in 2005 and 2006 divided the coastline into five regional areas. These areas were considered "Rockfish/Lingcod Management Areas" (RLMAs; Figure 4.1) and are as follows (PFMC and NMFS 2006):

- Northern RLMA (California/Oregon Border to Cape Mendocino at 40°10' N latitude)
- Northern Central RLMA (Cape Mendocino to Pigeon Point at 37°11' N latitude)
- Northern South-Central RLMA (Pigeon Point to Lopez Point at 36° N latitude)
- Southern South-Central RLMA (Lopez Point to Point Conception at 34°27' N latitude)
- Southern RLMA (Point Conception to U.S./Mexico Border)

The State of California, through the California Department of Fish and Game, is also attempting to apply the concepts of spatial management to state waters through implementation of the Marine Life Protection Act (MLPA). The MLPA was signed into law in 1999 and directs the state to "redesign California's system of marine protected areas (MPAs) to increase its coherence and effectiveness in protecting the state's marine life and habitats, marine ecosystems, and marine natural heritage, as well as to improve recreational, educational and study opportunities provided by marine ecosystems" (MLPA Summary: http://www.dfg.ca.gov/mlpa/background.asp).

The MPAs are being designed for the purpose of protection and conserving marine life. More specifically, six overarching goals are defined by the Act [FGC subsection 2853(b)]:

1) To protect the natural diversity and abundance of marine life, and the structure, function, and integrity of marine ecosystems.
2) To help sustain, conserve, and protect marine life populations, including those of economic value, and rebuild those that are depleted.

3) To improve recreational, educational, and study opportunities provided by marine ecosystems that are subject to minimal human disturbance, and to manage these uses in a manner consistent with protecting biodiversity.
4) To protect marine natural heritage, including protection of representative and unique marine life habitats in California waters for their intrinsic value.
5) To ensure that California's MPAs have clearly defined objectives, effective management measures, and adequate enforcement, and are based on sound scientific guidelines.
6) To ensure that the state's MPAs are designed and managed, to the extent possible, as a network.

The process began with the development of the master plan framework. Four levels of MPAs were identified to provide the stakeholder groups involved in the process more flexibility in the regulations imposed for the various areas. The California Fish and Game Commission has evaluated alternative MPA proposals for the central coast and made a final decision on April 13, 2007 (Figure 4.2). There are four classifications of marine protected areas along the central coast (CDFG 2007); State Marine Reserve (SMR), State Marine Park (SMP), State Marine Conservation Area (SMCA), and State Marine Recreational Management Area (SMRMA). These categories of MPAs differ in their breadth of regulatory limitations:

- **State Marine Reserve (SMR):** The most restrictive classification, these are no-take areas (i.e., extractive activities are prohibited).
- **State Marine Park (SMP):** May allow recreational take, or limit it in some way, but does not allow commercial take.
- **State Marine Conservation Area (SMCA):** May limit recreational and/or commercial take to protect a specific resource or habitat.
- **State Marine Recreational Management Area (SMRMA):** A SMRMA is designated to limit or restrict recreational opportunities to meet other than purely local needs while preserving basic resource values for present and future generations. This category of marine management area prohibits any activities that would compromise the recreational values for which the area may be designated (http://www.dfg.ca.gov/mlpa/faqs.asp).

Oregon

The Marine Resources Program of the Oregon Department of Fish and Wildlife (ODFW) is authorized by the State Legislature to administer the regulation, harvest and management of commercial and recreational fisheries in Oregon (ODFW 2007b). The agency uses a variety of tools to manage these fisheries include trip and bag limits, area closures and species- specific management zones. Areas closures include Marine Gardens, Research Reserves, Habitat Refuges, and closed areas around river mouths (ODFW 2007). ODFW is in the process of revising their nearshore commercial fishery management plan. This revised plan will include descriptions of alternative management tools, such as area-based management for nearshore species.

The recreational groundfish fishery in Oregon primarily targets black rockfish, with lesser catches of other nearshore rockfish species such as china, copper, and yellowtail rockfish, lingcod, cabezon, and greenling (ODFW 2002).

Commercial groundfish fisheries in Oregon include federally managed groundfish trawl fisheries, which target species like petrale and Dover sole; federally managed open-access fisheries for species such as sablefish and lingcod, and the state-managed, limited entry black rockfish, blue rockfish and nearshore fishery. The live-fish fishery for nearshore species experienced rapid growth in the late 1990s. Special black rockfish management areas were established in 1994, restricting commercial harvest within areas of high recreational use (ODFW 2007a). The goal of this management approach is to minimize user conflicts between commercial and recreational fishermen and recognize differences in needs of the fishing communities up and down the coast (ODFW 2002).

The Black Rockfish Management Areas are delineated below. Within these areas the take of black rockfish is limited to less than 200 pounds of black rockfish, or 65 fish, whichever is greater, per vessel on a single trip (Figure 4.1, ODFW 2002):

- Tillamook Head (45º 56' 45" N. latitude) to Cape Lookout (45º 20' 15" N. latitude)
- Cascade Head (45º 03' 50" N. latitude) to Cape Perpetua (44º 18' N. latitude)
- From a point approximately 8½ miles north of the Coos Bay north jetty (43º 30' N. latitude) to a point adjacent to the mouth of Fourmile Creek, approximately 4½ miles south of the Bandon south jetty (43º 03' N. latitude)
- Mack Arch (42º 13' 40" N. latitude) to the Oregon/California border (42º N. latitude)

Oregon is undergoing an additional spatially oriented management process through the Governor's office and the Governor's Ocean Policy Advisory Council (OPAC) to develop a network of marine reserves along the Oregon coast to protect the natural diversity and abundance of species that live in each type of habitat in Oregon's Territorial Sea. Site proposals are being solicited from the public in a process that is scheduled to begin in summer 2008. The Marine Reserve Working Group, a subset of OPAC, is responsible for drafting objectives for the sites. Currently, some of the draft objectives include:

- Identifying and protecting areas of high or unique marine biodiversity and/or special natural features
- Designing and siting marine reserves to minimize potential adverse socioeconomic impacts on ocean users and dependent communities
- Designing and managing the areas, to the extent possible, as an integrated ecological network

The proposal process is expected to take up to four months. Upon completion, the proposal package will be reviewed by ODFW and submitted to the Governors office in order to be presented to the State Legislature at the beginning of 2009 to gain funding for implementation, monitoring and enforcement (M. Mackey, pers.comm.)

Washington

Washington Department of Fish and Wildlife has jurisdiction over fishery resources within state waters (0-3 miles) as well as the inland fisheries of Puget Sound. WDFW employs a variety of management tools for nearshore groundfish. These tools have evolved over time and include area-based management.

The following are examples of the agency's evolution and application of area-based management in coastal waters. In 1991, in response to evidence of localized depletion, WDFW implemented black rockfish conservation zones around key recreational ports in the form of restrictive trip limits for commercial fisheries. This action was accomplished utilizing an Environmental Assessment developed through the PFMC process. At this time the recreational rockfish bag limit was reduced from 15 to 12 fish (Brian Culver, pers. comm.).

A larger-scale area-management tool was applied in 1996 when the agency prohibited directed commercial non-trawl harvest of groundfish in coastal state waters (< 3mi.). A rule limiting trawl footrope diameter to 5" (to keep trawl gear away from hard bottom) and a reduction of the sport rockfish bag limit from 12 fish to 10 fish accompanied this commercial area closure. Trawl was left open in state waters to provide access to nearshore flatfish (e.g., sand sole, starry flounder). Subsequent analysis over the next few years demonstrated incidental rockfish take to still be at unacceptable levels. As a result, coastal state waters were closed to trawling in 2000. Also, the Fish and Wildlife Commission adopted a rule prohibiting the commercial live-fish fishery for groundfish. The rationale for this latter action was that the agency did not have sufficient science to inform commercial catch levels for species targeted by the live-fish fishery. The 2000 actions resulted in a ban on all directed commercial harvest of groundfish in state waters, although salmon trollers can currently retain 1 yellowtail rockfish for every 2 salmon landed (Brian Culver, pers. comm.).

WDFW developed and implemented yelloweye rockfish conservation areas (YRCAs) in federal waters through the PFMC process (Figure 4.1, PFMC and NMFS 2006).

Washington coastal recreational fisheries are currently being managed in three areas (Figure 4.1, PFMC and NMFS 2006):

1. Marine Areas 3 and 4 (Queets River to the U.S./Canada border)
2. Marine Area 2 (Leadbetter Pt. to the Queets River)
3. Marine Area 1 (Oregon/Washington border to Leadbetter Pt.)

These regulatory actions are a form of spatial management. In addition, Washington recreational fisheries are fairly constrained by operational logistics to the area surrounding the four coastal ports: Neah Bay, La Push, Westport and Ilwaco. Since there is no commercial groundfish harvest, this results in de facto refugia for nearshore species in areas distant from Washington coastal ports (Brian Culver, pers. comm.).

IMPLICATIONS OF AREA RESTRICTIONS

The use of area restrictions for management comes with some significant issues. For example, the Oregon recreational groundfish fishery has been closed offshore of 40 fm (73 m) from June through September since 2004. It is likely that due to these closures, most anglers who would have fished offshore during the closure periods instead relocated their activities inshore. The effort shift onto nearshore species that resulted contributed to the early attainment of the black rockfish harvest cap in 2004 and 2005 and to the early closure of the recreational fishery in both years. For many of these nearshore stocks, there are few data to support an assessment of its stock status, suggesting that the effect of this effort shift is difficult to monitor and evaluate. Fishing pressure on groundfish stocks that may have previously been spread over a broad area could become more concentrated, increasing the potential for localized depletion of some species and highlighting the need to develop and implement localized monitoring programs.

5. MATCHES AND MISMATCHES BETWEEN ECOLOGY, ECONOMY AND MANAGEMENT

INTRODUCTION

Almost two decades ago, and inspired by the history of California fisheries (McEvoy 1986), environmental historian Arthur McEvoy presented an innovative, broad and comprehensive context for marine fishery science and management, with a strong emphasis on direct interactions and relationships, of which those occurring within the ecosystem are just a part. Ten years later he built on this experience to define a fishery as an interaction between three variables: an ecological system (ecosystem), a group of people working (economy), and the system of social controls within which the work takes place (management) (McEvoy 1996). His key assertion is that management must equally weigh the many social and economic relationships within the fishery and how, in turn, they both influence and are influenced by marine ecosystem processes and dynamics. In fact it is human interrelationships that are of particular concern to decision makers. What McEvoy (1996) says is that a fishery is a classic example of a social-ecological system (Berkes et al. 2003, Berkes 2004): an integrated concept of humans in nature. And the essence of a sustainable fishery is the health of the interactions between the ecosystem, economy and management (Field and Francis 2006).

What we are trying to do in this section is to operationalize McEvoy's concept. Suppose, as proponents of a broader ecosystem-based approach to fishery management seem to agree, preserving biological structure (e.g., age or size structure of a stock, foodweb pathways of an assemblage or community, diversity of an ecosystem) is equally important to management as preserving harvestable biomass. And clearly we manage human activity and not biological entities. These human activities—fishing in this case—are what create the interactions between economy and an ecosystem. So how might management facilitate sustaining such interactions through, in this particular case, increased spatial resolution of the interactions? One way is for management to create incentives in the economy to preserve biological structure in the ecosystem by, for example, tying an individual fisher's opportunity to fish (something to be sustained within the economy) with the achievement of broader conservation objectives. Spatial management seems to provide the vehicle for doing this.

One clear spatial attribute of all fisheries is that effort, yield and the ecological consequences of fishing are not evenly distributed over space (O'Farrell and Botsford 2006). Therefore, whatever spatial structure is chosen in the implementation of management incentives, resource allocations should be weighted towards those regions with better track records of achieving identified conservation objectives. This spatially explicit approach would allow management to create tighter positive feedback between economic incentives (e.g., the individual opportunity to fish) and conservation objectives. As it stands now and, as the recent rockfish closures show, coastwide management provides few and largely ineffective incentives for sustainable interactions between economies and the ecosystem. Explicitly incorporating spatial context into management seems essential to creating a sustainable groundfish fishery.

This section attempts to identify spatially explicit matches and mismatches between regional ecosystems, fleets, and management. Specifically, we ask the question: what are the McEvoy interactions and how are they spatially structured? Perhaps the most important question we could ask is: **Can the west coast groundfish fishery be spatially compartmentalized into modules where feedback is tight (economy and ecosystem highly connected) within modules and feedback is loose between modules?** Walker and Salt (2007) indicate that modularity and tightness of feedback are key factors in maintaining general resilience, and that "the degree of modularity in the system allows individual modules to keep functioning when loosely linked modules fail, and the system as a whole has a chance to self-organize and therefore a greater capacity to absorb shocks."

THE CAPES

Our analysis indicates that the west coast capes may provide an initial modular framework described by Walker and Salt (2007). For example, one might partition the coast into 3 modules with divisions occurring somewhere in the transition zone between Capes Blanco and Mendocino, and at Point Conception. Evidence for this modular structure is summarized from sections 2 and 3 of this paper as follows:

- Latitude is the second only to depth as the most important factor influencing population and assemblage boundaries (Gabriel 1982). Dynamic atmosphere-ocean processes such as wind stress and current patterns are likely the most important factors controlling these north-south structures. There are two major latitudinal breaks in groundfish biophysics: 1) the turbulent wedge between Capes Blanco and Mendocino – a transition region between north and south which has the strongest upwelling winds and most turbulent coastal flows of the entire CCS (GLOBEC 1994, Peterson et al. 2006, Botsford and Lawrence 2002) and 2) Point Conception - the area south of Conception is very different from the area to the north – much smaller local wind stress, warmer subtropical water, different timing in the upwelling season (Hickey 1998).

- The analysis of Groundfish Fleet Reduction (GFR) maps (Scholz 2003) of spatial distribution of 2000 limited entry landings revealed that overlap in harvest areas is low between distant ports, and high between adjacent ports. Highest percent overlap occurred between port groups north of Cape Mendocino, but high percent overlap also existed between San Francisco and its adjacent ports. The only high percent overlap across Cape Blanco, Cape Mendocino, or Point Conception was between Coos Bay and Brookings port groups.

Figure 5.1 attempts to express the intensity of interactions between economy and ecosystem both between and within modules defined by breaks at the Cape Blanco – Cape Mendocino transition and Point Conception. It is quite clear that there are regions of high overlap ranging from Southwest Washington ports to Eureka, CA (north of Cape Mendocino) and from Bodega Bay to Monterey, CA. Based on our biophysical and socio-economic analyses, this three area structure seems to provide modules (spatial matches) capable of strengthening overall systemresilience. This is not to say that this structure is devoid of mismatches. For example, our biophysical synthesis suggest that the three areas might be too large to capture the essential nearshore groundfish spatial structure (scale of ones to tens of miles) and might be too small to capture the essential slope groundfish spatial structure (scale of thousands of miles). These mismatches will be further discussed in the next section.

GENERAL MATCHES AND MISMATCHES

While the capes serve as a pivot point for our match-mismatch analysis, there are a number of more general matches and mismatches that seem useful in evaluating spatial structure as a groundfish management tool.

- There is a clear mismatch between the coastwide management of overfished groundfish species and the impact of coastwide closures on coastal fishing communities. These closures, most notably Rockfish Conservation Areas (RCAs), have constrained fishing activity to smaller areas of state and federal waters, and have penalized fishing communities for excesses in removals they had little to do with. The blunt instrument of coastwide management has provided weak linkages between the activities of individual fishers to conserve and their access to the resource.

- As coastal communities, such as Morro Bay (CA) and Port Orford (OR), become more engaged in managing adjacent nearshore fisheries, they become more involved in scientific assessment and monitoring of their local resources. Most current groundfish management science is based on large scale annual (NMFS) surveys and statistically sophisticated data heavy, but ecologically narrow, single species stock assessments. Without careful coordination between local and Pacific Fishery Management Council (PFMC) scientific activities, local scientific efforts risk the likelihood of being ignored at the coastwide level, thus creating significant mismatches.

- Waples et al. (in review) discuss the matches and mismatches between units on which stock assessment and management are based and those inferred from genetic data. Table 1 of their paper shows these matches and mismatches for west coast groundfishes. Some of the reasons for the mismatches are a) assessments are almost always single species whereas most stocks are influenced by multi-species (and ecosystem) effects, b) management is based on political boundaries which do not necessarily reflect biology (e.g., black rockfish, *Sebastes melanops*) or actual use patterns, c) managing multiple species as one putative species (e.g., blue rockfish, *Sebastes mystinus*), and d) local management is implemented on too fine a scale thereby subjecting a single biological population "to independent and perhaps conflicting management regimes in different areas of its range."

- The resilience of coastal fishing communities, particularly those with a predominance of small vessels, tends to be dependent on diversity of fishing opportunities – the potential for fleets to shift among target species. There is concern that fleet-specific rationalization (e.g., LE trawl Individual Fishing Quota Program) could reduce the diversity of the portfolio available to some of these small boat fleets and to individual fishermen, thus fracturing the way some coastal communities currently fish.

- Because of their compressed and extensive depth ranges, many of the continental shelf banks (e.g., Hecata, Cordell), islands (e.g., Channel Islands, Farallon Islands) and submarine canyons (e.g., Monterey, Astoria) have very high groundfish production and concentrate a diverse array of groundfish in a relatively small area (Yoklavich et al. 2000). In essence, they bring slope species close to shore and move nearshore species offshore. Because they provide diverse high quality rocky reef habitat, they tend to have high fish production. As a result of all of these factors they create significant mismatches with the general metapopulation model proposed by Gunderson and Vetter (2006) and used to support the Cape to Cape area stratification discussed above.

- McEvoy (1996) emphasizes that the essence of a sustainable fishery is the health of the interactions between the ecosystem, economy and management. If one looks at the scientific basis for west coast groundfish management from this perspective, one sees a number of matches and mismatches. The strongest link between science and management occurs at the stock assessment level. However that match is very narrow in that most of the focus is at the single stock production level. There is a distinct mismatch in terms of management informing decisions based on scientific assessments at the biological community and ecosystem scale. In addition, there is a mismatch between the use of biological and socio-economic assessments in informing the decision making process.

6. MANAGEMENT ALTERNATIVES AND RECOMMENDATIONS

INTRODUCTION

If one looks at the fishery from the McEvoy perspective, ecosystem-based fishery management should strive to focus on maintaining or creating healthy interactions between the economy and the ecosystem. As mentioned earlier, sustainability of coastal communities would be enhanced where coastal ecosystems were healthy and the individual opportunities to fish were as high as possible. Conservation objectives might include low bycatch, avoiding rapid shifts in the structures of biological communities, minimizing the destruction of habitat by fishing, and maintaining biological structure (e.g., age or size structure, lifetime egg production). We feel that since the effects of fishing are not evenly distributed over space, spatial management could help provide incentives for achieving conservation objectives.

This final section starts with the spatially explicit matches and mismatches between regional ecosystems, fleets, and management identified in the previous section. We then attempt to answer two critical questions: How to structure management to 1) enhance the matches and 2) reduce the mismatches?

THE CAPES

Our analysis and synthesis indicate that as one moves from nearshore to shelf to slope, the larger the appropriate spatial scale of management. Generally, management of nearshore fisheries might be structured at scales of ones to tens of kilometers, shelf fisheries at the scale of hundreds of kilometers (e.g., Cape to Cape or INPFC areas), and slope fisheries at scales of thousands of kilometers (e.g., coastwide). We think that the three modules, mentioned above, may actually work quite well for all three inshore-offshore components of the coastwide groundfish fishery. Let's call the three areas defined the Northern (NCC), Central (CCC) and Southern California Current (SCC)(Figure 5.1). The states already manage their nearshore zones separately, and all three seem to be working towards fine scale management. The three modules seem to be ideally suited for the shelf fisheries and their associated social-ecological interactions. And the slope fisheries (Pacific whiting, Dover sole, sablefish – NCC; thornyheads-SCC) tend to partition out along the three module scale.

GENERAL MATCHES AND MISMATCHES

We now look at how spatial management might enhance the more general matches and reduce the more general mismatches discussed above.

- We think that the three-area management proposed above could be a strong first step in linking individual access to the resource with the achievement of conservation objectives. The simplest way to start would be to manage the bycatch of all overfished species on this spatial grid. This would greatly reduce the likelihood of coastwide closure of the entire groundfish fishery.

- In order for coastal communities to become fully engaged in the assessment and management of their adjacent nearshore fisheries, there need to be clear performance standards for the data used, assessment methodologies and criteria for community harvest allocations.
- Waples et al. (in review) outline a number of measures that could help to reduce the spatial mismatches between genetic assessments, stock assessments and management. One of the most prevalent uncertainties relates to "how many populations exist and what their statuses are." Management Strategy Evaluation (MSE – Smith 1994) is a modelling technique used to determine which assumptions (e.g., one population, multiple populations), if violated, would most seriously compromise the ability to achieve management objectives. In the case of a mismatch between genetic and management spatial structure, "genetic information can be used through the MSE process to help assess the consequences of ignoring population structure."
- Every effort should be made to evaluate the impact of proposed management measures on coastal community resilience. This is discussed in more detail under the final bullet.
- Physical areas of high concentration of nearshore, slope and shelf species (e.g., banks, islands, canyons, headlands) need finer scale management than our three proposed management areas can provide. For example, if one looks at the two areas of strong overlap between at least three port groups in Figure 3.3, they both occur in such areas. The footprint overlap between Newport, Coos Bay and Brookings (OR) occurs off Cape Blanco (Bandon High Spot) and the overlap between Bodega Bay, San Francisco and Monterey occurs at the Farallon Islands. In 2006 these (and other) areas were declared essential fish habitat (EFH) conservation areas and were closed to bottom trawling (Figure 6.1).
- The groundfish management community needs to become more balanced and comprehensive in terms of the nature of its scientific assessments. If we are to move into the realm of ecosystem-based management, then assessments must be conducted at the ecosystem scale. And as Harvey et al. (2006) clearly show, the ecosystem effects of fishing are not uniformly distributed over space. As is done by the North Pacific Fishery Management Council, ecosystem assessments need to be routinely conducted and incorporated into management policy. The same can be said for socio-economic assessments. Management policy can have significant community-wide ripple effects when, for example, rules are changed in one sector. For example, the 2003 buy-back of 16 trawlers in Crescent City (CA) further destabilized the broader fishing community through its reduced use of and demand for local fishery infrastructure (Carrie Pomeroy, pers. commun.). Also, the recent Nature Conservancy buy-out of all seven Morro Bay federal groundfish trawl permits, as well as four aging open access trawlers (San Luis Obispo Tribune, 19 Oct 2007), indirectly impacted the nearshore fixed gear fleet by affecting a closing of the local cold storage facility (Mark Carr, pers. commun.). We encourage any EIS analyses of proposed management measures (e.g., LE trawl Individual Fishing Quotas) to include

meaningful socio-economic assessments of potential impacts on coastal fishing communities.

CONCLUSIONS

It is clear that space can be a powerful tool in moving towards a more comprehensive and balanced west coast groundfish management. However simply applying the status quo to newly delineated management areas will, in our view, do little to move west coast groundfish policy into the 21st century. Spatial management must be accompanied by clear objectives for what is to be achieved. We think that space can be used as a powerful tool to enhance positive feedbacks between the west coast groundfish economy and ecosystem. The potential is there for management to use space to provide incentives for individual fishers to achieve ecosystem-based conservation objectives. However those objectives must be made explicit and their achievements monitored comprehensively and carefully.

As we state in the introduction to the white paper, "an ecosystem approach to management is management that is adaptive, specified geographically, takes into account ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse social objectives" (Francis et al. 2007). This is a management approach that is proactive and seeks to preserve existing ecological and social processes and variabilities. It is also an approach that requires resilience thinking, and its unifying concept of adaptive capacity, through heterogeneity, modularity and tight feedback. If adaptive capacity is at the heart of ecosystem-based fishery management, then it seems spatial management is a powerful and essential component of ecosystem based fishery management.

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Appendix I:

Latitudinal Variations in the Physical and Biological Oceanography in the California Current: gradients or boundaries?

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The California Current begins at the northern tip of Vancouver Island Canada, and ends somewhere between Punta Eugenia and the tip of Baja California Mexico. The alongshore extent is on the order of 28° of latitude (51°N to 23°N). As the current flows from north to south, the waters warm and mix with offshore waters such that both temperature and salinity increase gradually in a southward direction. Not surprisingly, observations of the biota of the California Current show that there are pronounced latitudinal differences in the species composition of plankton, fish, and benthic communities, ranging from cold water boreal sub-arctic species in the north to warm water subtropical species in the south. But are species changes along a temperature gradient gradual, or are there abrupt faunal boundaries where sudden shifts in species composition occur? That answer is of course, "it depends…".

