Pelagic Predators, Prey and Processes (P4): A multi-species approach to the conservation of offshore organisms and habitats in the California Current System

Kaya C. Pederson [1]
K. David Hyrenbach [1, 2]
Ken Morgan [3]
Gregg Elliott [1]
Peggy Yen [1]
William J. Sydeman [1]

[1] **Marine Science Division, PRBO Conservation Science, 4990 Shoreline Highway, Stinson Beach, California 94970, USA**

[2] **Duke University Marine Laboratory, 135 Duke Marine Lab. Road, Beaufort, North Carolina, 28516, USA**

[3] **Canadian Wildlife Service, P.O. Box 6000, Sidney, British Columbia, Canada V8L 4B2**

ABSTRACT

"Pelagic Predators, Prey and Processes" (P4) is an inter-disciplinary initiative developed to address the conservation of marine top predators along the West Coast of North America. P4 integrates research and policy components lead by PRBO Conservation Science (formerly Point Reyes Bird Observatory), Duke University Marine Laboratory and Canadian Wildlife Service, in conjunction with numerous partners that include funding and resource management agencies, academia, and researchers. Herein, we provide an overview of the P4 conservation initiative background, objectives, and initial products. We include a brief summary of data collected on collaborative research cruises and preliminary analyses of seabird, cetacean, and marine turtle ocean habitat selection. Data reveal that continental shelf-break and slope areas in the California Current System (CCS) support rich and diverse top predator assemblages. Moreover, results suggest that bathymetry may be useful in selecting appropriate marine habitats for Marine Protected Areas (MPAs) [1] designation to protect highly mobile marine vertebrates. We also summarize the highlights from a workshop held in January 2002 to explore the "scientific basis for offshore / pelagic marine reserves" [2] and report on the resulting establishment of the "Pelagic Working Group" (PWG). The PWG concluded that persistent ocean productivity patterns and pelagic species distributions could be readily identified in the

---

[1] *Marine Protected Area* (MPA) is a broad term referring to a site that has been afforded some level of protection (e.g. limiting oil and gas exploration) to preserve biological, geophysical or cultural resources (U.S. Executive Order 13158). However, the majority of MPAs allow recreational and commercial fishing.

[2] *Marine Reserves* (MRVs) are specifically designed to protect biological resources by excluding extractive activities such as fishing, and in some cases, deleterious recreational activities.

CCS. In principle, MPAs could be used to protect some of these offshore species and habitats from certain anthropogenic impacts.

INTRODUCTION

Marine vertebrates, including seabirds, turtles, large predatory fishes, pinnipeds and cetaceans, are conspicuous and important ecological constituents of pelagic ecosystems. Many of these species are economically, culturally and recreationally important, supporting commercial and artisanal fisheries and ecotourism. Moreover, the existence of these organisms enriches human experience in ways that cannot be quantified with cost-benefit analyses. Many species and populations are impacted by anthropogenic threats, which harm these organisms directly (e.g., fisheries bycatch, ship strikes, oil spills), and indirectly, by degrading their ecosystems (e.g., pollutants, plastic debris), and depleting their food base (e.g., hypoxic conditions, over-fishing). Additionally, natural variability in ocean conditions can make these species more susceptible to anthropogenic impacts, especially during periods of poor foraging conditions, such as El Niño.

The movement to designate marine protected areas (MPAs) and no-take marine reserves (MRVs) is proceeding rapidly along the West Coast of North America, spurred by the California Marine Life Protection Act (1999) and the U.S. President's Executive Order 13158 on MPAs (2000). In Canada, there are numerous mechanisms for the creation of MPAs, although Fisheries and Oceans Canada has the primary federal authority. Other venues to MPA or MRV designation include the following federal and provincial statutes: federal Fisheries Act, National Parks Act, Marine Conservation Areas Act, Canada Wildlife Act, Migratory Bird Convention Act, and the British Columbia Ecological Reserves Act, Park Act, Wildlife Act or Environment and Land Use Act. Scientific support for the establishment of no-take reserves reached unprecedented levels in February 2001, when the National Center for Ecological Analysis and Synthesis (NCEAS) issued a broad-based consensus statement, signed by over 160 marine scientists and conservation biologists, declaring that "existing scientific information justifies the immediate application of fully protected marine reserves as a central management tool" (NCEAS 2001).