In considering this question, one must keep in mind several processes which affect the circulation of the California Current and biota contained therein. First, it is critically important to understand the origin of the source waters that feed the current. In the branch of the northern California Current that flows over the continental shelf, there is a strong seasonal cycle in source waters due to reversals of flows in summer and winter, resulting from seasonal reversals in wind stress. In summer, the winds blow from the north which forces the coastal currents to flow southward and offshore, resulting in upwelling at the coast. Source waters for are pulled into the California Current from the north, but also from deep waters offshore that brought onto the continental shelf and to the sea surface, nearshore, by the upwelling process. However, in winter, intense southwesterly storms push offshore waters onshore, from the south, resulting in a reversal of coastal currents such that waters flow northward. This northward flow in winter is named the Davidson Current. This current brings to the shelf warm "subtropical" waters from the offshore California Current. Seasonal reversals in currents have not been well-studied in a spatial context although generally speaking, reversals are seen mostly in continental shelf and slope waters, and reversals are strongest north of central California.

The transition points in the winds and currents are referred to as the "spring transition" and "fall transition". The timing of the occurrence of these events is important to biological productivity because an early spring transition signals an early start to the upwelling season.

Offshore of the continental shelf, at all latitudes, the California Current experiences a net flow towards the south year around. Thus when considering gradients in species composition of planktonic plants and animals, both season and location must be taken into account. For example, off Oregon, Keister and Peterson (2003) have shown that copepod community composition in offshore waters (deeper than ~ 1000 m) do not show any seasonal changes whereas continental shelf waters have a summer community that is distinctly different from a winter community. The offshore community observed year-around is more temperature-subtropical in character, a result of the fact that the offshore portions of the California Current have their origin in the southern part of the sub-Arctic Pacific and the Transition Zone. The continental shelf/slope copepod community observed during the summer is boreal in character due to upwelling; the winter community is subtropical due to northward and shoreward transport of "warm-water" coastal species (first described by Peterson and Miller 1977, Peterson and Keister 2003).

The strong contrast in species composition between shelf and offshore waters during summer is due to the upwelling process. A combination of upwelling itself along with the sub-Arctic water which feeds the inshore arm of the northern end of the California Current create conditions favorable for development of a huge biomass of sub-Arctic zooplankton. This pattern is slightly modified as a function of the phase of the Pacific Decadal Oscillation. During cool phase, all of the northern California Current becomes more sub-Arctic in character (both shelf-slope-oceanic regions); during warm phase of the PDO, the copepod community becomes far more similar to a sub-tropical community. Copepod biodiversity increases in coastal waters, due to shore-ward movement of offshore waters onto the continental shelf, due to either weakening of southward wind stress in summer or strengthening of northward wind stress in winter. Thus, when PDO is in positive phase, a greater proportion of the water entering the northern end of the Current is sub-tropical in character rather than sub-Arctic.

Large El Niño events, as observed in 1983 and 1997-98 completely change this paradigm because massive quantities of subtropical waters flood the northern California Current. These floods can persist for many months after the "end" of an event because mixing and advective processes have to flush this lousy water from the system and replace it with good water (from the sub-Arctic) before the system has any chance of recovering. Thus, during such times, although physical oceanographers may declare an end to an El Niño event, there will be significant time lags (6-9 months) before the system has returned to a "normal" state (Peterson et al. 2002).

The undercurrent is another important feature – it transports large volumes of water north in the California Current, at a depth of 150-300 m, along the continental slope, usually adjacent to shelf break. The commercially-important fish with the largest biomass in the California Current (Pacific whiting) ride this current north in summer from their winter spawning grounds off central and southern California to their summer feeding grounds off northern California, Oregon and Washington (Agostini et al. 2006). They chase krill. Their migration may well be linked to krill availability in that years of high krill abundance may result in a truncated hake migration in summer, whereas when krill abundance is low, the hake may either migrate further north in search of krill and/or feed on other fishes such as anchovies, sardines and osmeriids.

Thus, when considering the question of "gradients in species composition", vs. "faunal boundaries" for pelagic species influenced by the currents, one must specify the region of interest: shelf waters vs. offshore waters, the latitude, and the season.

Having said all of that, here is what I believe to be the consensus on faunal boundaries:

The U.S. GLOBEC-Northeast Pacific Program divided the California Current into four regions: Dixon Entrance/Vancouver Island Canada to Cape Blanco Oregon; Blanco to Point Conception California; Conception to Punta Baja Mexico; and Punta Baja to Cabo San Lucas (U.S. GLOBEC 1994) with the regions defined in terms of differences in physical forcing, seasonality of plankton production, zooplankton species composition, and fish spawning strategies. The Blanco-Mendocino region is a faunal boundary to some species largely because of high winds in this region, resulting in more intense upwelling, and greater rates of offshore transport of coastal waters. Thus there is a high potential for the loss of larvae (poor recruitment) of organisms with pelagic larvae. Point Concepcion is a faunal boundary, but not necessarily due to changes in the wind field in that region, rather the orientation of the California coast changes from north-south to east-west at Concepcion. At Point Concepcion, the California Current continues to run south (not east west), carrying with it the coastal plankton (and "recruits) into deep waters.

Within the domain of the California Current, there is a strong latitudinal gradient in the strength of upwelling. The upwelling process is relatively gentle in shelf waters off Vancouver Island (Canada), Washington and northern Oregon. Winds are weak and upwelling is a "linear" 2-dimensional process – surface waters are driven offshore by the northerly winds and deep waters are upwelled at the coast. The circulation more-or-less tracks the bathymetry, with a southward-flowing upwelling jet current usually developing in mid-outer shelf waters. At the southern end of Heceta Bank (44°N), there can be flow-topography interactions due to the orientation of the Bank, such that the upwelling jet can separate from the coast and "wanders" around in more offshore waters. There can also be reversals of the flows over Heceta Bank during brief downwelling events (Barth et al. 2005).

Winds become even stronger at Cape Blanco (~ 42°40'N) and the California Current begins to "break-up" so to speak, becoming more 3-dimensional in that the upwelling jet separates from the shelf (Barth et al. 2000) can shoot offshore, inshore or even towards the north, and many mesoscale eddies are generated. Thus, at and near Blanco, what was once an apparently simple lazy southward current, becomes a maze of swirling eddies. Granted there is a net flow to the south, but eddies and jets complicate things greatly. Critically important is the fact that the jets and eddies can rip large quantities of water from coastal regions and deposit them into offshore waters. Thus, boreal coastal planktonic species from the subarctic begin to have a hard time maintaining a viable population in the coastal waters south of Cape Blanco. There is good evidence demonstrating the loss of some of the boreal copepod species, *Calanus marshallae, Pseudocalanus mimus* and *Centropages abdominalis*, and we begin to see the appearance of two subtropical species that become dominant farther south (*Calanus pacificus* and *Paracalanus parvus* (Keister and Peterson 2003). However other species show no change. Since this paper was published, we have collected lots more data and Julie Keister has continued this work as part of a Ph.D. dissertation devoted partially to working out the problem of offshore losses of plankton due to jets and eddies in the central-southern Oregon region. The thesis is expected to be finished by April 2008.

Although it is clear from our work on copepods that sub-Arctic species begin to decline in abundance in the region near Cape Blanco the euphausiids do not seem to notice. In fact, if anything, they may well have their greatest abundance in the Blanco-Crescent City region (work of one of my staff, Jen Menkel, who should be able to start writing this up by this fall or early winter).

Here is a brief summary of the above comments:

- Seasonal reversals in coastal currents bring radically different copepod communities into the coastal waters of the northern end of the California Current, a process that must result in very different feeding conditions for planktivorous fishes.

- The onset of upwelling in spring creates strong cross-shelf gradients in copepod community composition – a boreal subarctic community in shelf waters and a temperate-subtropical community in offshore waters.

- When upwelling is weak or non-existent (as in winters or during summers during positive PDO phase), cross shelf gradients are weak to non-existent and the copepod community in continental shelf waters looks much like the offshore copepod community.

- In the region between southern Heceta Bank (44°N) and Cape Blanco 42°30'N) upwelling intensifies, the region influenced by upwelling broadens and coastal waters are carried offshore. Moreover the California Current itself begins to change from a nice simple "2-dimensional" system a "3-dimensional" system dominated by high activity of mesoscale jets and eddies that wander around seemingly at random. There is a general (average) transport to the south, but it is not hard to image that some water particles (and plankton contained therein) might only be transported in circles, thus experience no latitudinal transport, for days-to-weeks on end.

- It is in the Blanco region that we begin to see the dominant boreal copepods disappear (such as *Calanus marshallae, Pseudocalanus mimus* and *Centropages abdominalis*) and we begin to see their subtropical congeners appear (*Calanus pacificus* and *Paracalanus parvus*).

So, is Cape Blanco a faunal boundary for zooplankton? For some zooplankton species "yes", but for others "no". The "no" applies to the more oceanic (but sub-Arctic) species such as *Neocalanus plumchrus* and *N. cristatus* which are transported farther south, but become uncommon south of Mendocino (CalCOFI Atlases No. 2 and No. 7). Note however that *N. plumchrus* occurs off Baja California in cold years, such as during the La Niña of 1999 (Jimenez-Perez and Lavaniegos 2004). So, although one could be safe in stating that there is a "faunal boundary" between Capes Blanco and Mendocino, because changes in community composition are relatively rapid there, the "boundary" can be rather fuzzy.

But what about other species? Certainly for the rocky-intertidal benthic invertebrates, it is clear that there is a latitudinal gradient in recruitment both at Cape Blanco (Connolly et al. 2001) as well as Point Conception (Hayden and Dolan. 1976, Blanchette et al. 2007). However, other species may not notice these features:

- Two euphausiid species dominate the California Current, *Euphausia pacifica* and *Thysanoessa spinifera*. They appear to be as abundant off Oregon as off California. There is certainly a boundary for *T. spinifera* at Point Concepcion (U.S. GLOBEC 1994), whereas E. pacifica can range south to waters off Baja; it is also clear that during the "cold" years (negative PDO), *E. pacifica* can be found almost as far south as Cabo San Lucas, at the tip of Baja California. In an opposite manner, a subtropical species, *Nyctiphanes simplex* is usually most abundant off Baja and into the S. California Bight, however during El Niño events, this species is transported as far north as Oregon (Keister et al. 2005). Thus this species is a great indicator of the degree to which subtropical plankton (and subtropical water) can be transported latitudinally.

- Fish. The dominant large fish species (biomass wise) is hake, and they know no bounds. As for other fishes, I do not know much about possible changes in distribution or recruitment that might be associated with capes. Moreover, this is probably too large of topic for me to review here.

- I think that it is still true (or at least widely believed) that no pelagic fish in their right mind spawn in the region between Capes Blanco and Mendocino, due largely to the high degree of turbulence there (in spring and summer), caused by high winds (Parrish et al. 1981). Also offshore transport associated with the mesoscale filaments, jets and eddies will quickly sweep larvae way away to the deep blue sea. So, one can view the Blanco-Mendocino couplet as a boundary to spawning by fishes such as anchovies, sardines, whiting and mackerels.

- It is definitely true that many fish species spawn in winter, long before upwelling starts, so that their weak-swimming larvae have become strong-swimming juveniles by the time that upwelling begins (and in so doing, they are better prepared to avoid being swept out of the upwelling system). However I often wonder about this paradigm since all that a fish (or copepod) has to do to avoid being swept out of the upwelling system off Washington and Oregon is to swim down to a depth of 15 m or more and there they will experience either no net offshore transport, or onshore transport.

- Most rockfish species give live birth, presumably to avoid losses due to transport. But are they worried about offshore or along shore transport? I do not know.

- Seabirds. I think there may be some stories here but they get complicated quickly because many of them are limited by nesting sites or by habitat where a colony can be established.

- Gray and humpback whales, like whiting, have figured out the winter/summer thing and make the best of both worlds (reproduce in a care-free environment down south in winter; feed where the lipids abound up north in summer). I think they are unaware of the faunal boundary concept.

Bottom line. You have to know your species and a fair bit about their life history before you generalize about faunal boundaries. A book by Briggs (1974), which I have not consulted, apparently reviews many of the examples of species and faunal boundaries.

Appendix II. Port groupings by state.
Source: PacFIN ports, subregions, countries, joint-ventures (PCID) code list.

WASHINGTON

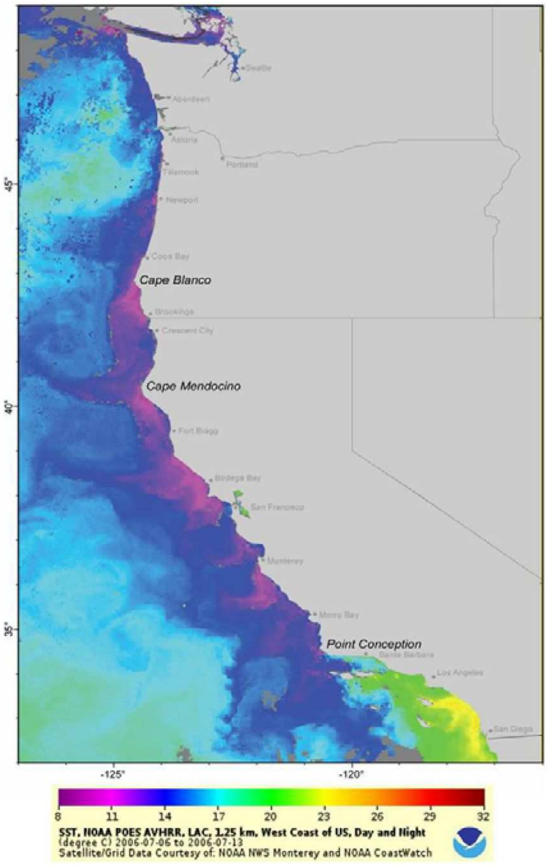
- Puget Sound
  - Neah Bay
  - Port Angeles
  - Sequim
  - Port Townsend
  - Blaine
  - Bellingham Bay
  - Anacortes
  - La Conner
  - Friday Harbor
  - Everett
  - Seattle
  - Tacoma
  - Olympia
  - Shelton
  - Other Puget Sound Ports
- Washington Coastal Ports
  - La Push
  - Copalis Beach
  - Grays Harbor
  - Westport
  - Willapa Bay
  - Ilwaco/Chinook
  - Other Washingtion Coastal Ports

OREGON

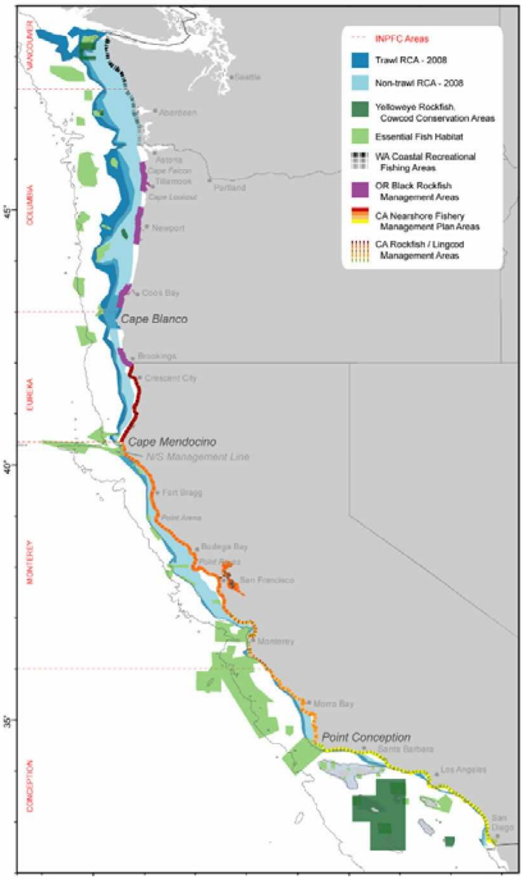
- Astoria
  - Astoria
  - Gearhart - Seaside
  - Cannon Beach
- Tillamook Area Ports
  - Tillamook/Garibaldi
  - Nehalem Bay
  - Netarts Bay
  - Pacific City
  - Salmon River
- Newport Area Ports
  - Depoe Bay
  - Siletz Bay
  - Newport
  - Waldport
  - Yachats
- Coos Bay Area Ports
  - Winchester Bay
  - Charleston (Coos Bay)
  - Bandon
  - Florence
- Brookings Area Ports
  - Port Orford
  - Gold Beach
  - Brookings

CALIFORNIA

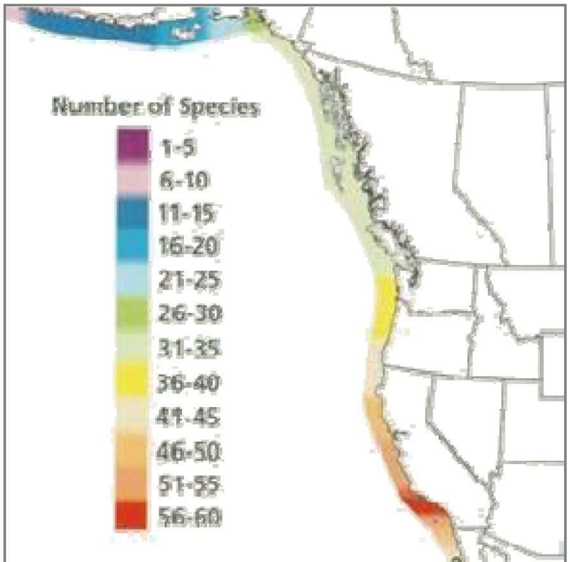
- Crescent City Area Ports
  - Crescent City
  - Other Del Norte County Ports
- Eureka Area Ports
  - Eureka
  - Trinidad
  - Other Humboldt County Ports
  - Fields Landing
- Fort Bragg Area Ports
  - Fort Bragg
  - Albion
  - Other Mendocino County Ports
  - Point Arena
- Bodega Bay Area Ports
  - Bodega Bay
  - Point Reyes
  - Tomales Bay
  - Other Sonoma And Marin County Outer Coast Ports
  - Bolinas
- San Francisco Area Ports
  - San Francisco
  - Sausalito
  - Oakland
  - Princeton / Half Moon Bay
  - Other S. F. Bay And San Mateo County Ports
  - Alameda
  - Berkeley
  - Richmond
- Monterey Area Ports
  - Monterey
  - Moss Landing
  - Santa Cruz
  - Other Santa Cruz And Monterey County Ports
- Morro Bay Area Ports
  - Morro Bay
  - Avila
  - Other San Luis Obispo County Ports
- Santa Barbara Area Ports
  - Santa Barbara
  - Port Hueneme
  - Oxnard
  - Other Santa Barbara And Ventura County Ports
  - Ventura
- Los Angeles Area Ports
  - Terminal Island
  - San Pedro
  - Willmington
  - Newport Beach
  - Dana Point
  - Other LA And Orange County Ports
  - Long Beach
- San Diego Area Ports
  - San Diego
  - Oceanside
  - Other San Diego County Ports



Chlorophyll Distribution
July 2006 (NOAA 2008)



Examples of Spatially
Explicit Management



Rockfish Species Diversity
(from Love et al. 2002)

Figure 1.1. Spatial variability in west coast physical environment, species diversity and management.

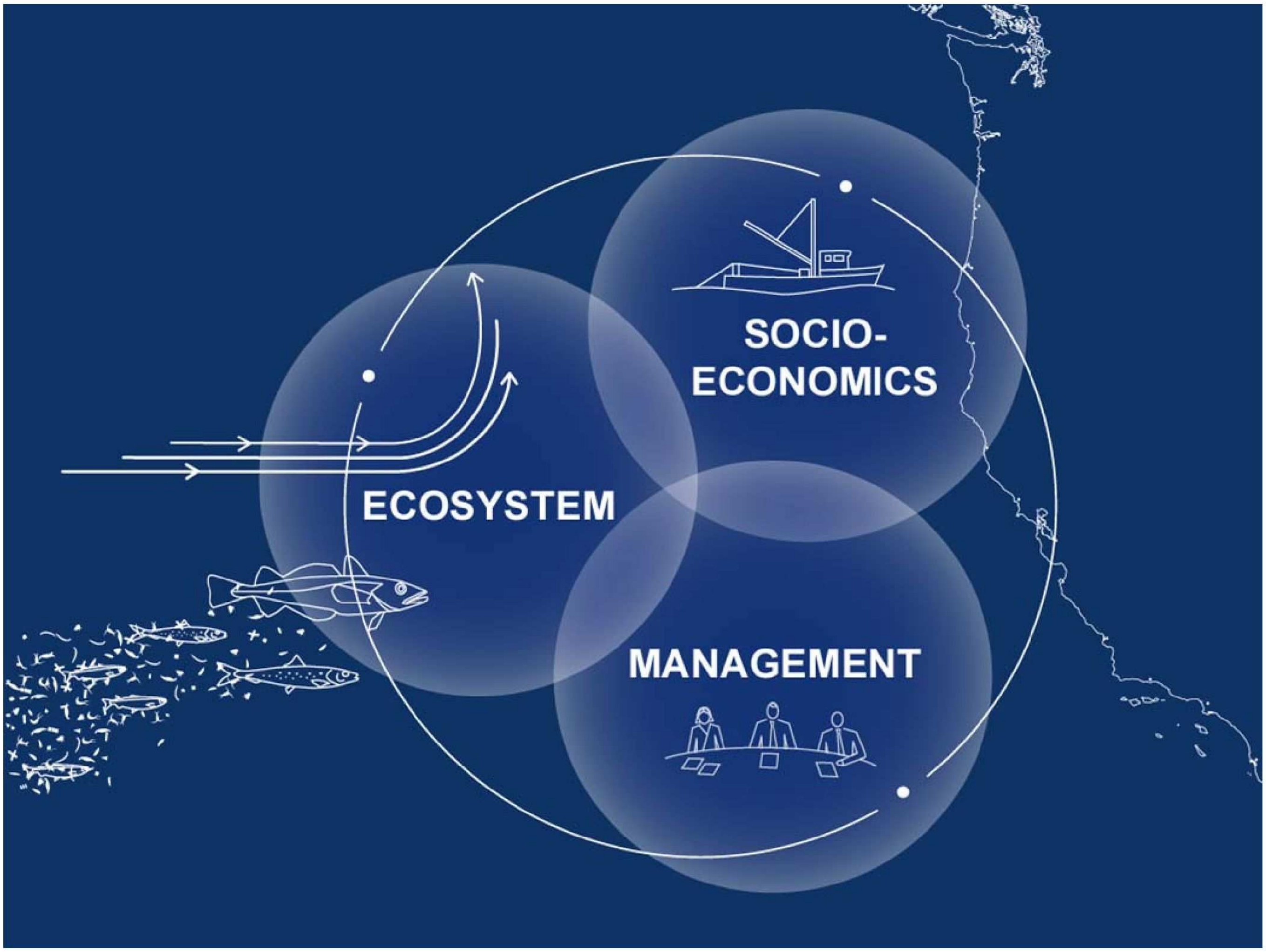


Figure 1.2. West coast groundfish fishery as a social-ecological system.

Species or assemblage	**Seasonal movement**	**Ontogenetic**	**Nomatic movement**
Nearshore rockfish (olive, copper, quillback, kelp, blue, black)	small scale movement suspected for some species[1,2,3]	Some small-scale movement suggested [2, 3]	Low for most species, greater movement in black rockfish [3, 4, 5, 6, 7, 8]
Semi-pelagic shelf rockfish (yellowtail, widow, bocaccio)	small scale movement suspected for some species[1,6,7]	Some movement of juveniles to deeper or offshore habitat with age [2, 7]	Less than 10 km for most mature adults, small numbers of yellowtail moved 50-250 km [1, 9, 10, 11]
Shelf and slope rockfish (canary, Pacific ocean perch, darkblotched, greenspotted)	none known or suspected	movement to deeper habitat with age for many species (canary, darkblotched) [12, 13, 14]	Thought to be highly limited (1-5 km) for most species [11, 12]
Thornyheads (shortspine and longspine)	none known or suspected	juvenile shortspine move deeper with age, no movement for longspine [15, 16]	thought to be highly sedentary, may be some movement on the order of 50 km [17]
Lingcod	bathymetric movement patterns related to spawning activity (~10 to 50 km) [18,19, 20]	uncertain	Movements of up to 400 km for a small fraction of tagging study recoveries [18, 19, 20, 21]
California Scorpionfish	form large seasonal spawning aggregations in deep water [1, 22]	uncertain	Dispersed and mobile in non-spawning season [1, 22]
Sablefish	poorly understood	Movement to deeper water with age [23]	Movement of up to 250 km common (~35% recoveries), with ~10% up to 1000 km [24, 25, 26]
Dover sole, English sole, Petrale sole	Bathymetric movement shallow in summer (spawning for Dover, Petrale), deep in winter (spawning for English) [27, 28, 29, 30]	Dover, English sole disperse to deeper water with age	Most recoveries within 10-50km of release. 10 to 20% were 50-200 km. Strong spawning site fidelity for Petrale [27, 28, 29, 30]

1 Love (1981), 2 Love et al. (2002), 3 Matthews (1990), 4 Coombs (1979), 5 Culver (1987), 6 Matthews and Barker (1983), 7 Hartmann (1987), 8 Eisenhart (2003), 9 Pearcy (1992), 10 Stanley et al. (1994), 11 Starr et al. (2002), 12 Gunderson (1997), 13 Methot and Stewart (2005), 14 Rogers (2005), 15 Wakefield (1990), 16 Jacobson and Vetter (1996), 17 Gaichas and Ianelli (2005), 18 Matthews and LaRiviere (1987), 19 Jagielo (1990), 20 Jagielo (1999), 21 Starr et al. (2004), 22 Love et al. (1987), 23 Methot et al. (1999), 24 Dark (1983), 25 Beamish and McFarlane (1983), 26 Kimura et al. (1998), 27 Ketchen and Forrester (1966), 28 Jow (1969), 29 Pederson (1975), 30 Westrheim et al. (1992)

Table 2.1. Summary of known or suspected movement patterns for key groundfish species in the California Current system (reproduced from Field et al. 2006b).

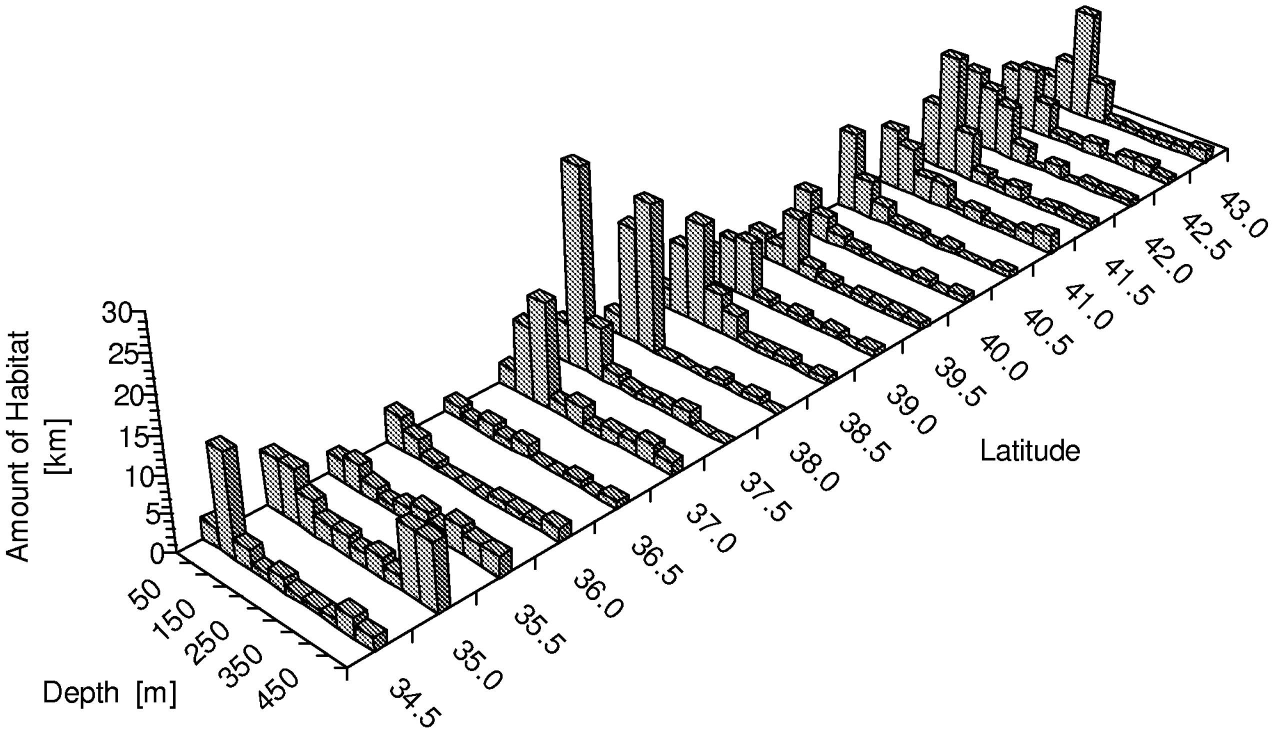


Figure 2.1. Estimated groundfish habitat by depth and latitude from Point Conception to Cape Blanco (from Williams and Ralston 2002).

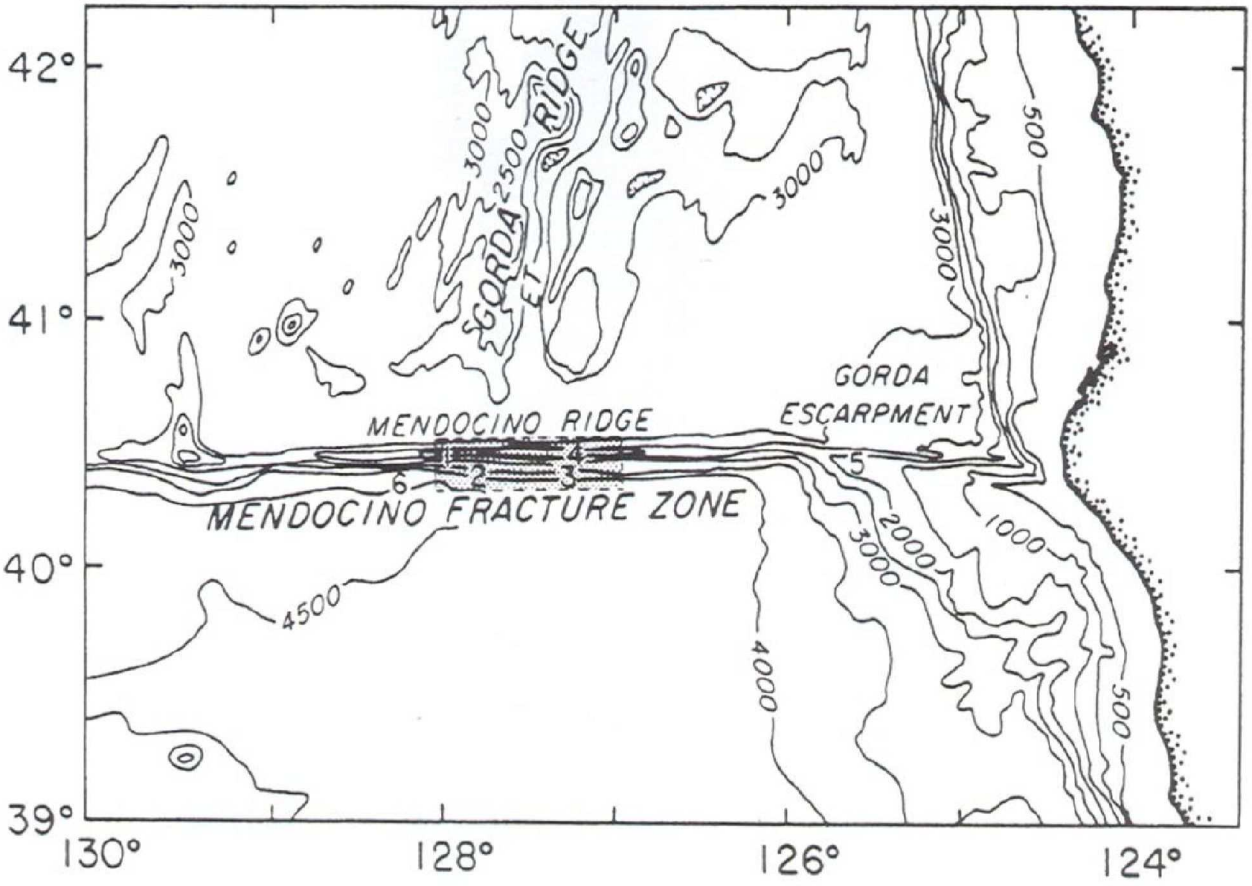


Figure 2.2. Mendocino Escarpment (from Fisk et al. 1993)

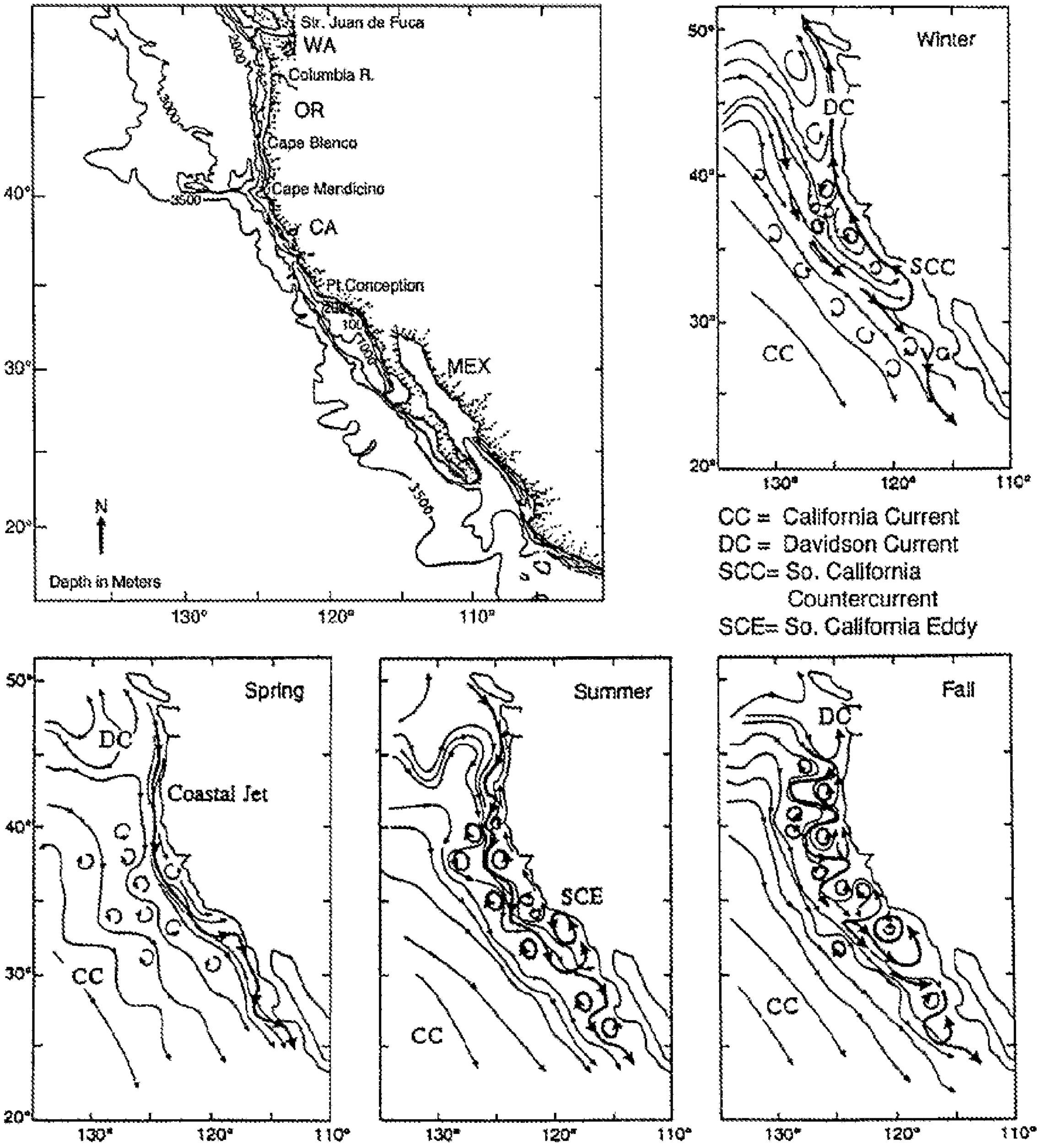


Figure 2.3. Seasonal circulation in the California Current System (from Hickey and Banas 2003).

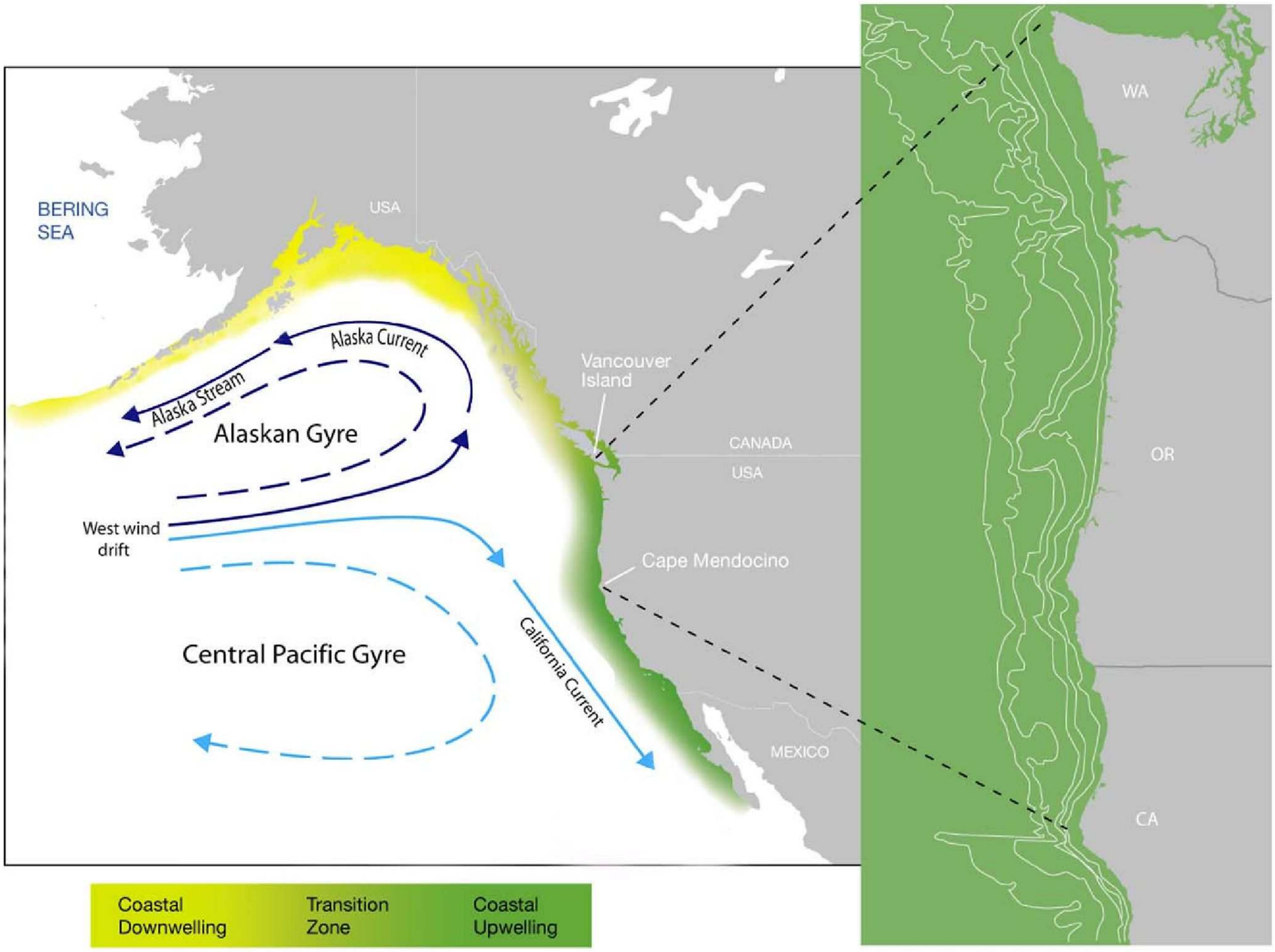


Figure 2.4. Northeast Pacific large marine ecosystems and oceanographic domains (adapted from Ware and McFarlane 1989).

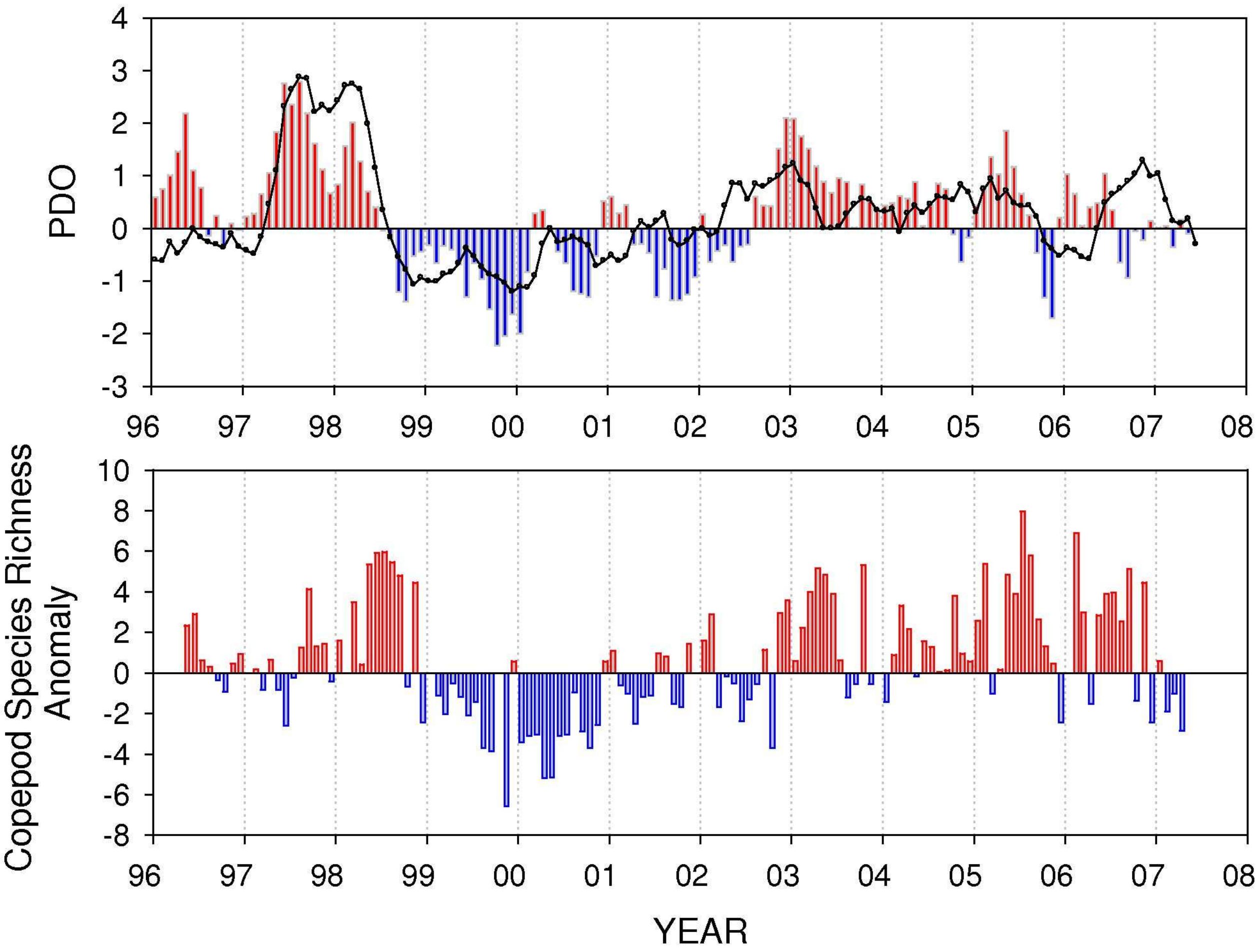


Figure 2.5. Pacific Decadal Oscillation and Oregon coastal copepod species richness (from Peterson et al. 2006).

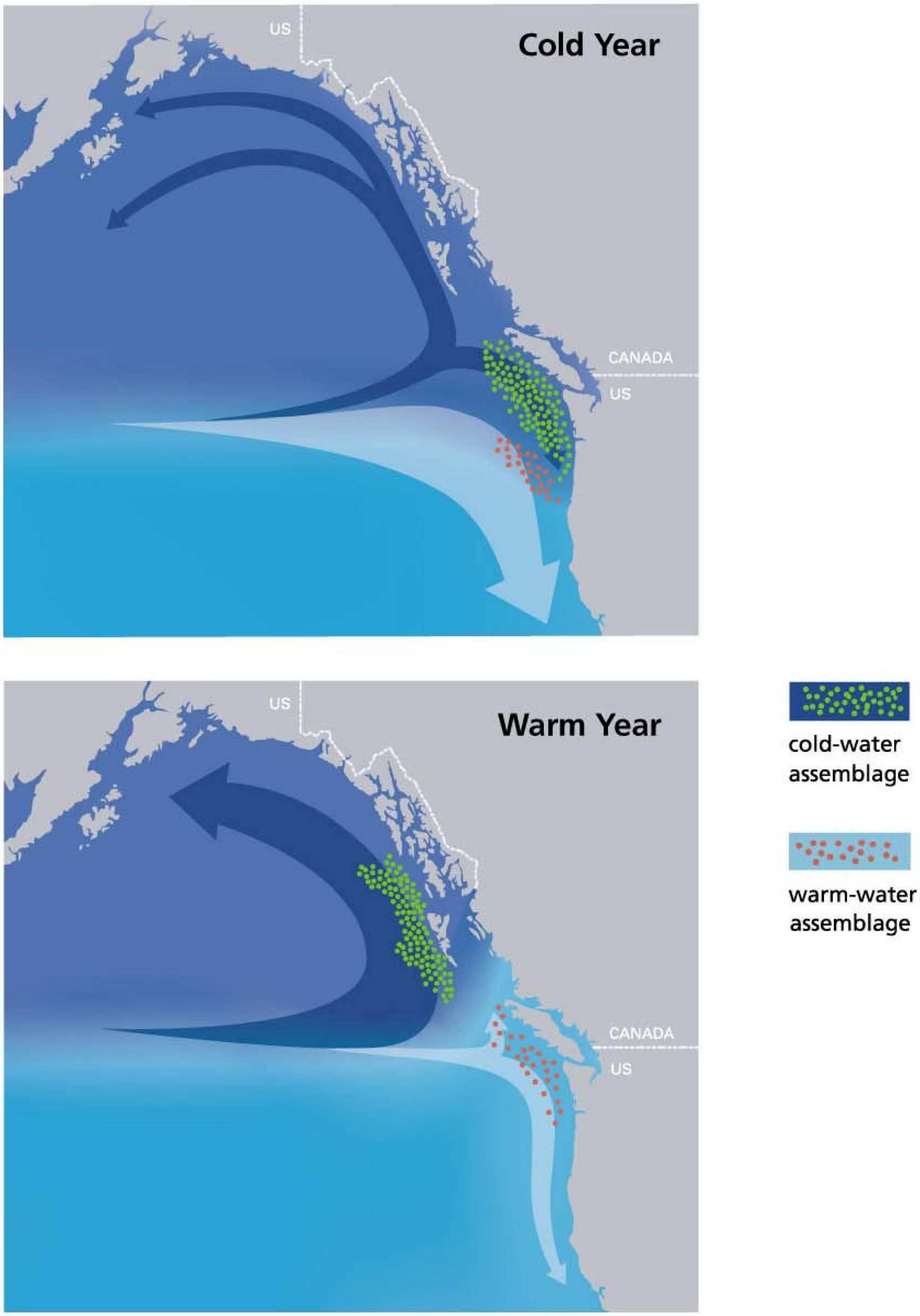


Figure 2.6. Difference in Northern California Current circulation between cold and warm climate regimes (adapted from Peterson et al. 2006).