The widespread belief in the use of MPAs as a marine conservation tool is underscored by several recent developments, including designation of a network of MRVs within the Channel Islands National Marine Sanctuary, and the consideration in the MPAs for the Nearshore Fishery Management Plan under development by the California Department of Fish & Game. Since 1997, when the Oceans Act came into force, two MPAs have been established in Pacific Canadian waters. Currently, Environment Canada is exploring the possibility of establishing a Marine Wildlife Reserve off the northern end of Vancouver Island, under the framework of the Canada Wildlife Act. Under the Oceans Act, one seamount area is under consideration while the Canadian Parks Agency is considering nearshore and marine conservation area designations around the southern Queen Charlotte Islands (Gwaii Hanaas) and the southern Gulf Islands, using the National Marine Conservation Areas legislation.

Provincially marine conservation areas are being identified and designated through their Marine Tenure Planning Process.

Historically, MPA initiatives have focused on intertidal and benthic systems, which already constitute the vast majority of existing marine reserves worldwide (Agardy 1994, Murray et al. 1999). Research has shown nearshore reserves to be an effective conservation tool for certain systems, especially for sessile species with restricted ranges and for benthic habitats (NCEAS 2001, Halpern & Warner 2002). Pioneering studies (Hooker et al. 1999, 2002) and concept papers (Duffus & Dearden 1995, Hyrenbach et al. 2000) have set the foundation for ecosystem-level pelagic protected areas. However, the conservation of mobile marine vertebrates still largely relies on single-species management including regulations (e.g., quotas), and fishing gear modifications (e.g., bycatch mitigation).

OBJECTIVES

The P4 initiative seeks to ensure that marine predators and the dynamic pelagic habitats upon which they depend are considered within the context of MPA planning for the West Coast of North America. Specifically, the goal of P4 is to assess the feasibility of pelagic protected areas, and to evaluate potential reserve designs based on an understanding of the ecology of marine top predators in relation to oceanographic variability. In particular, we seek to characterize which physical and biological characteristics make certain ocean habitats more productive than others, and to determine if the food webs exploited by top predators in the CCS are persistent and predictable enough in space and time to warrant designation as MPAs. Ultimately, our objective is to provide ocean and wildlife managers (e.g., NOAA, USFWS, state resource agencies, Fisheries and Oceans Canada) with scientific recommendations to guide the design of a network of MPAs for top predators along the West Coast of North America. Eventually, we hope this initiative will stimulate research on the design and effectiveness of pelagic / offshore protected areas and will serve as a model for marine conservation planning in other large marine ecosystems (Sherman & Duda 1999).

CONCEPTUAL FRAMEWORK

MPA design concepts (e.g., the number, location, size, and shape of protected areas) need to accommodate the ecology of the target species and the natural variability inherent in the ecosystems under consideration (Russ & Alcala 1995, Hyrenbach et al. 2000). Therefore, to consider the need for a multi-species / ecosystem approach for the CCS, we address various complementary habitat metrics and MPA selection criteria.

Oceanographic Considerations: The CCS may be divided into three physically and biologically distinct oceanographic domains (Figure 1), British Columbia, Washington and Oregon (Region A); central and northern California (Region B); and southern California (Region C) (GLOBEC 1992). Reserve designs will need to consider differences in physical forcing (e.g., intensity of coastal upwelling), water mass distributions (e.g., influence of the California Current), and food-web structure (e.g., species composition) that characterize each of these different regions. Therefore, P4 integrates observations from two distinct "regional" and "local" spatial scales (Figure 2). We have designed a regional research plan including observational surveys of predators at-sea in the northern and southern limits of the CCS (off British Columbia and Southern California), and in the central CCS, where large populations of seabirds and pinnipeds breed (Fulton & LeBrasseur 1985, Moser & Smith 1993, Sydeman & Allen 1999, Sydeman et al. 2001). Because these three regions are not homogeneous, research is also needed to assess the ecological significance of smaller-scale areas and habitats. These regional domains contain a mosaic of ocean habitats, some associated with coastal upwelling centers and other mesoscale (10s – 100s km) hydrographic features such as fronts and eddies, and others affiliated with bathymetric structures, such as canyons, seamounts and banks. Therefore, smaller-scale studies are needed to assess the habitat associations of predator aggregations and the ecological significance of particular areas. Shelf-slope regions and predictable coastal upwelling centers off southern and central California and along the southwest coast of Vancouver Island, British Columbia are prime examples of productive small-scale habitats within this larger regional context (Briggs et al. 1987, Wahl et al. 1993).

Selection Criteria for MPA Designation: We have developed multiple ecological criteria for considering the relative importance of potential MPA habitats: (1) the value of a site to the conservation of species of "special concern"; (2) the importance of a site to top predator trophic relationships and food web dynamics; and (3) the significance of the site to overall marine ecosystem biodiversity (Table 1 and 2).