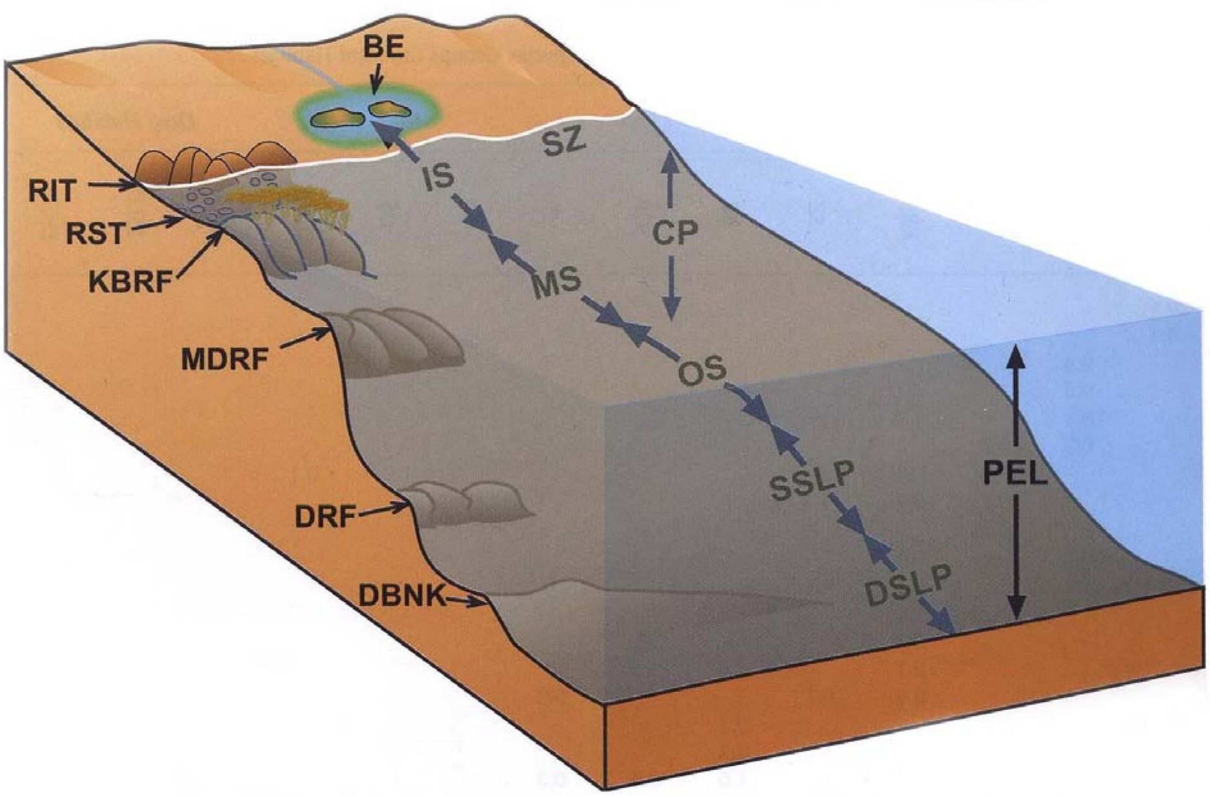


Figure 2.7. Major demersal habitats; bay/estuary (BE), surf zone (SZ), coastal pelagic (CP), pelagic (PEL), rocky intertidal (RIT), rocky subtidal (RST), kelp bed rock reef (KBRF), mid-depth rock reef (MDRF), deep rock reef (DRF), deep bank (DBNK), inner shelf (IS), middle shelf (MS), outer shelf (OS), shallow slope (SSLP), deep slope (DSLP) (from Allen et al. 2006).

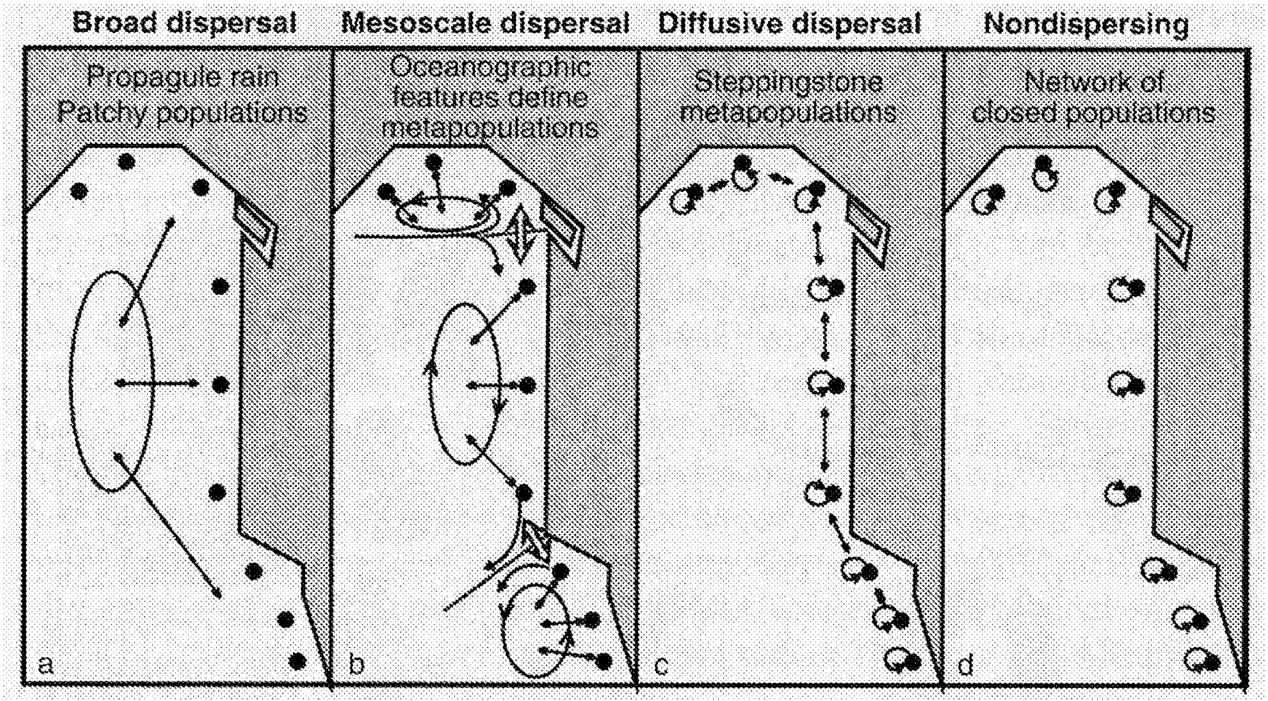


Figure 2.8. Four scenarios for meta population structure (from Gunderson and Vetter 2006).

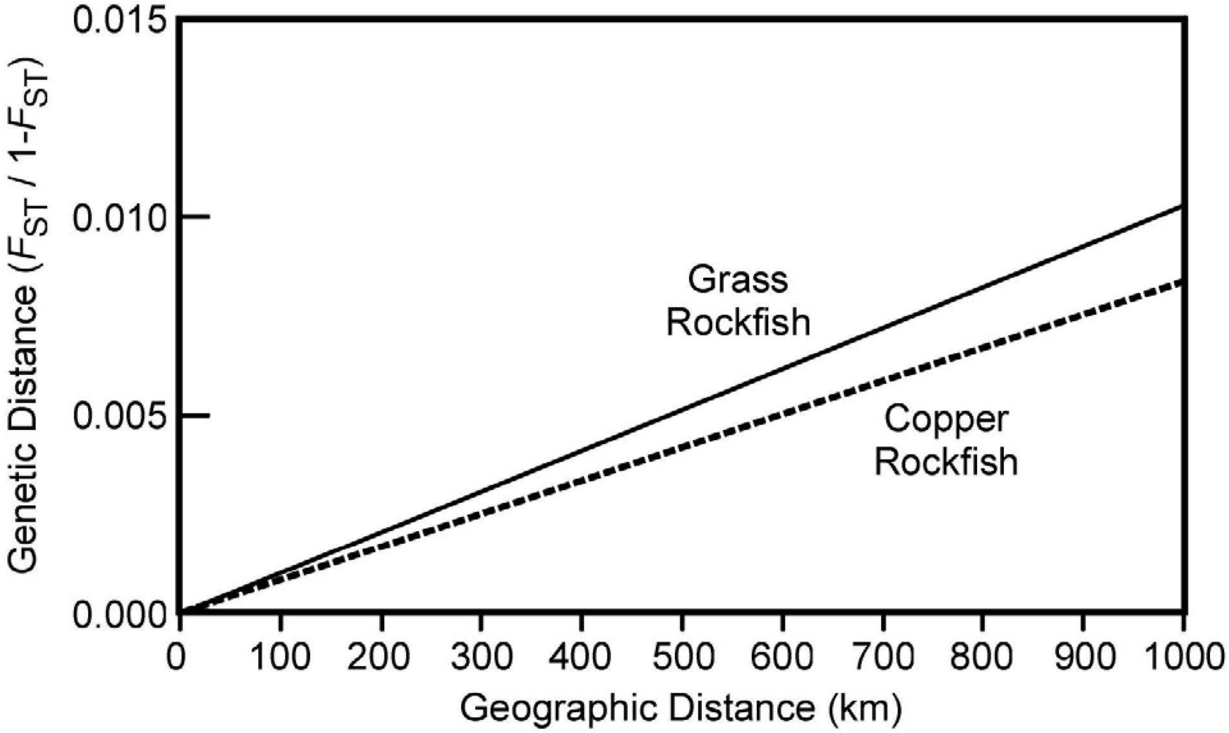


Figure 2.9. Genetic distance as a function of geographic distance for grass and copper rockfish (from Gunderson and Vetter 2006).

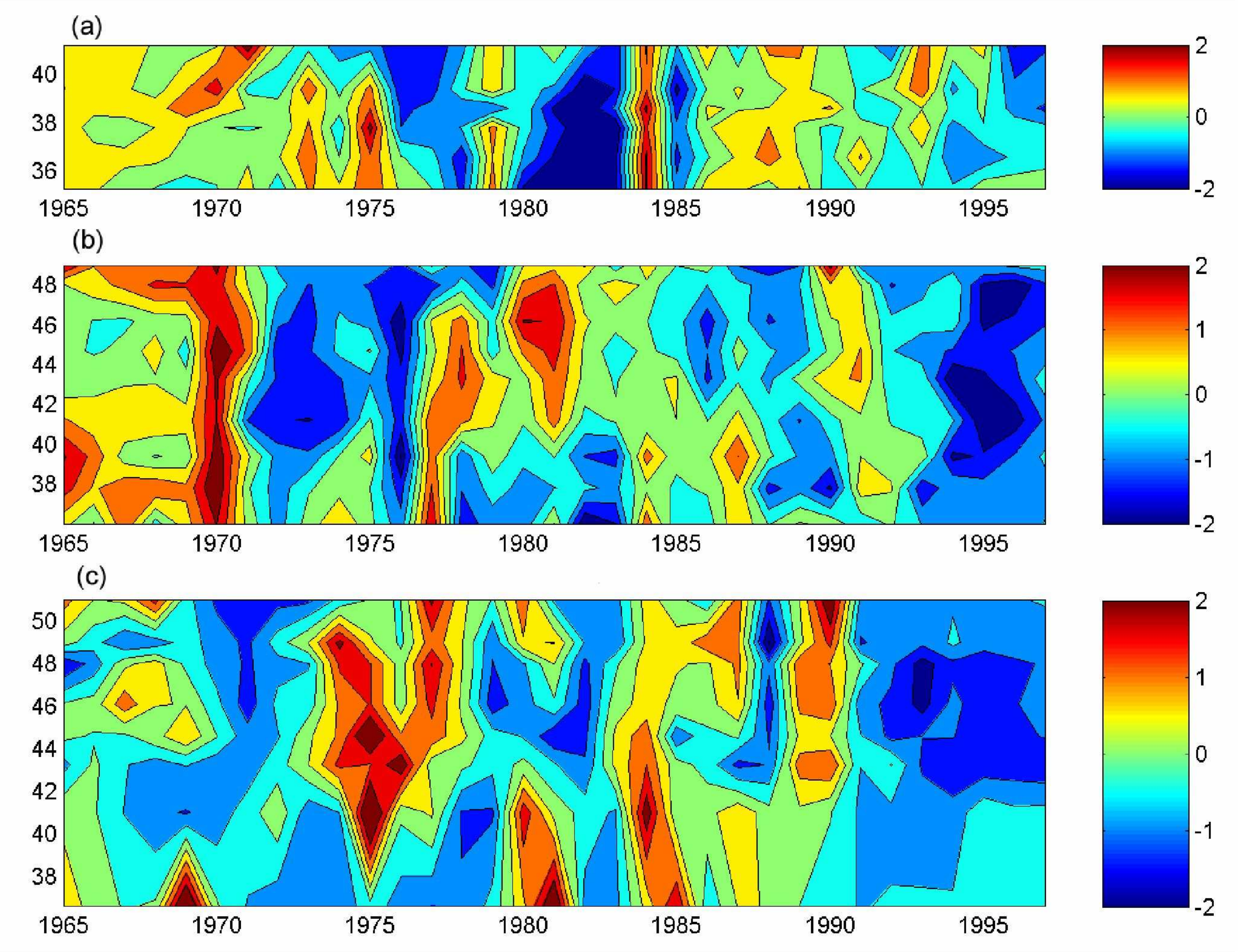


Figure 2.10. Latitudinal recruitment variation of (a) chilipepper, (b) widow and (c) yellowtail rockfish (from Field and Ralston 2004).

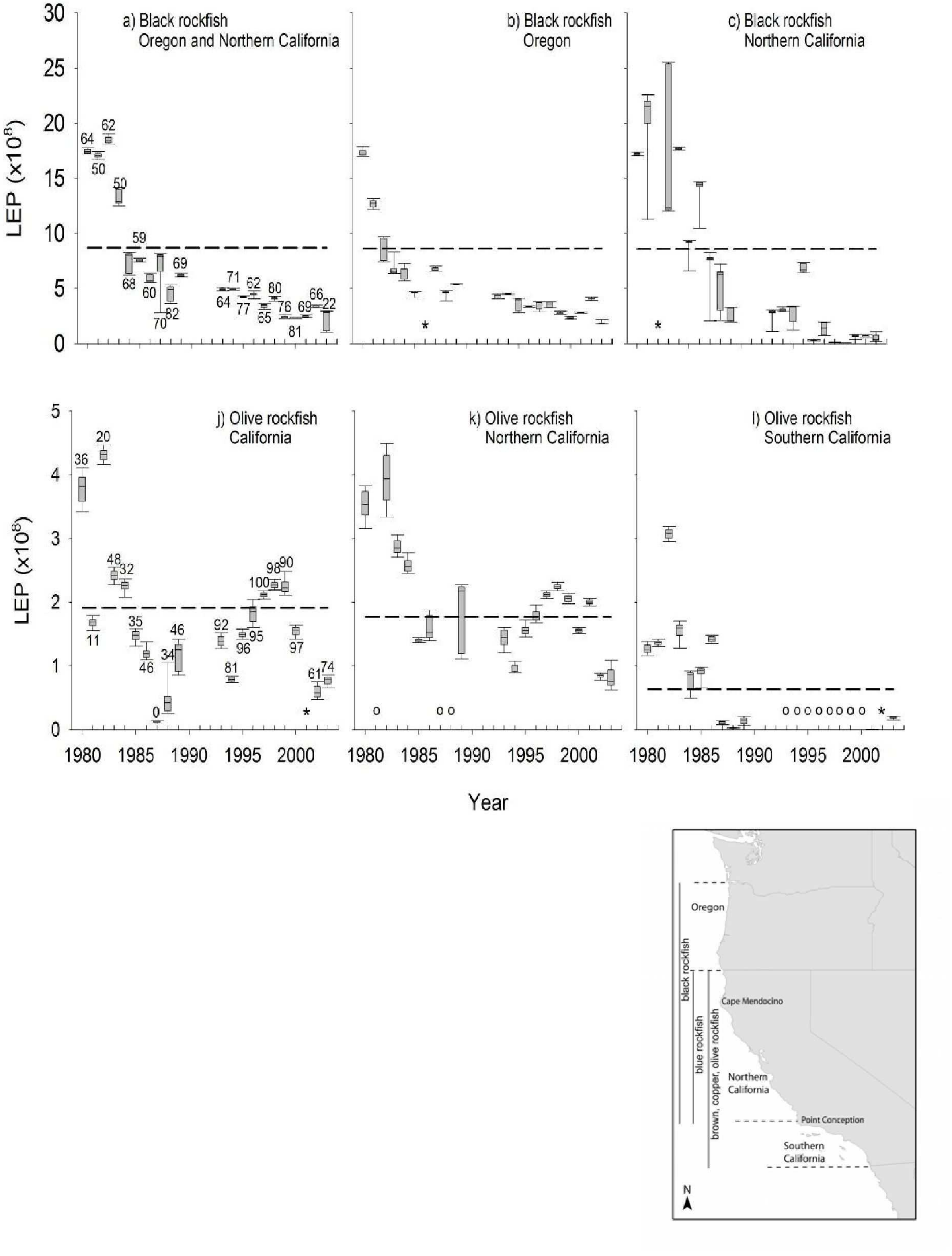


Figure 2.11. Lifetime egg production (LEP) for black and olive rockfish estimated from data over entire range and data decomposed into neighboring regions (from O'Farrell and Botsford 2006).

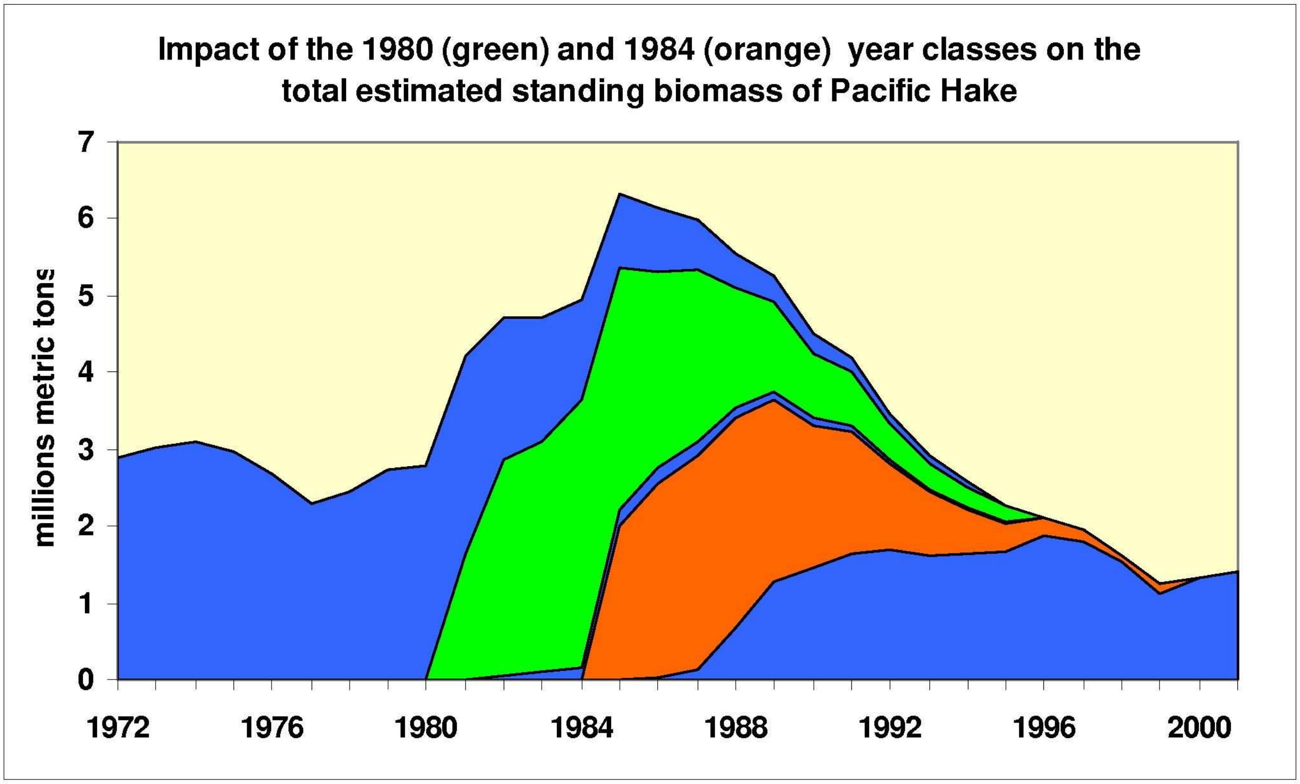


Figure 2.12. Pacific hake biomass trajectory with contributions of two strong year classes (Field and Francis 2006).

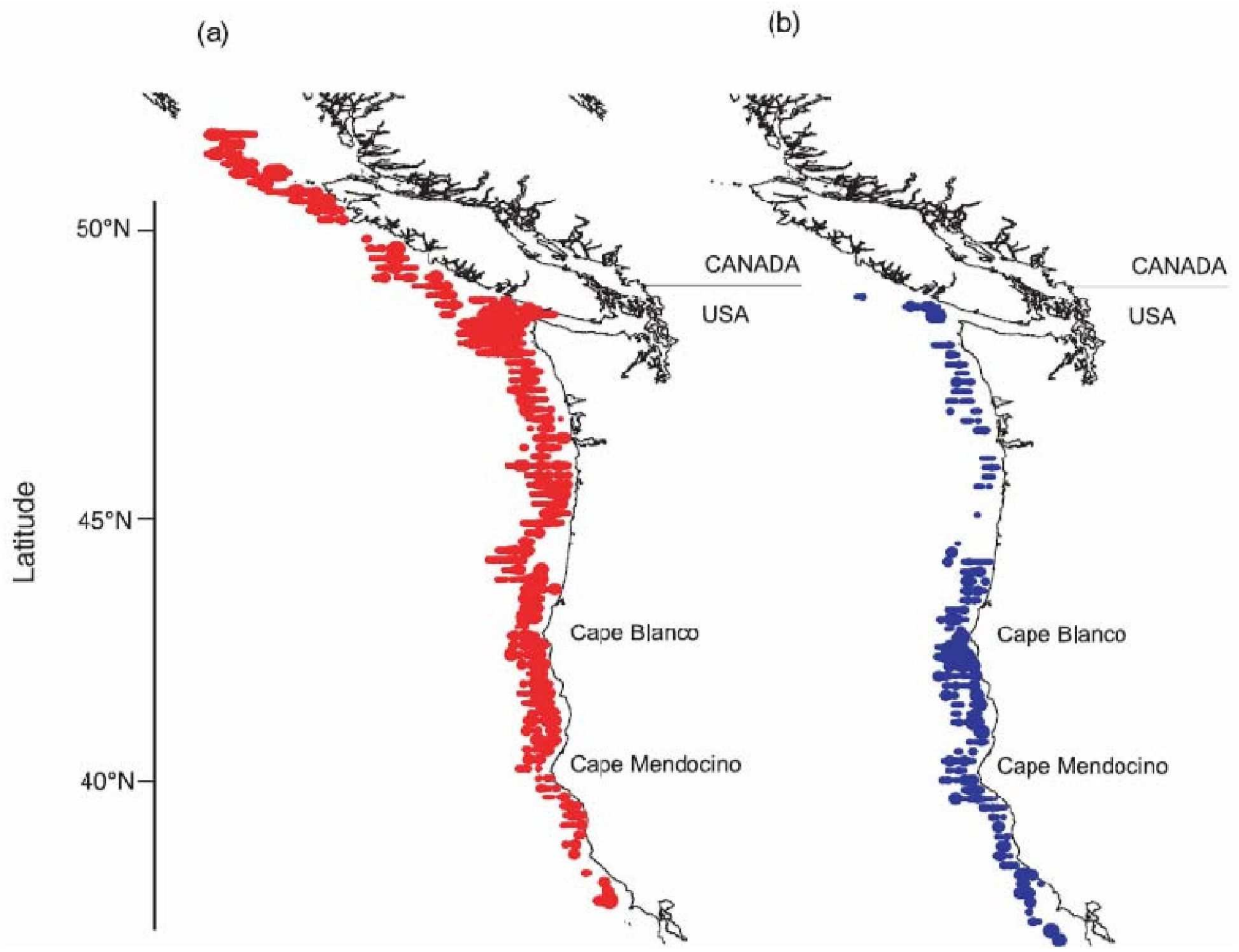


Figure 2.13. Difference in spatial distribution of hake between (a) 1998 and (b) 2001 (from Agostini et al. 2006).

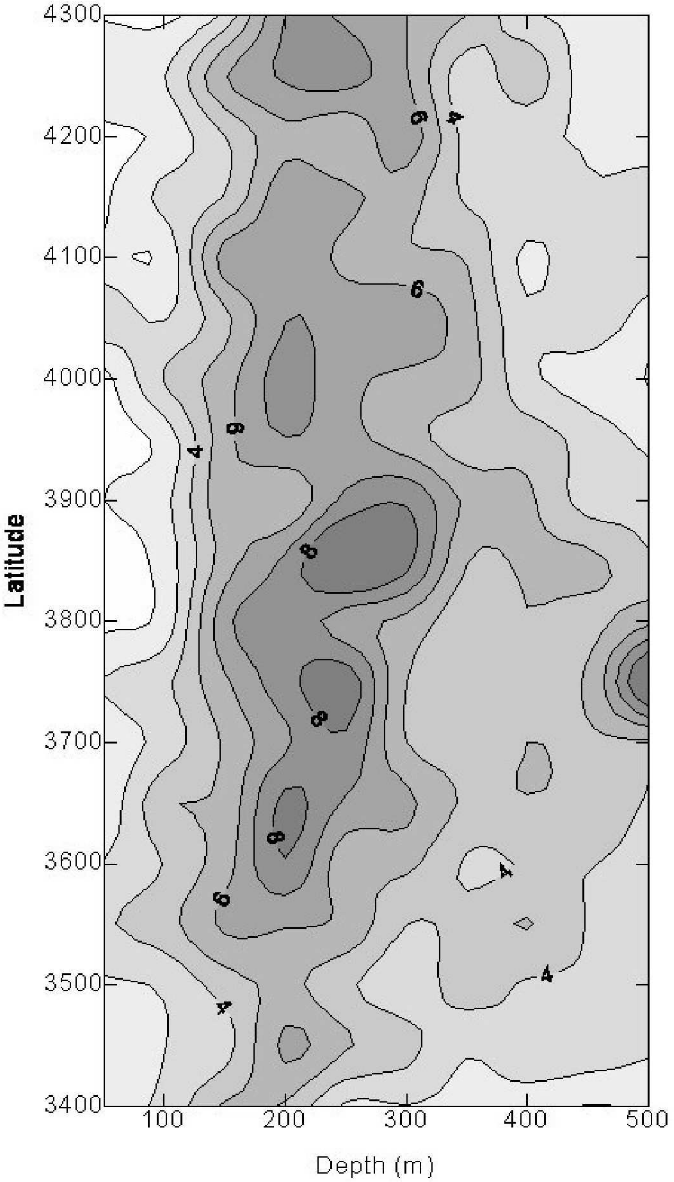


Figure 2.14. Rockfish species diversity by depth from Point Conception to Cape Blanco (from Williams and Ralston 2002).

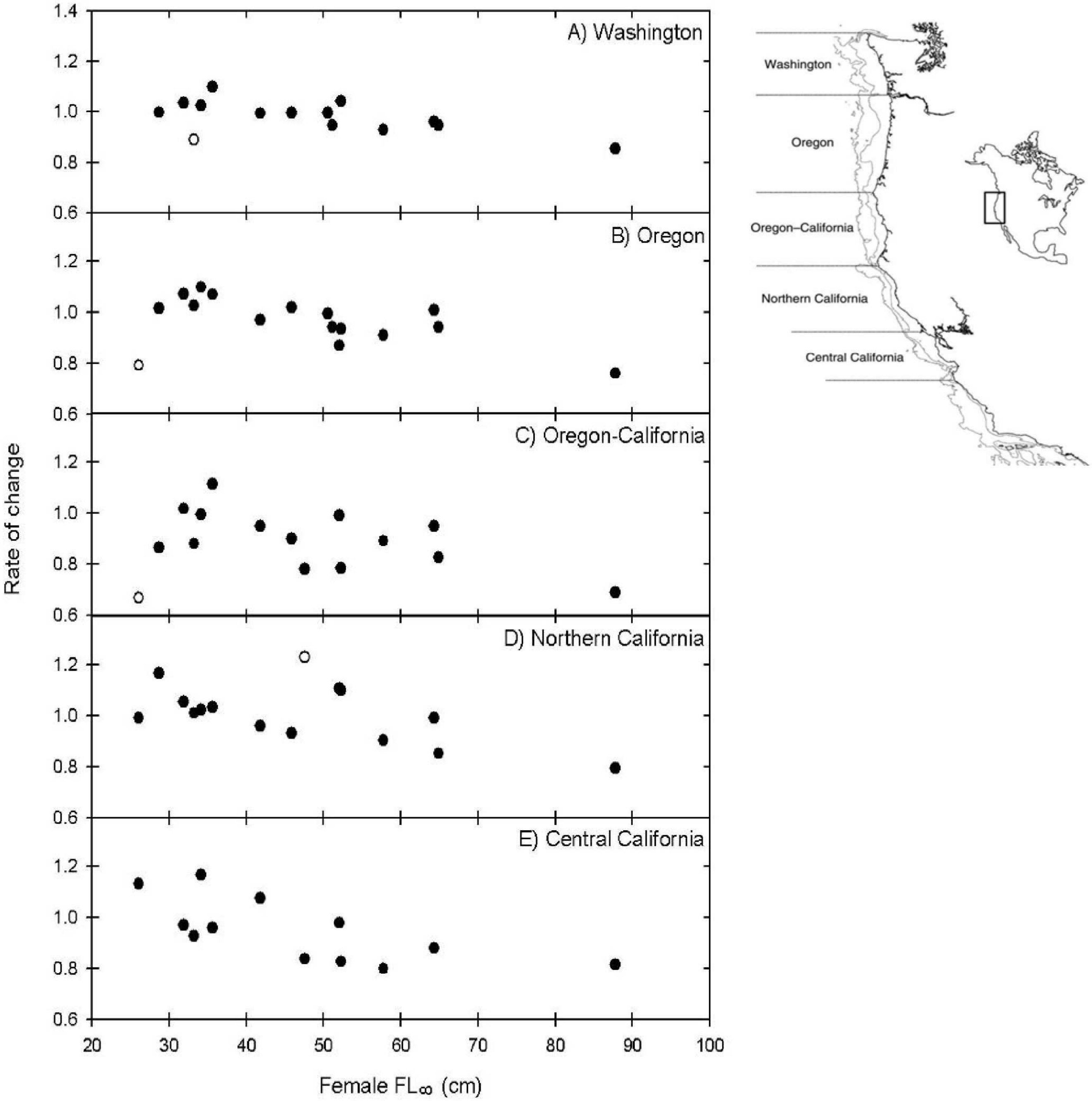


Figure 2.15. Annual percent change in observed shelf rockfish density as a function of maximum female fork length (from Harvey et al. 2006).

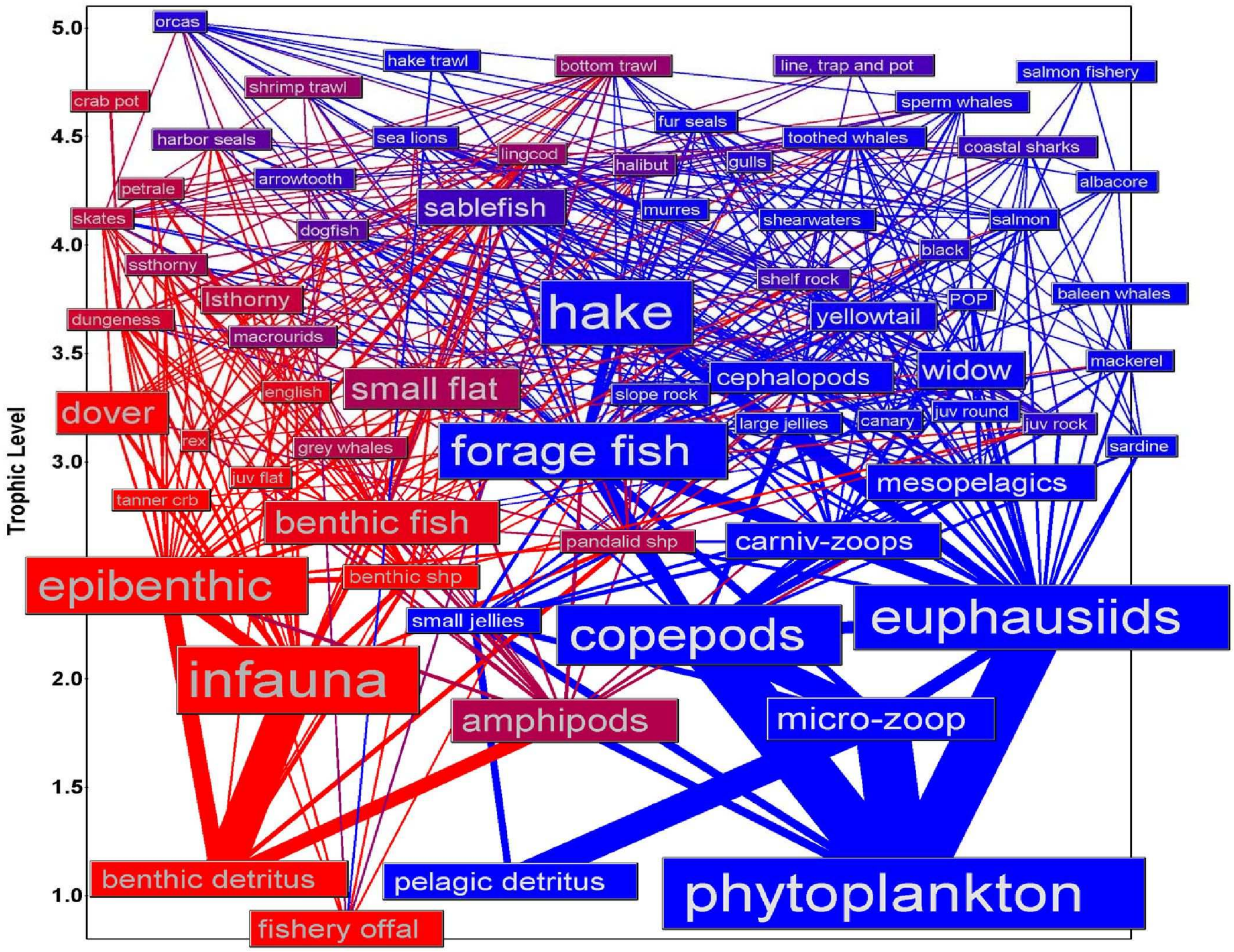


Figure 2.16. Northern California Current benthic (shaded in red) and pelagic (shaded in blue) production pathways (from Field et al. 2006).

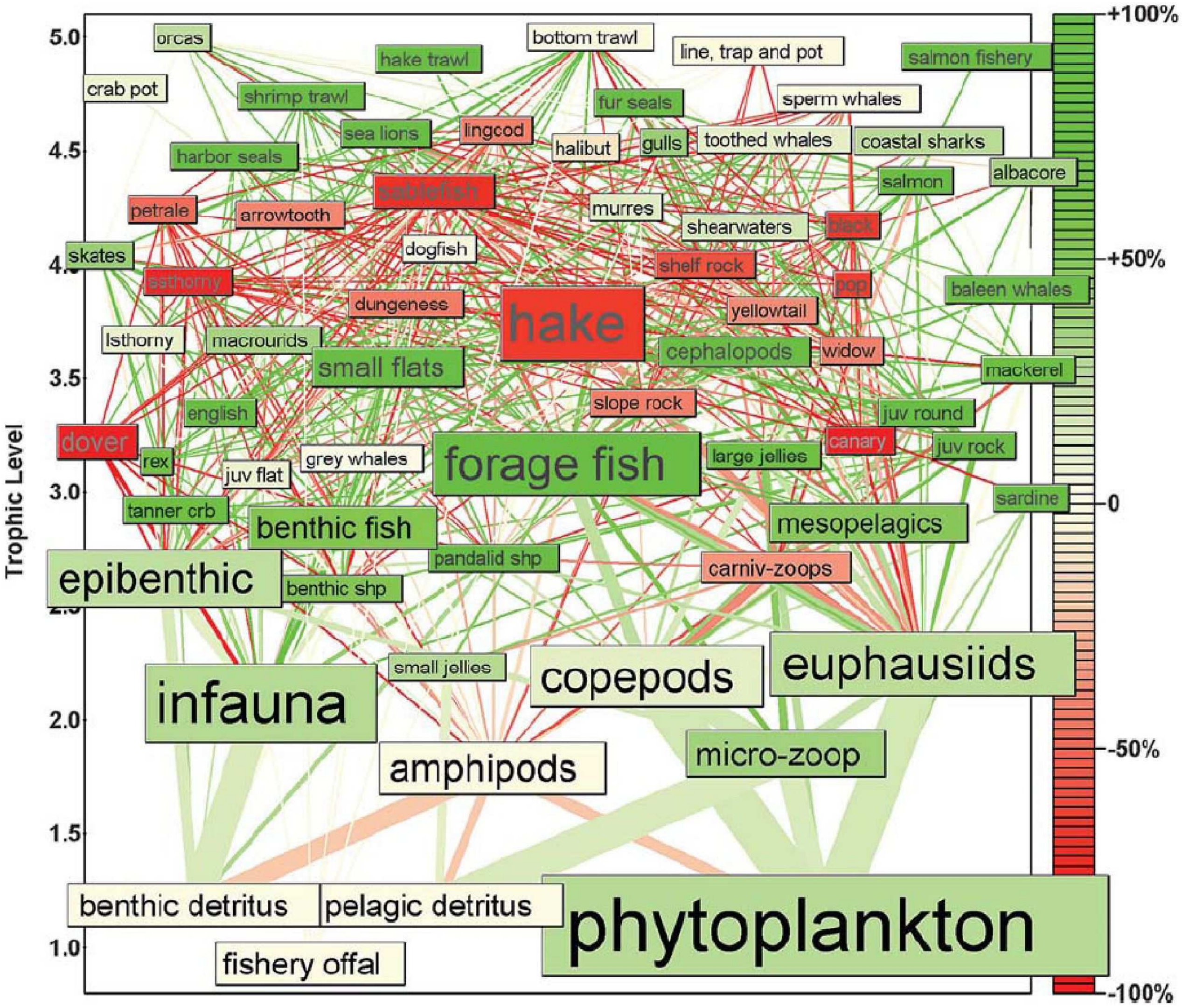


Figure 2.17. Estimated percent change in relative biomass of the significant food web of the Northern California Current ecosystem, 1960–2002 (from Field et al. 2006).

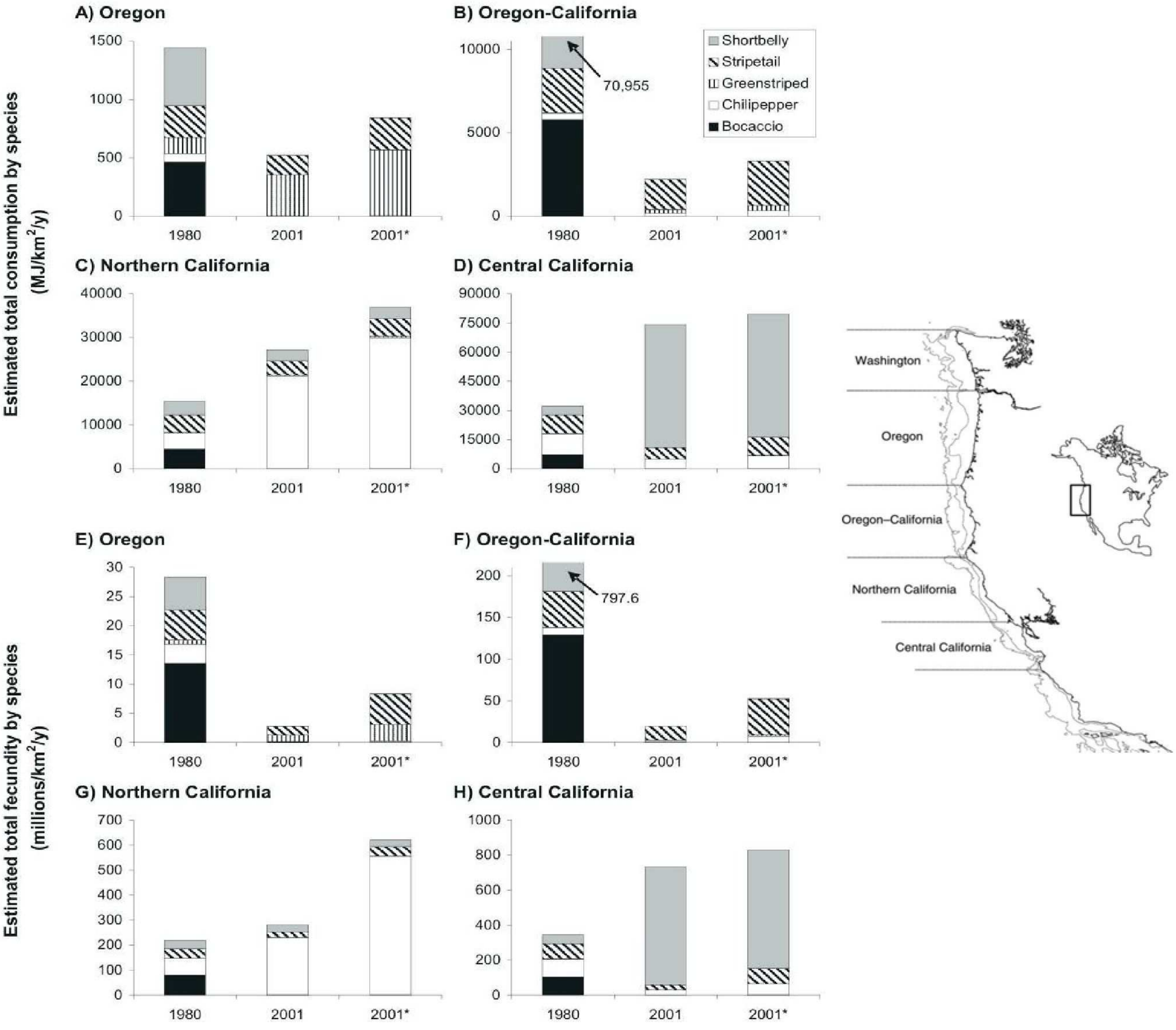


Figure 2.18. Estimates of population consumption and egg production by five populations of the boccacio rockfish assemblage (2001* assumes no change in average rockfish size since 1980) (from Harvey et al. 2006).

	% overlap* of Port Group Harvest Areas																	
Port Group (abbr.)$_i$ / Port Group$_j$	**PS**	**NW**	**SW**	**AS**	**TL**	**NP**	**CB**	**BK**	**CC**	**EK**	**FB**	**BB**	**SF**	**MT**	**MB**	**SB**	**LA**	**SD**
Puget Sound (PS)	-	21																
N. Washington (NW)	13	-	3	3														
SW. Washington (SW)		5	-	**66**	2	15												
Astoria (AS)		1	17	-	4	25	1											
Tillamook (TL)			4	**29**	-	**38**												
Newport (NP)			6	**38**	9	-	**33**	2										
Coos Bay (CB)				2		**26**	-	**36**	2	1								
Brookings (BK)						2	**57**	-	23	14								
Crescent City (CC)							5	**31**	-	**58**								
Eureka (EK)							1	14	**46**	-	9							
Fort Bragg (FB)										11	-	11						
Bodega Bay (BB)											12	-	**37**	2				
San Francisco (SF)												**34**	-	**35**				
Monterey (MT)												5	-	-				
Morro Bay (MB)															-	9		
Santa Barbara (SB)															13	-	10	
Los Angeles (LA)																13	-	9
San Diego (SD)																	12	-

* % overlap = % of Port Group$_i$ harvest area grid cells occupied by Port Group$_j$ harvest area grid cells

Table 3.1. Percent Overlap of Harvest Areas of Each Landing Port Group for the West Coast Commercial Groundfish Fleet, 2000. Overlap defined as %of Port Group$_i$ harvest area grid cells (see Figure 3.3) occupied by Port Group$_j$ harvest area grid cells. Red font indicates values >25% Source: derived from Figure 3.3, which are adapted from Ecotrust 2003.

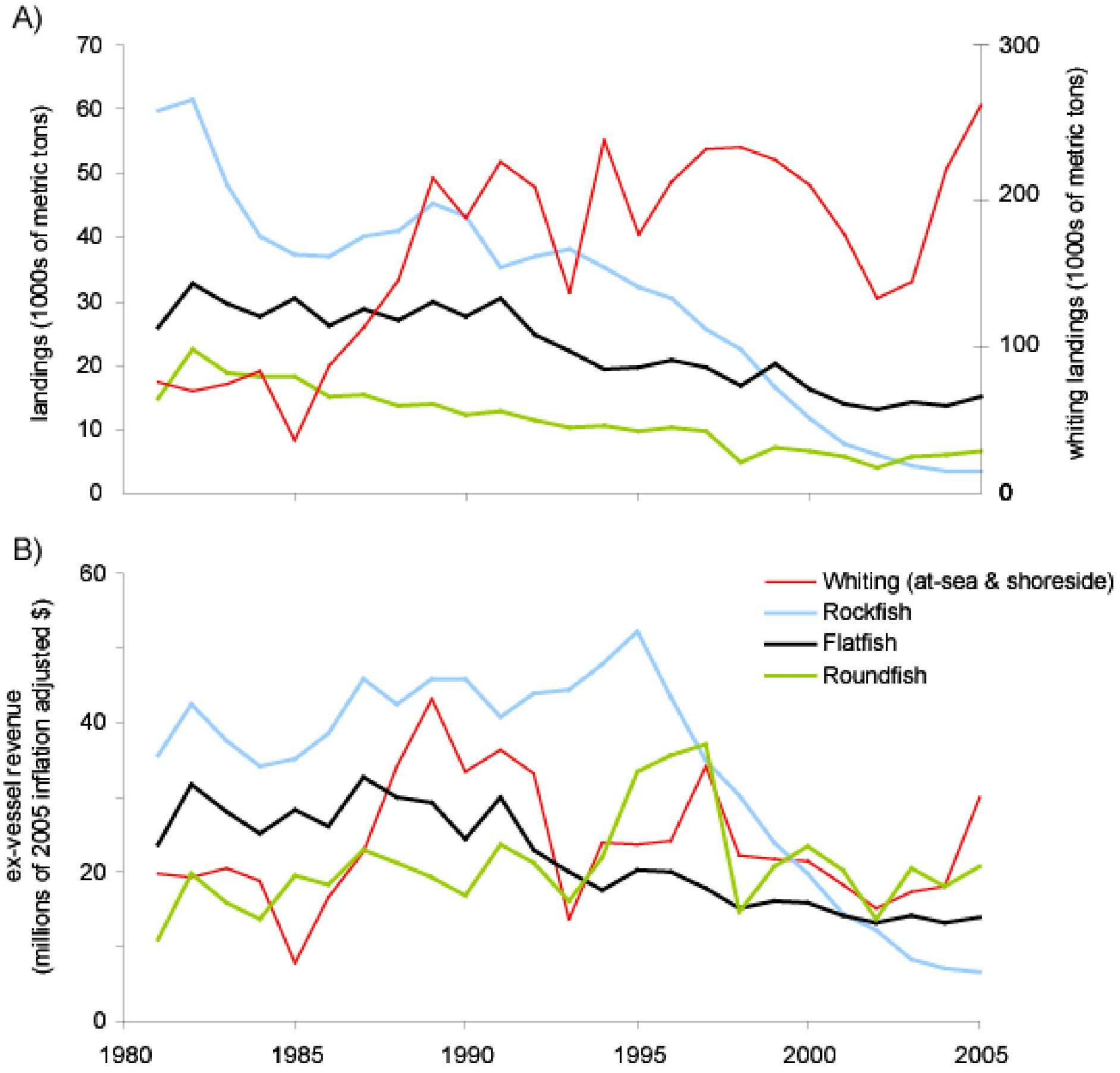


Table 3.1. U.S. West Coast commercial fisheries (WA, OR, CA: 0-200 miles from shore) total shoreside and at-sea A) landings (1000s of round weight metric tons) and B) ex-vessel revenue (millions of 2005 inflation adjusted $) by groundfish species group, 1981-2005. Includes tribal commercial data. Source: adapted from PFMC and NMFS 2006, Tables 7-2a, c.

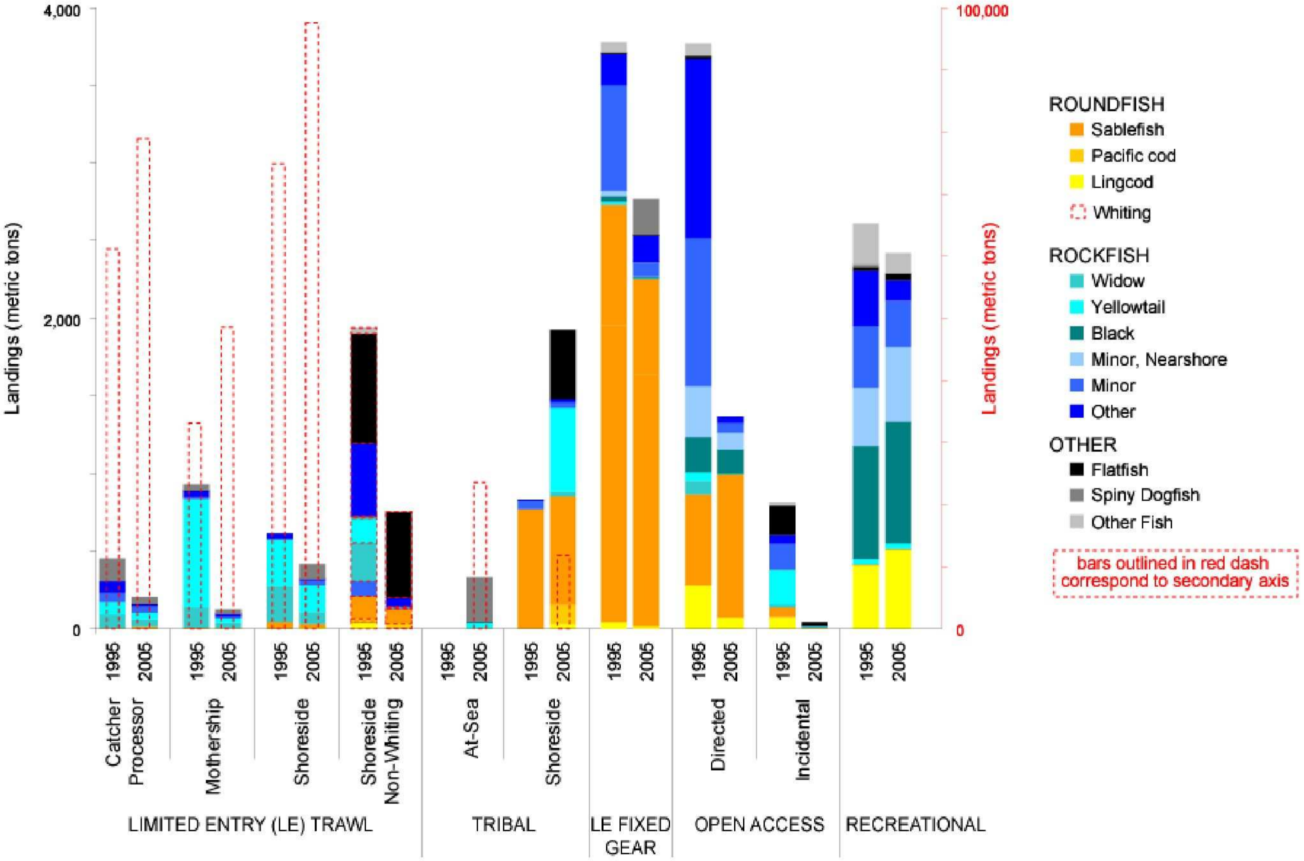


Figure 3.2. U.S. West Coast fisheries landings (metric tons) by species or species group (roundfish, rockfish, flatfish, other) and sector (Limited-entry (LE) trawl, tribal, LE fixed gear, open access, recreational) and subsector (e.g., Tribal: at-sea or shoreside); 1995, 2005. Bars outlined in red dash correspond to secondary axis. Source: adapted from PFMC 2007, Table 1.

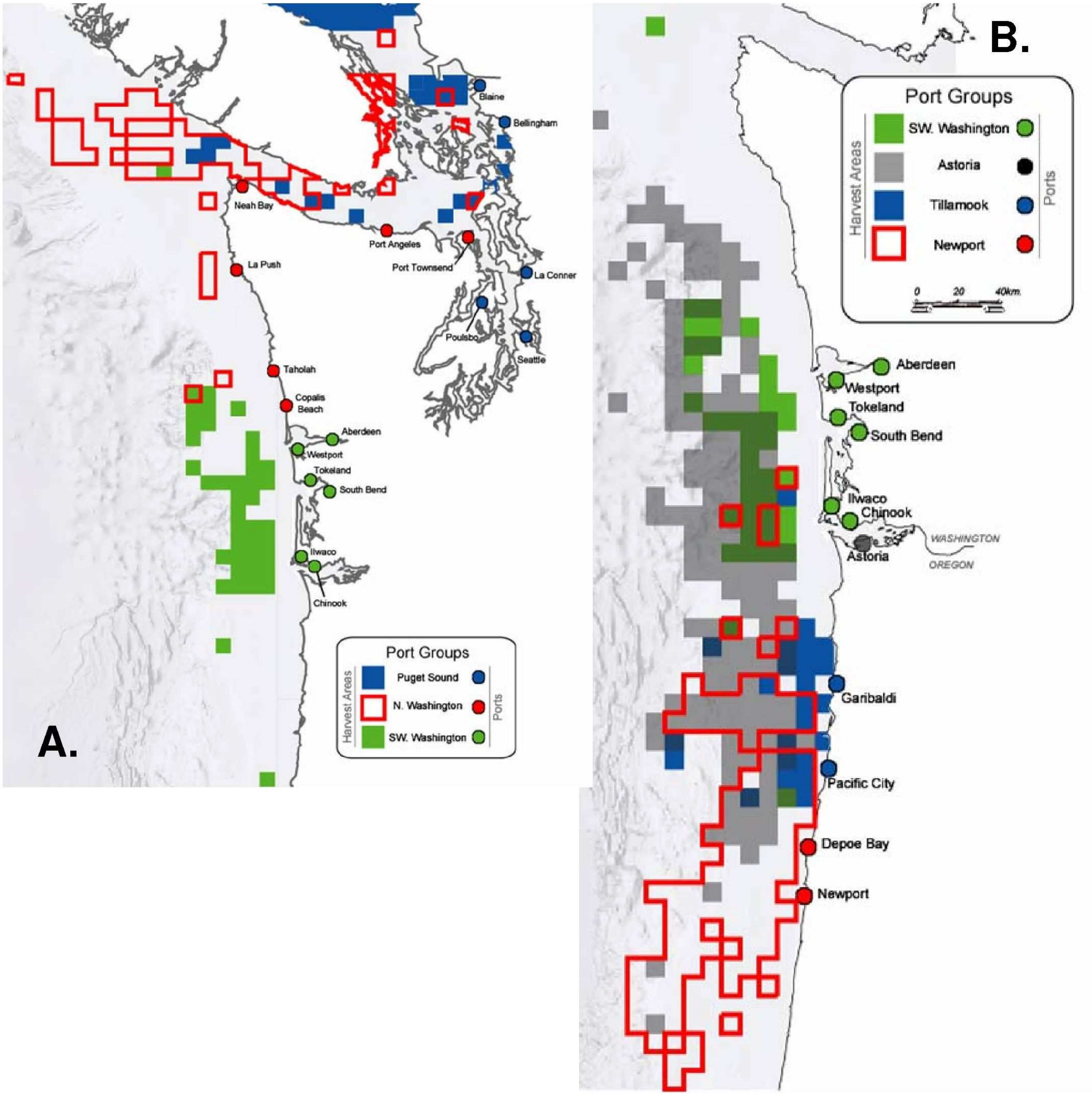


Figure 3.3. Harvest Areas of Each Landing Port Group for the West Coast Commercial Groundfish Fleet, 2000. Harvest areas modeled from fish tickets for trawl and non-trawl sectors. A) Washington State and Puget Sound Coast; B) N. Oregon and SW. Washington Coast. Source: adapted from Ecotrust 2003.

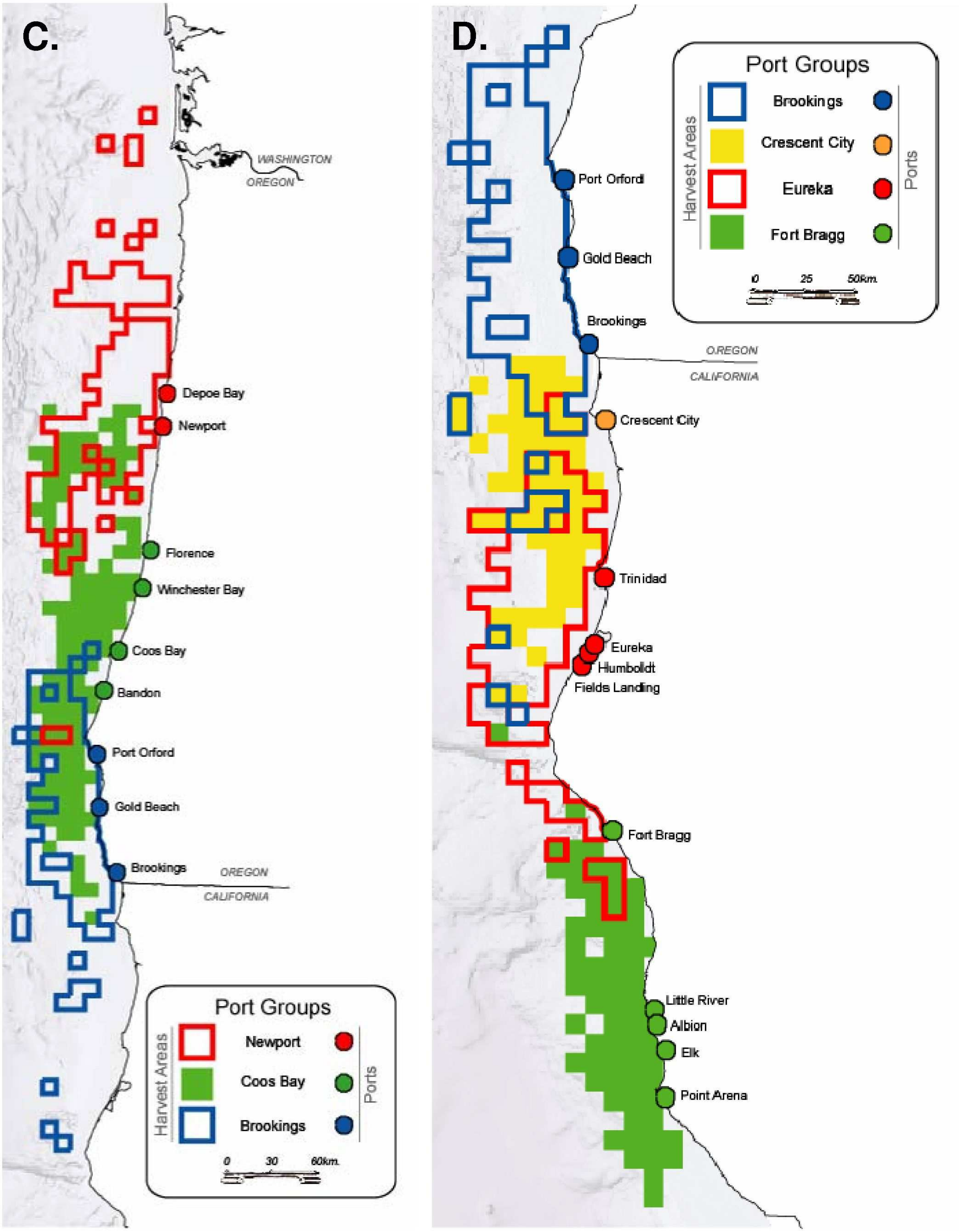


Figure 3.3 (cont.). C) S. Oregon (and N. California) Coast; D) N. California (and S. Oregon) Coast.

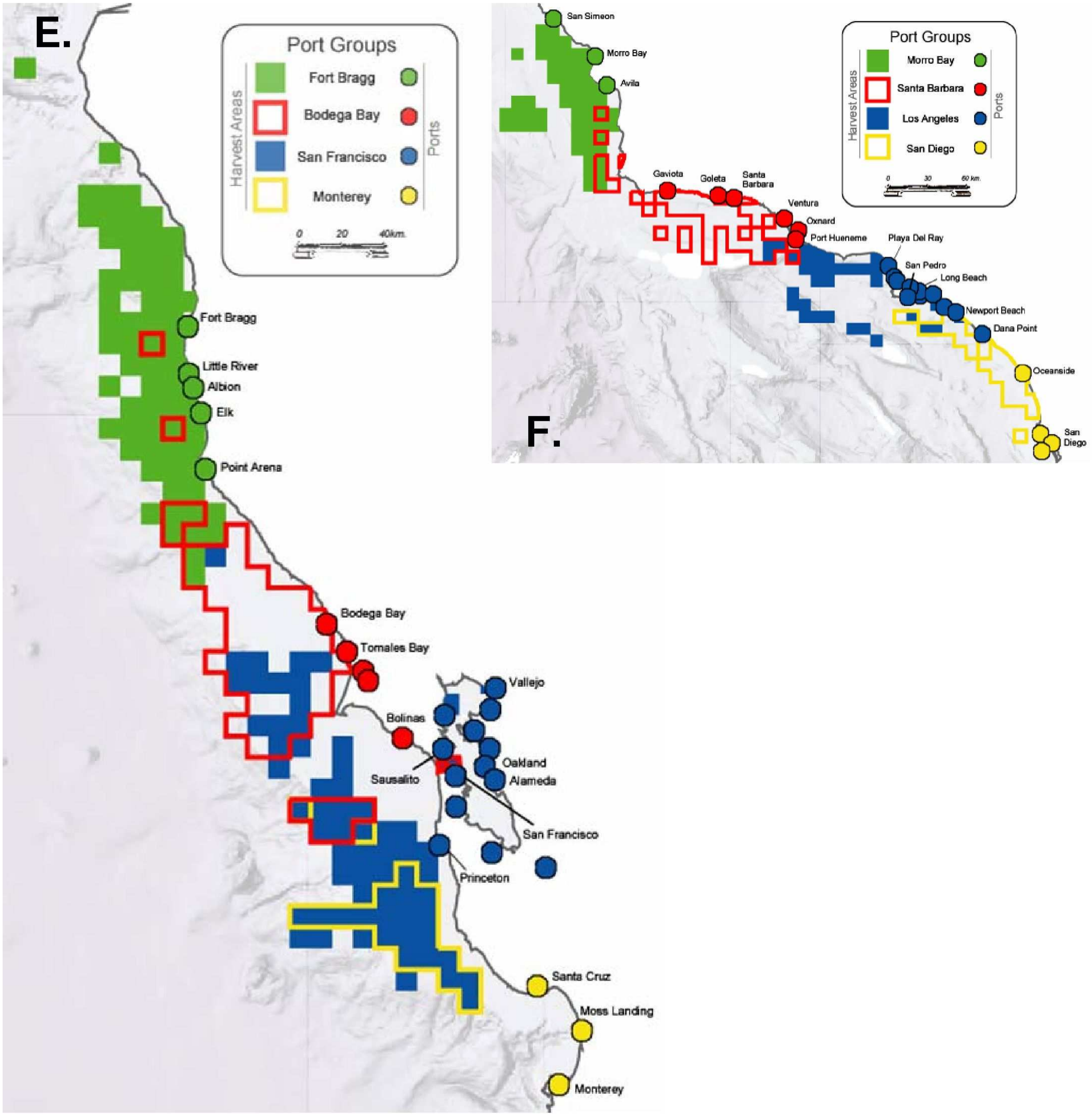


Figure 3.3 (cont.). E) Mid-Coast California; F) Southern California Coast.

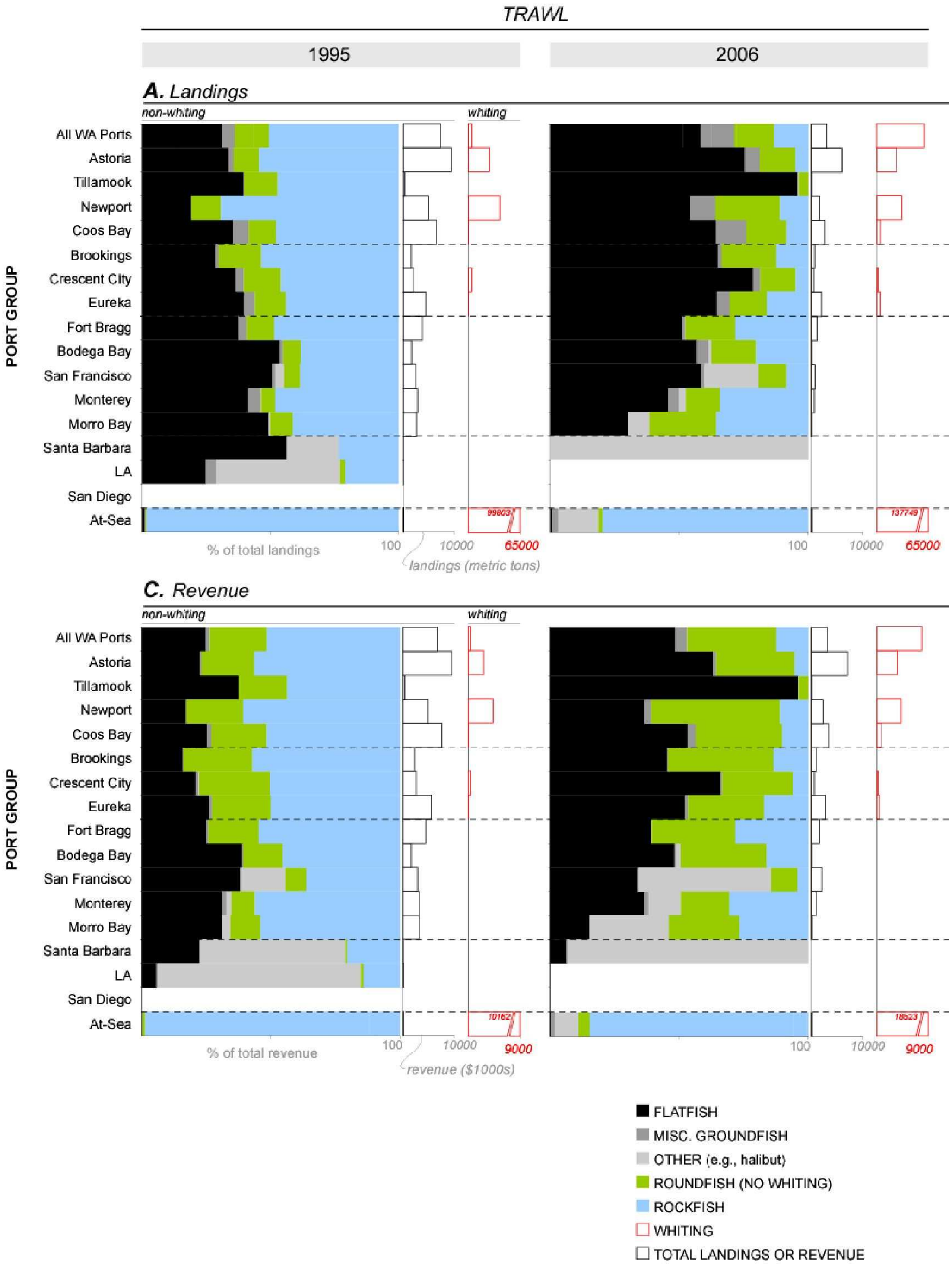


Figure 3.4. Landed groundfish catch (A & B; metric tons) and ex-vessel revenue (C & D; $1000s) by port and species groups for 1995 and 2006 trawl (limited-entry (LE) and tribal) and non-trawl (LE fixed gear and open access) sectors. Solid bars are proportion by species group of port group total, outlined bars are nominal values (metric tons or $1000s) by port group. Major biogeographic boundaries (Cape Blanco, Cape Mendocino, Point Conception) included for reference. Source: PSMFC 2007, Port Group Reports 010W, 010Wtwl, 020W, 020Wtwl.

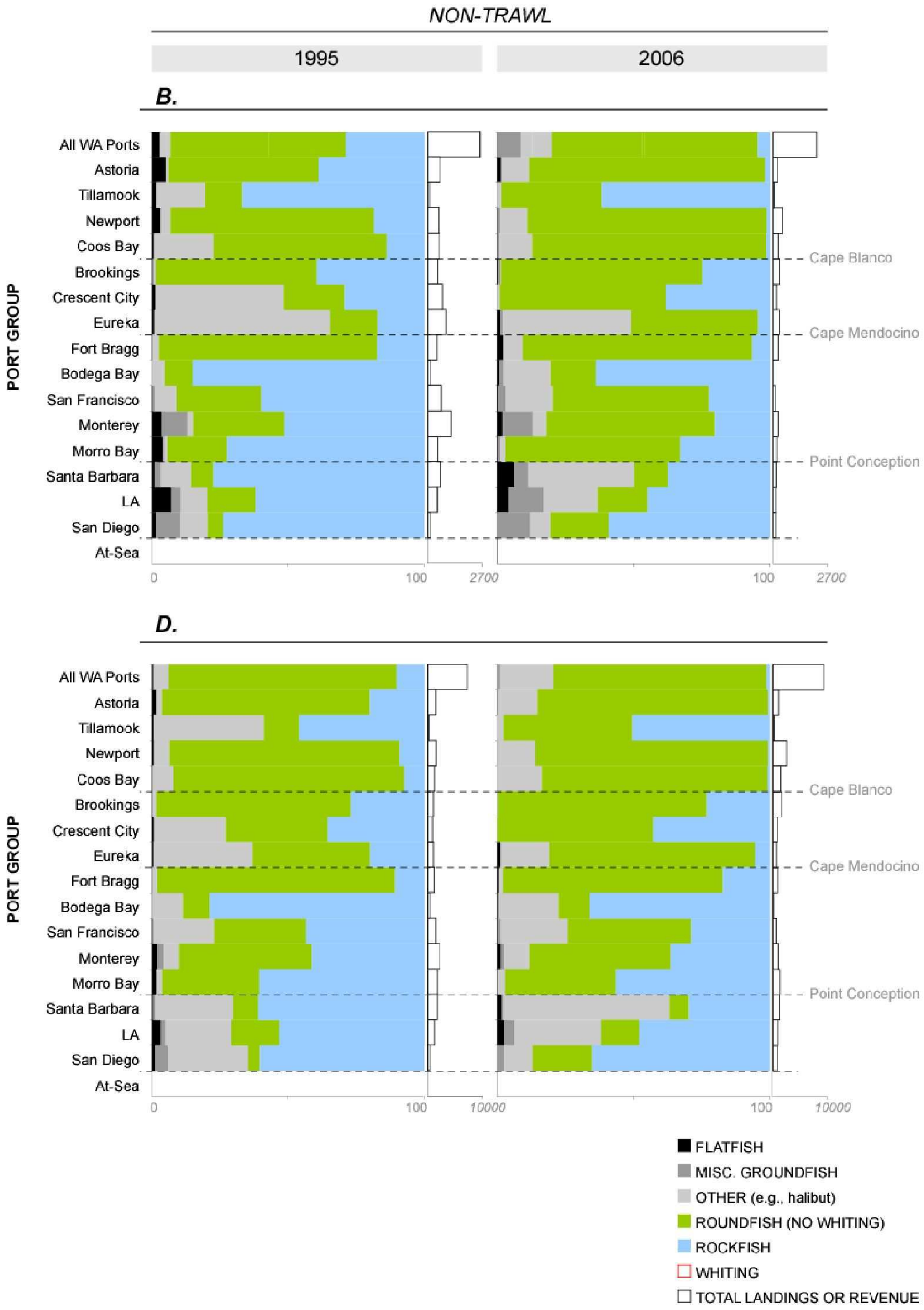


Figure 3.4. (cont.)

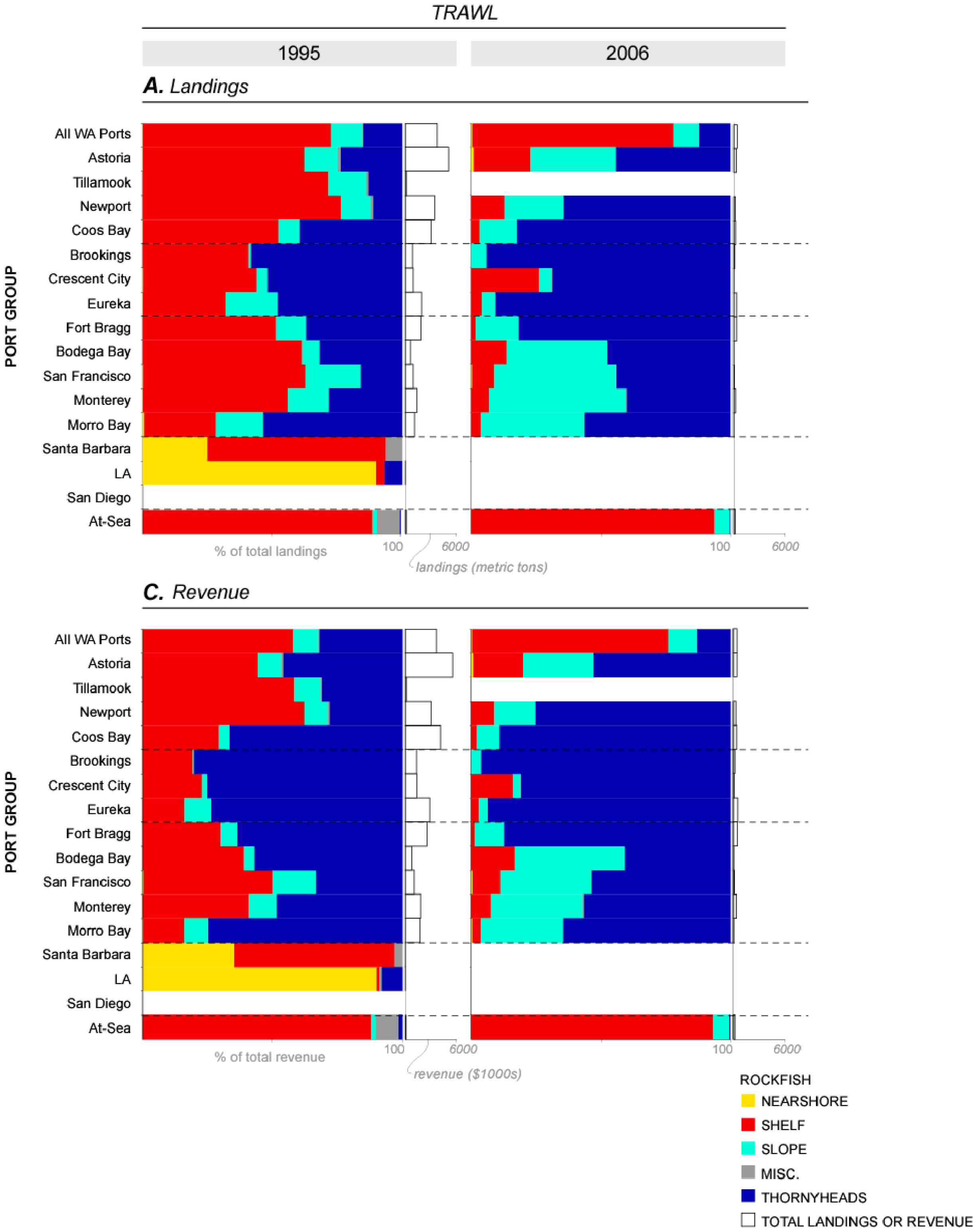


Figure 3.5. Landed rockfish catch (A & B; metric tons) and ex-vessel revenue (C & D; $1000s) by port and species groups for 1995 and 2006 trawl (limited-entry (LE) and tribal) and non-trawl (LE fixed gear and open access) sectors. Solid bars are proportion of port group total, outlined bars are nominal values (metric tons or $1000s) by port group. Major biogeographic boundaries (Cape Blanco, Cape Mendocino, Point Conception) included for reference. Source: PSMFC 2007, Port Group Reports 010W, 010Wtwl, 020W, 020Wtwl.

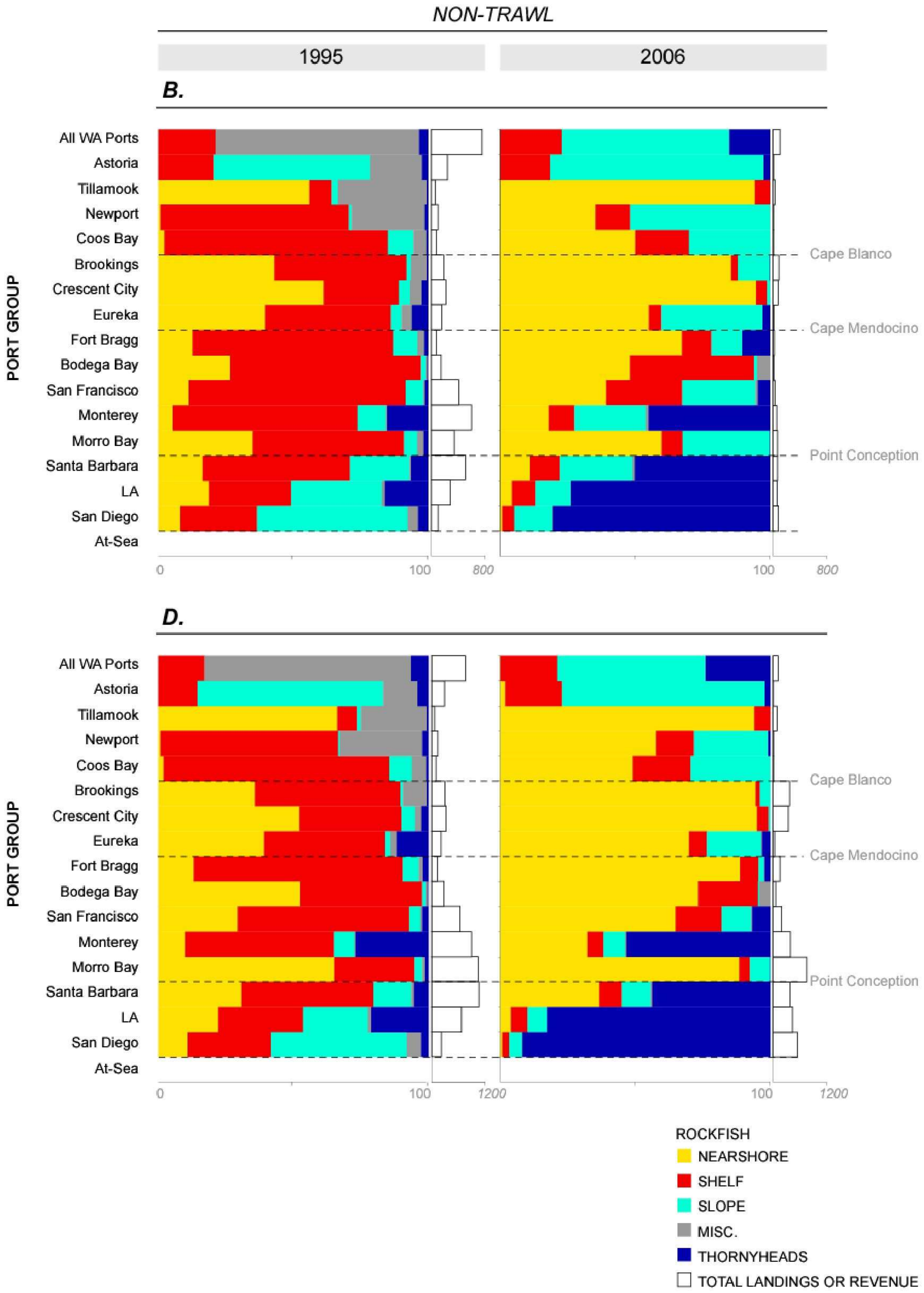


Figure 3.5. (cont.)

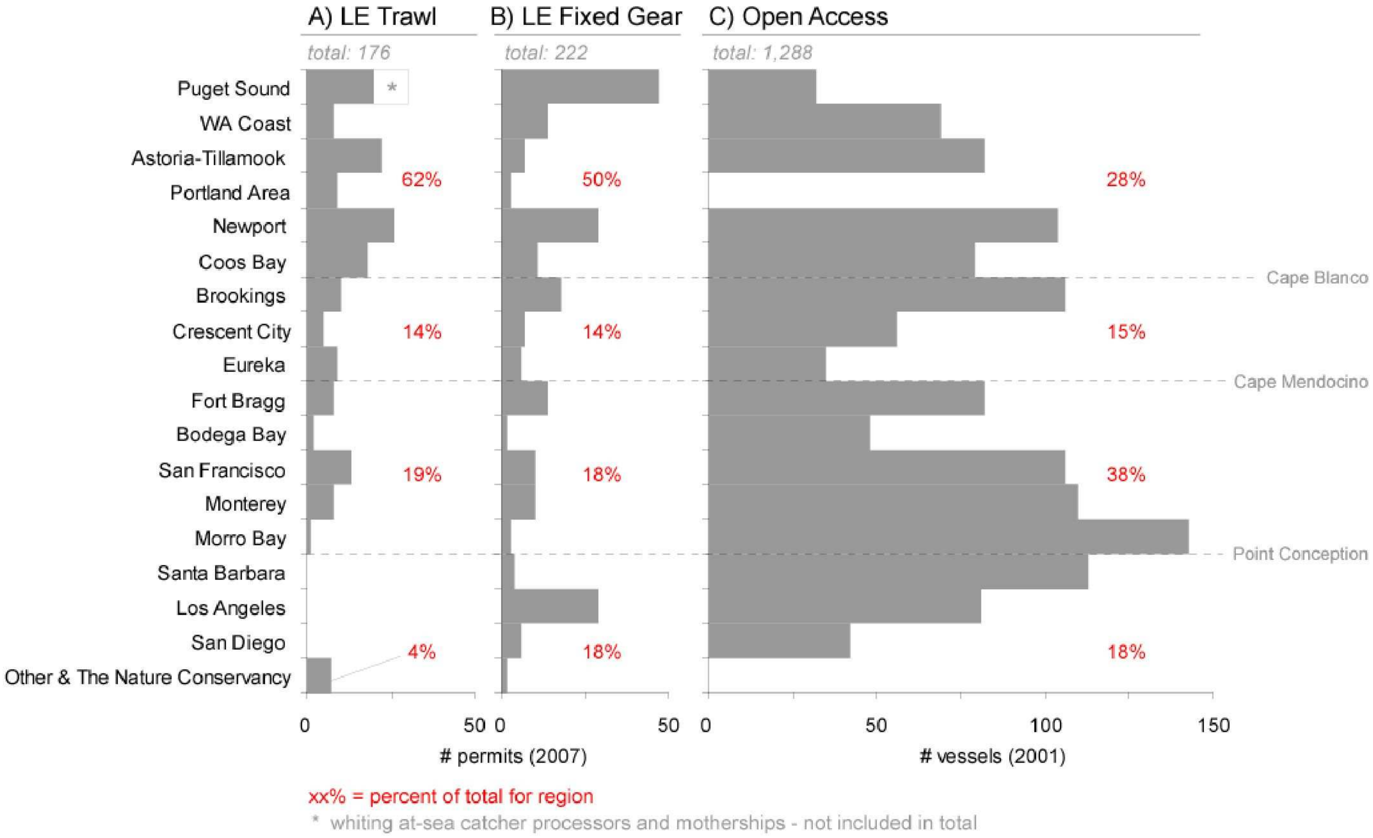


Figure 3.6. Participation in commercial groundfish fishery by port group for: A) Limited-entry (LE) trawl and B) LE fixed gear 2007 permit holders, and C) Open Access 2001 vessels. Major biogeographic boundaries (Cape Blanco, Cape Mendocino, Point Conception) included for reference. Percent of sector specific region (e.g., Cape Blanco to Cape Mendocino) total shown in red. Sources: A) and B) NMFS 2007; C) PFMC 2004, Table 8-4.

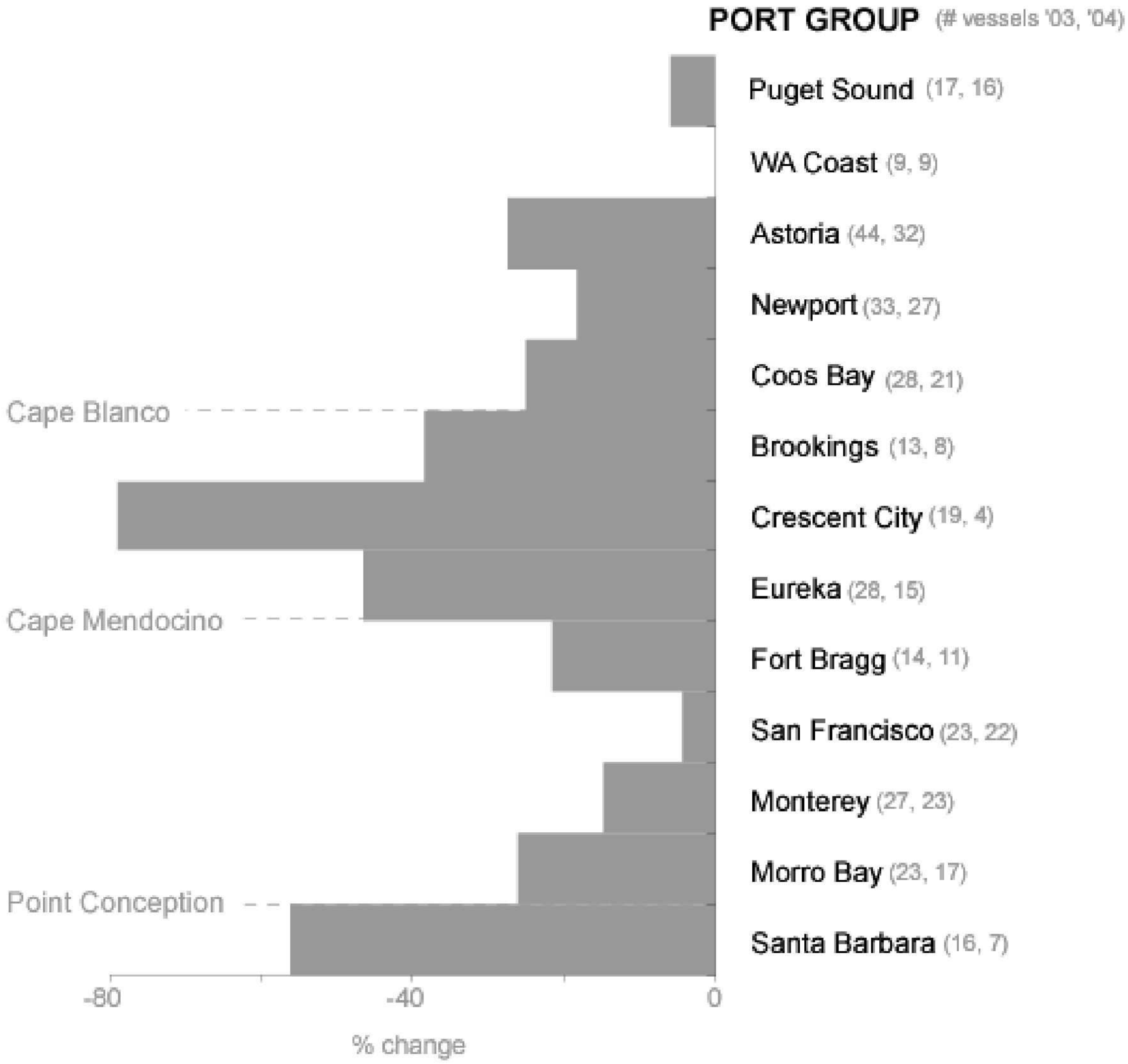
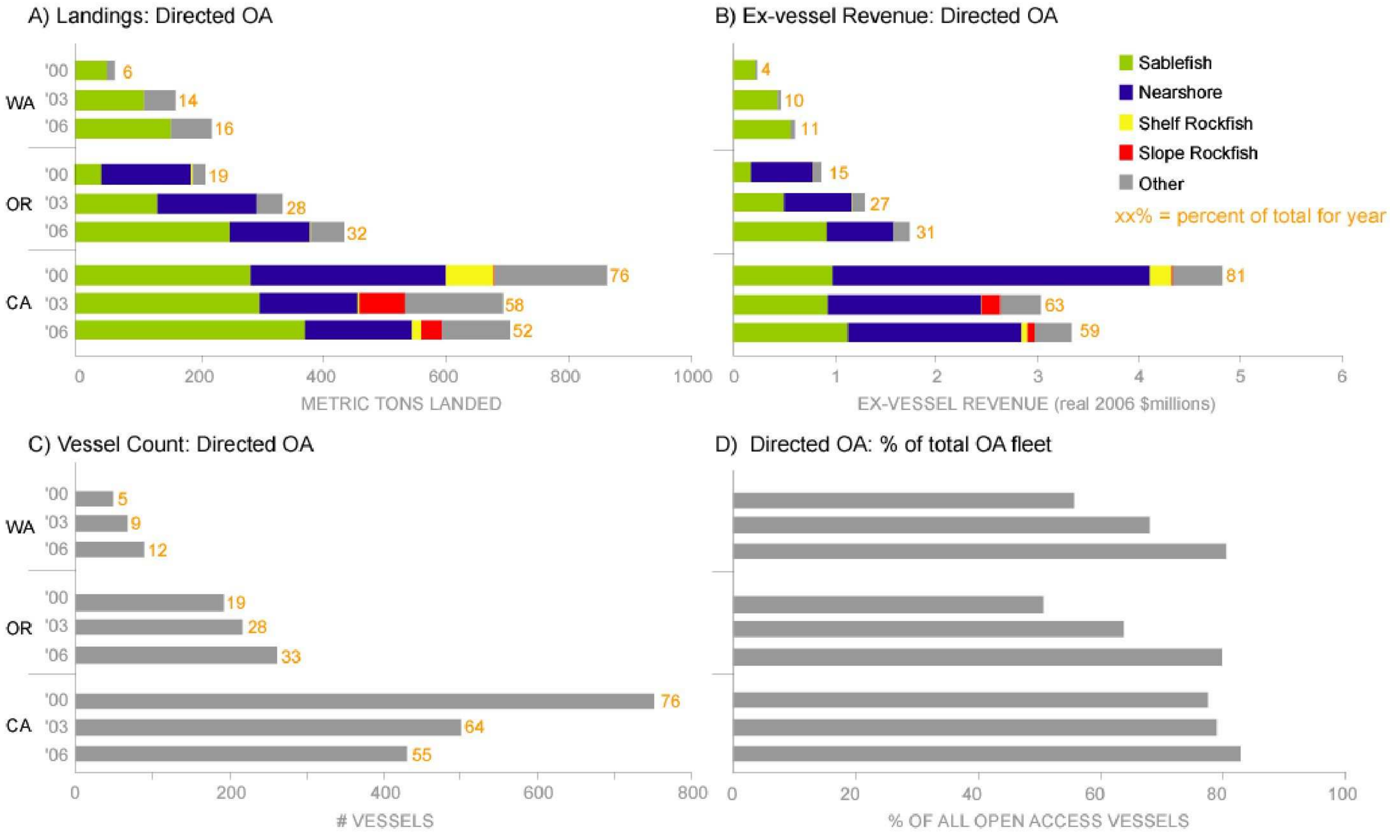


Figure 3.7. Percent change from 2003 to 2004 in number of trawl vessels landing non-whiting groundfish. Limited-entry trawl buyback program completed in 2003. Nominal vessel counts for 2003 and 2004 shown in grey next to port group name. Major biogeographic boundaries (Cape Blanco, Cape Mendocino, Point Conception) included for reference. Source: adapted from PFMC and NMFS 2006, Table 7-10.



A) Landings: Directed OA

B) Ex-vessel Revenue: Directed OA

C) Vessel Count: Directed OA

D) Directed OA: % of total OA fleet

Figure 3.8. Directed open access fleet metrics for Washington (WA), Oregon (OR), and California (CA) for years 2000, 2003, and 2006. A) landings (metric tons) and B) ex-vessel revenue ($millions) by species group, C) count of vessels, and D) percent of total open access fleet. Percent of total for year by state shown in orange. Source: CDFG 2007, Table 6.

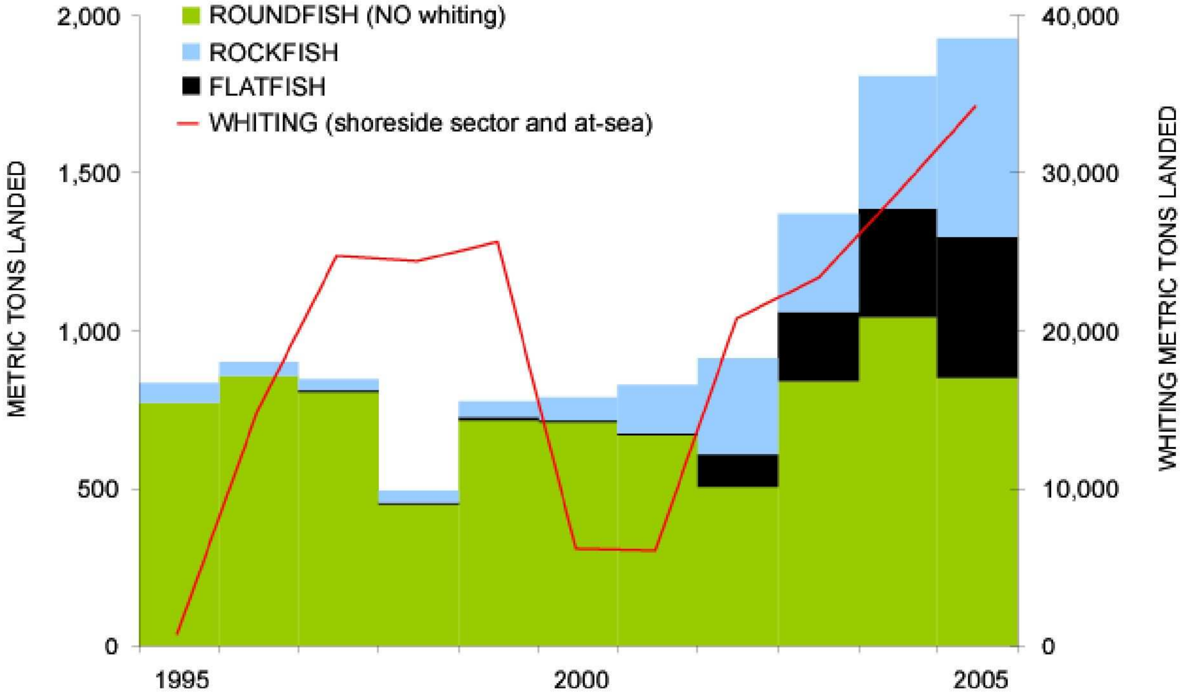


Figure 3.9. Tribal sector landings (at-sea and shoreside) of West Coast groundfish by species group, 1995-2005. Source: adapted from PFMC and NFMS 2006, Table 7-33.

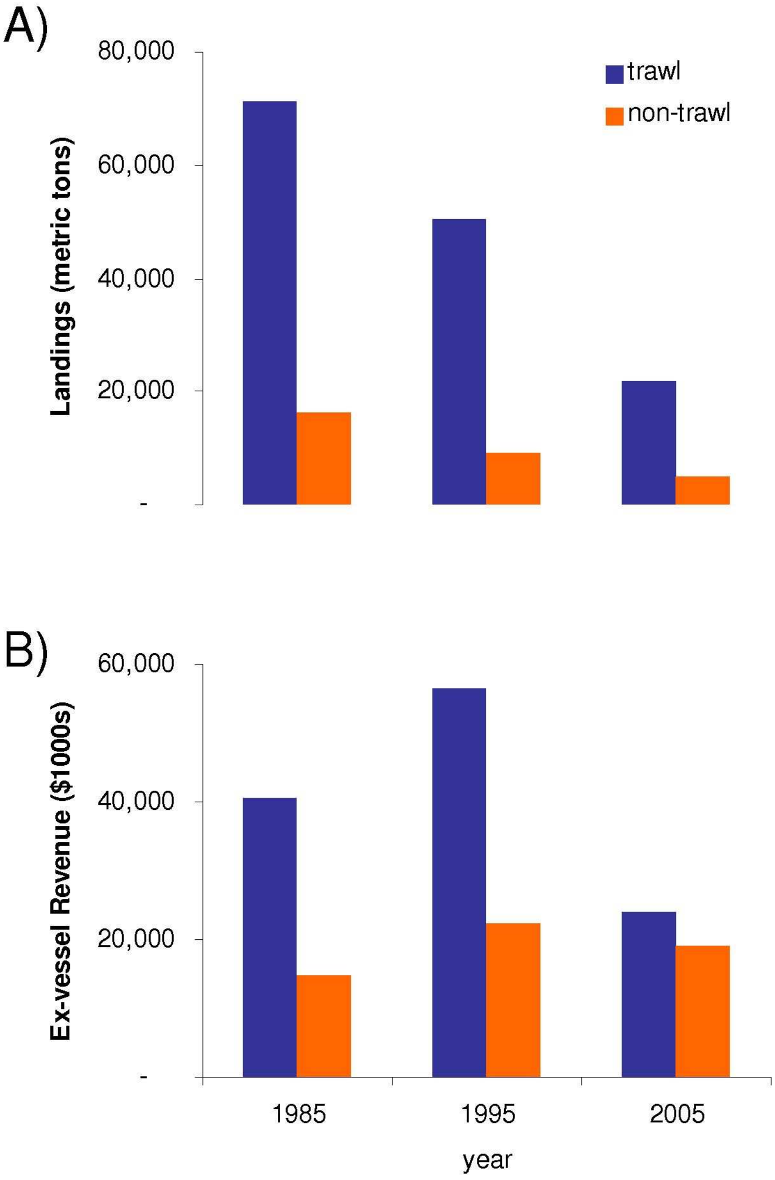


Figure 3.10. Trawl and Non-trawl A) landed non-whiting groundfish catch (metric tons) and B) ex-vessel revenue ($1000s); 1985, 1995, 2005. Source: PSMFC 2007.

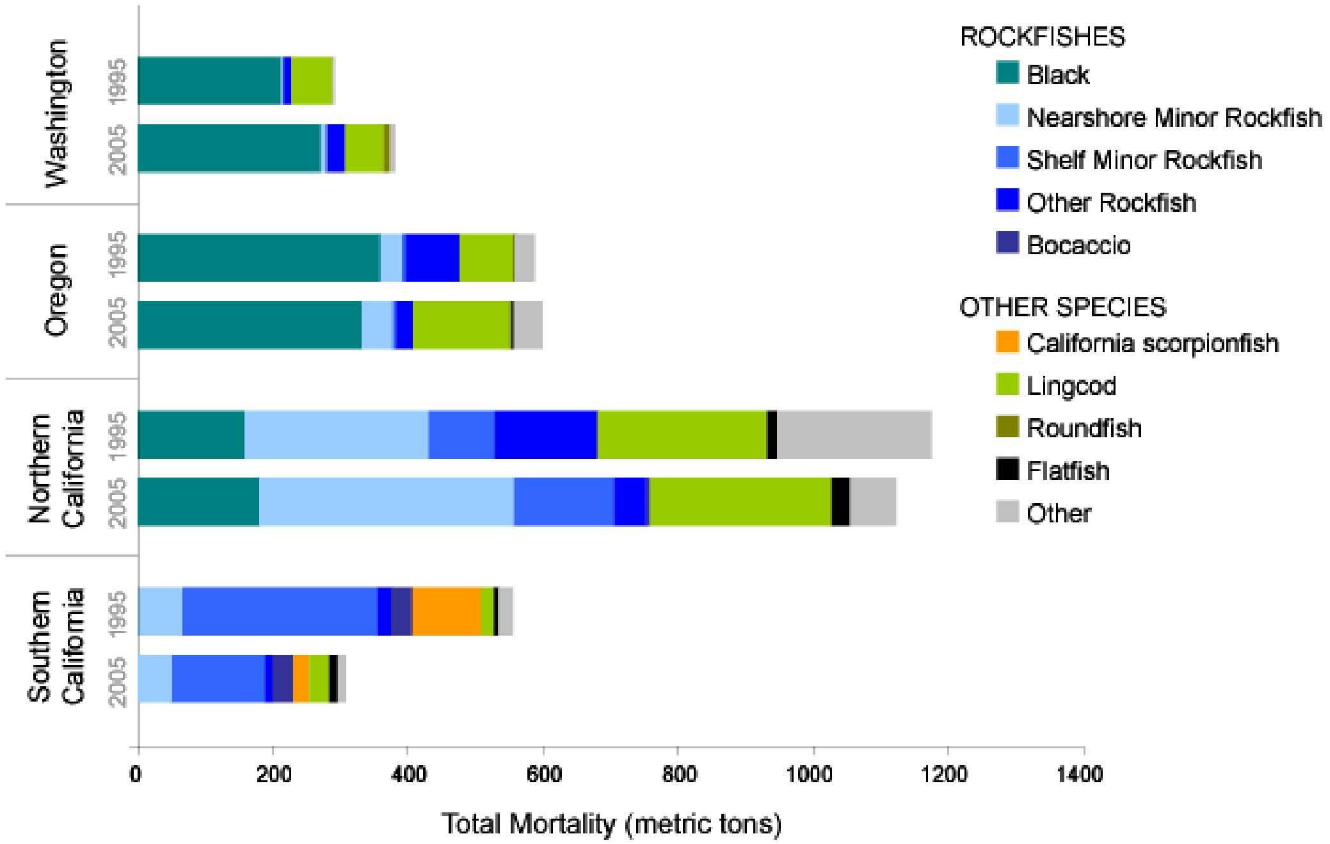


Figure 3.11. Recreational sector total groundfish mortality (estimated metric tons of retained plus observed discarded dead; ocean and estuary) by subregion (Washington, Oregon, N. California, S. California), 1995, 2005. N. and S. California split occurs at 34° 27' N. latitude. Source: adapted from PFMC 2007, Table 4.

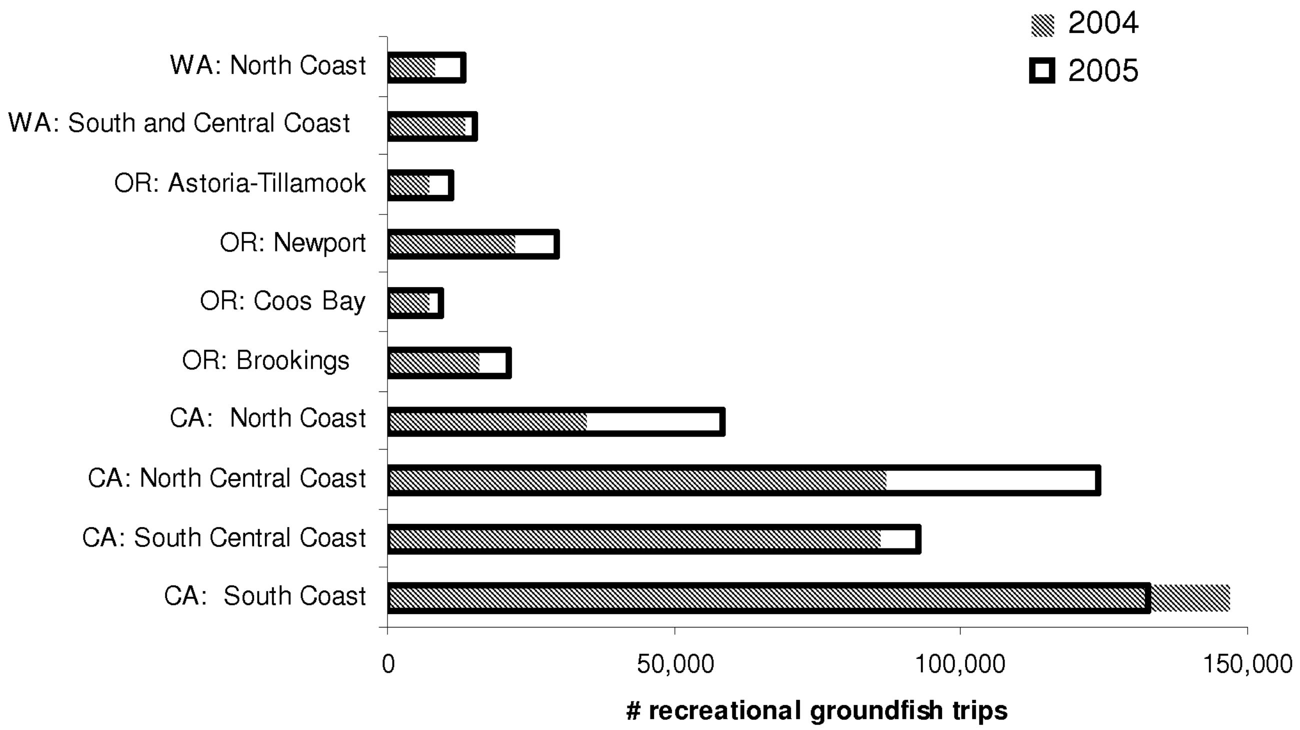


Figure 3.12. Estimate of number of recreational groundfish trips (charter and private) by region, 2004 and 2005. Source: adapted from PFMC and NFMS 2006, Table 7-41.

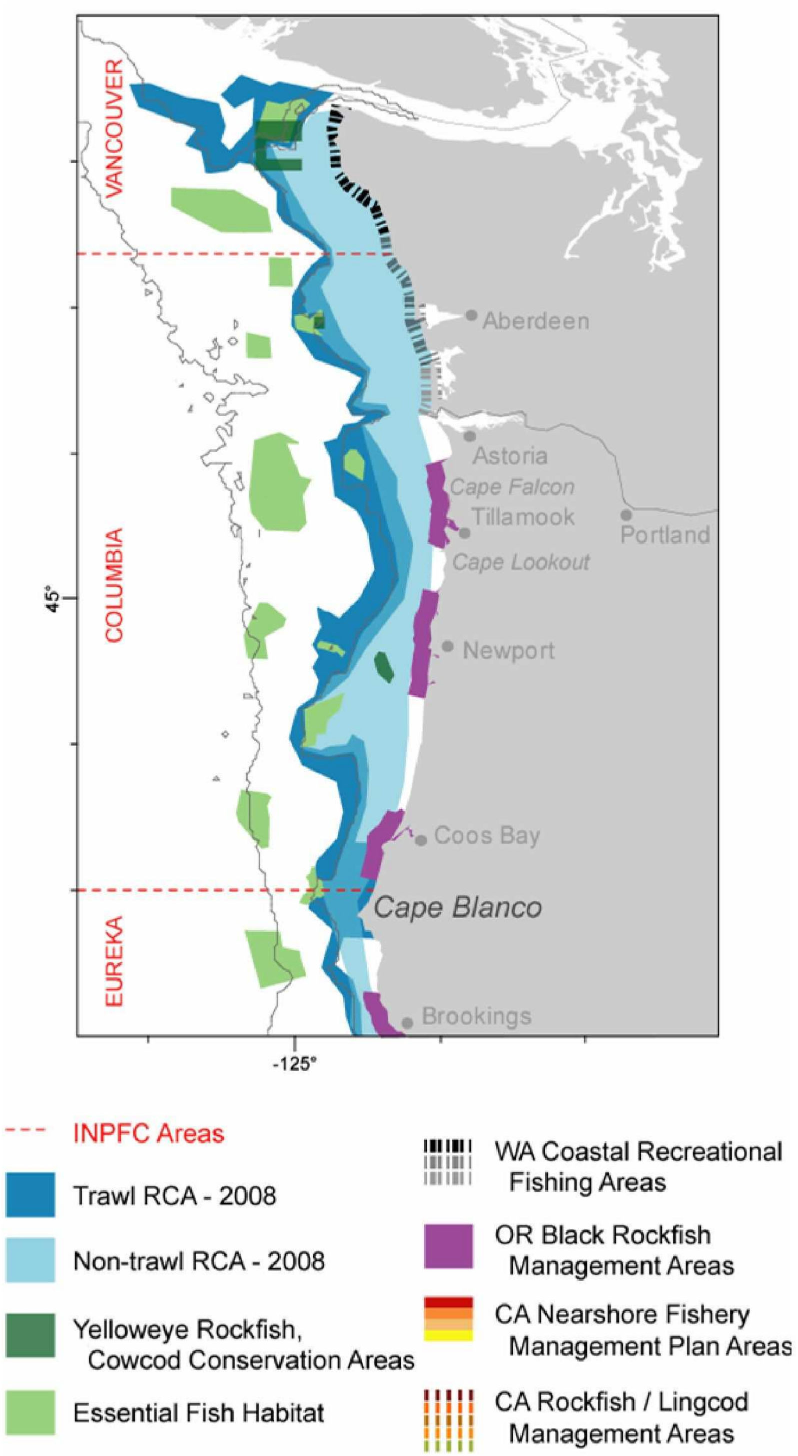


Figure 4.1. U.S. West Coast federal and state management areas. Federal areas: International North Pacific Fisheries Commission (INPFC), 2008 trawl and non-trawl Rockfish Conservation Areas (RCA), Yelloweye rockfish/cowcod conservation, Essential Fish Habitat. State areas: Washington coastal recreational, Oregon black rockfish, California nearshore, and California rockfish/lingcod. Sources cited in text.

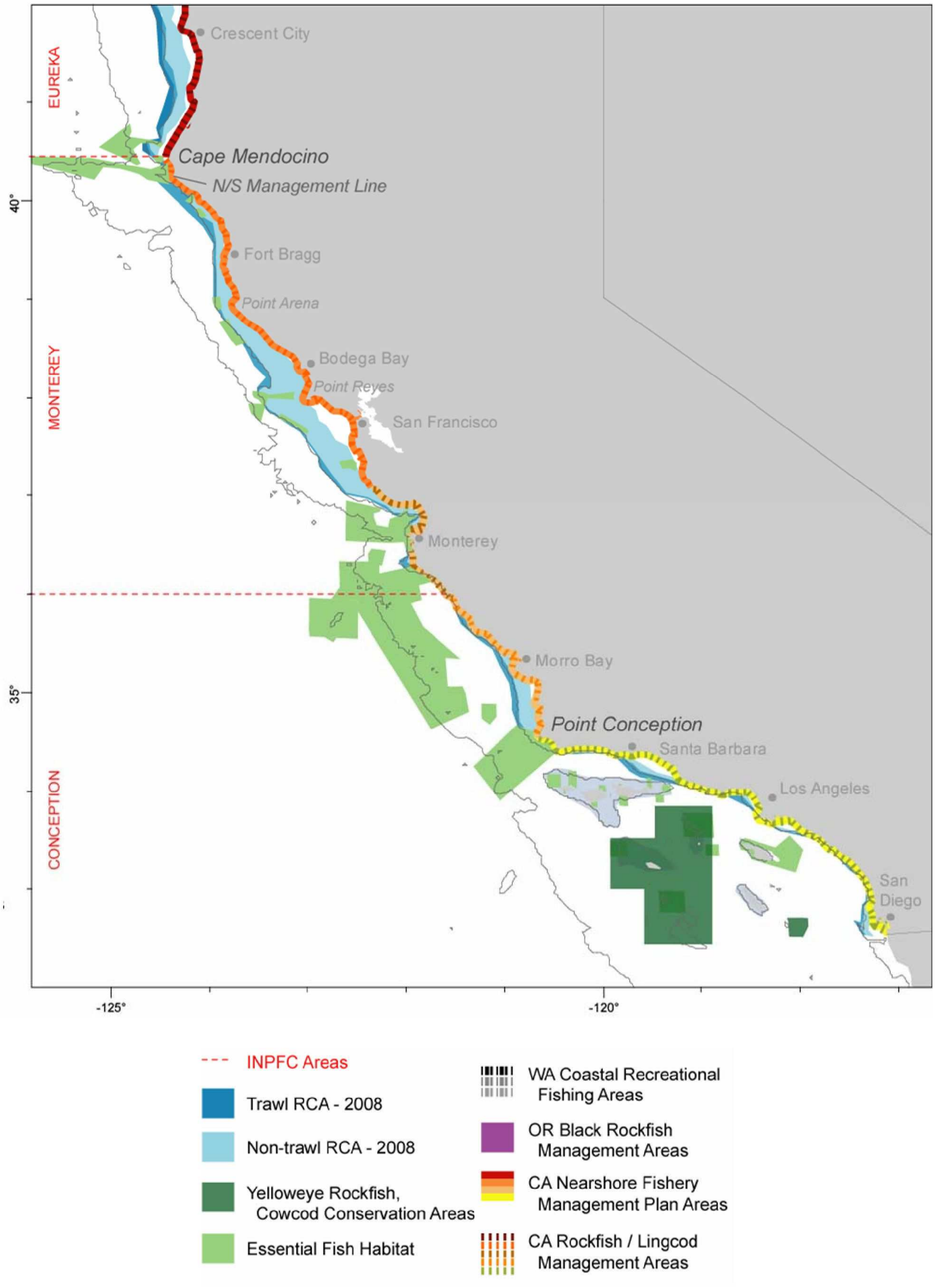


Figure 4.1. (cont.)

SMCA = state marine conservation area SMP = state marine park
SMR = state marine reserve SMRMA = state marine recreational management area

Figure 4.2. CDFG Central California Marine Protected Areas.
Source: www.dfg.ca.gov/mlpa

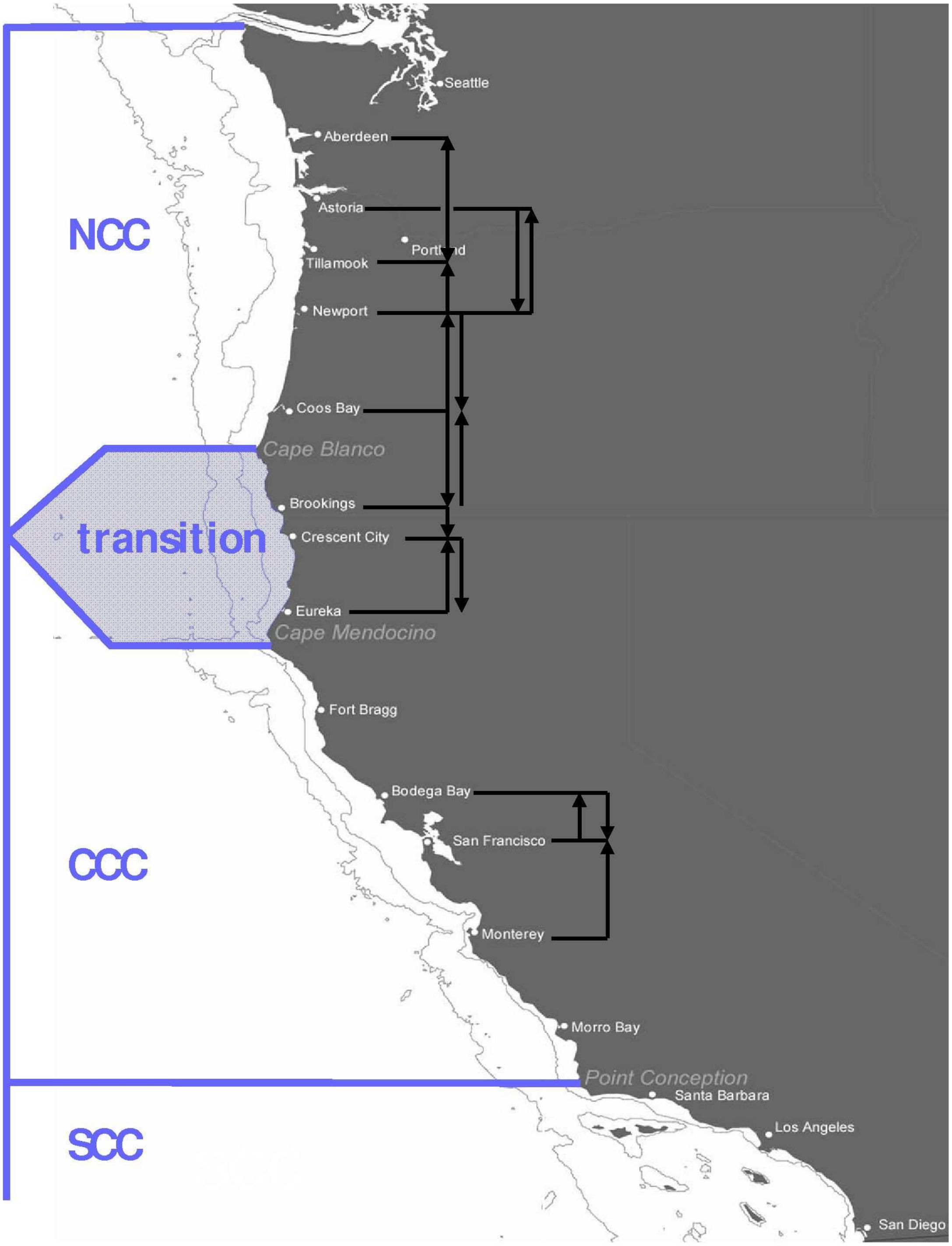


Figure 5.1. Port groups with greater than 25%overlap. Arrows show direction of overlap.

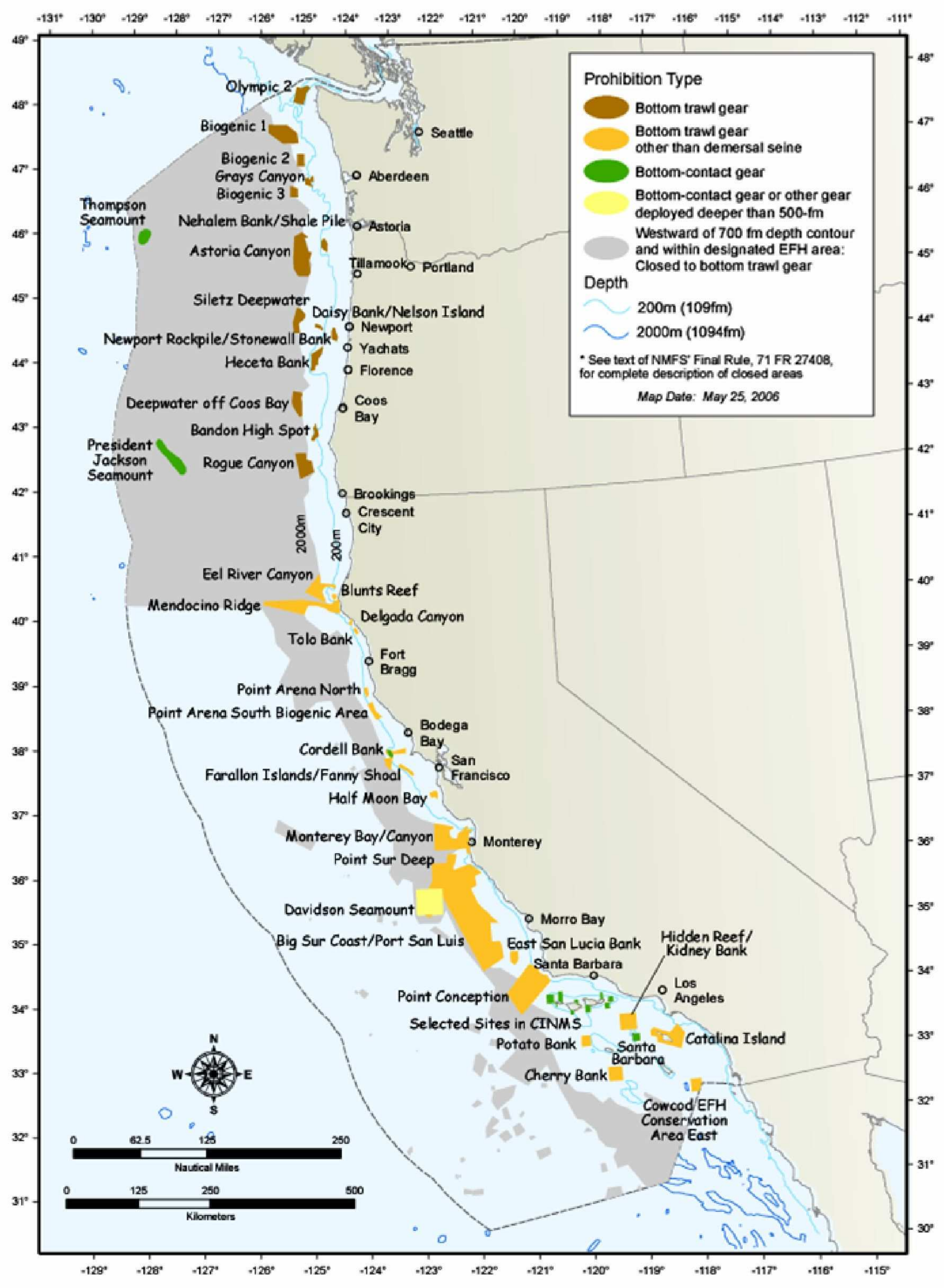


Figure 6.1. EFH area closures to protect Pacific Coast groundfish habitat – Coastwide. Source: NMFS 2008.