Species Conservation - Understanding the natural history, habitat preferences, and dispersion of marine top-level predators will help guide the selection of appropriate foraging grounds and migratory routes for protection. Several species of conservation concern are regularly sighted within our study sites (Tables 3 and 4). MPAs could be designed to protect those areas where these taxa forage or migrate. Identification of hydrographic or bathymetric habitats where multiple species aggregate is particularly important for successful designation (Hooker et al. 1999, Hyrenbach et al. 2000). Additionally, endemic, locally-breeding species may constitute especially suitable focal taxa for assessing the efficacy of marine zoning efforts, in part because one can measure changes in the biology of these species (e.g., feeding rates and diet composition) following reserve implementation (Table 2).

Food Web Conservation **-** Protecting food webs may help buffer marine resources against environmental variability, uncertainty, and poor management decisions. MPAs designed to protect trophic relationships and energy transfer should target biologically productive areas where large numbers of marine predators aggregate. Metrics of overall seabird and cetacean standing stocks (abundance) and aggregation (patchiness) can be used to pinpoint important foraging grounds. Additionally, the distributions of focal species with high energetic requirements (e.g., diving seabirds, large cetaceans) can be used as bio-indicators of the physical processes that promote ocean productivity (e.g., Cassin's auklets *Ptychoramphus aleuticus* foraging along the edge of upwelling plumes) and prey aggregation (e.g., blue whales *Balaenoptera* *musculus* tracking dense euphausiid aggregations) (Tables 3 and 4, Briggs et al. 1987, Croll et al. 1998). The protection of the food webs and foraging areas of these top predators may lead to other ecological benefits. For example, MPAs delineated to protect the food webs that support seabirds may also benefit economically valuable species (e.g., salmonids) that rely on the same prey resources (PRBO & NMFS, unpublished data), but are inherently more difficult to survey. A prime example of a food-web bio-indicator is the common murre *Uria aalge*, an abundant piscivorous bird that breeds in regions 1 and 2 of the CCS. Murre chick diet at the Farallon islands is indicative of the availability of juvenile rockfish (*Sebastes spp*.) to king salmon (*Oncorhynchus tshawytscha*) in the Gulf of the Farallones (Figure 3). Moreover, long-term common murre diet data have revealed changes in food-web structure, apparently in response to interannual and long-term oceanographic variability. Namely, murres change their prey base from juvenile rockfish during cold-water years to anchovy / sardine during warm-water periods (PRBO, unpublished data). These results underscore the need to incorporate temporal variability in food-web structure into the design of effective marine protected area networks.

Ecosystem Conservation: MPAs may also help maintain marine biodiversity by protecting productive "hotspots" and "transition zones" characterized by strong physical gradients. In particular, community-level metrics (e.g., species richness and diversity) may be useful bio-indicators of regions known to support a diverse community of predators exploiting the same prey resources (e.g., baleen whales, salmonids and seabirds foraging on euphausiids), and ecotones (e.g., fronts and water mass boundaries) separating distinct species assemblages. In other words, areas of high species richness / diversity, are indicative of localities where different predators aggregate to forage on a common resource, or of ecotones separating distinct species assemblages (e.g., a front).

PROGRESS TO DATE

During 2000-2002, P4 has progressed along two parallel tracks designed to establish a solid scientific / logistical foundation: "ocean habitat research" and "coalition building".

Ocean Habitat Research

We have adopted a multi-disciplinary approach to study the habitat associations of top predators in the CCS (see Briggs et al. 1987, Croll et al. 1998). This integrated perspective involves: (1) collecting and analyzing observations on oceanographic conditions, prey dispersion and marine mammal / seabird distributions; (2) implementing standardized survey and data analysis protocols to ensure consistency between future surveys and existing time series; and (3) developing the necessary methodological and conceptual framework to integrate disparate surveys and datasets from three distinct regions of the CCS (Figure 1 and 2). Since fall 2000, we have conducted surveys of predators at sea in conjunction with three fisheries oceanography programs: the California Cooperative Oceanic Fisheries Investigation grid (CalCOFI, southern California), the National Marine Fisheries Service Rockfish Recruitment Surveys (NMFS-RRS, central California), and the Department of Fisheries and Oceans

Line P cruises (British Columbia). To date, analyses of surveys conducted from fall 2000 to summer 2002 have focused on relating top predator distributions to static habitats delineated by bathymetric features (e.g., banks, seamounts, shelf-break-slope regions).

Concurrent surveys off the northern (Line P, British Columbia), and the southern (CalCOFI, southern California) limits of the CCS have highlighted some of the latitudinal and longitudinal gradients in physical and biological properties that characterize this heterogeneous marine ecosystem. In particular, preliminary analyses have revealed that overall seabird / marine mammal abundance and species composition changes with latitude and along an onshore-offshore gradient (PRBO, unpublished data). Surveys have documented species-specific distributions with different taxa preferentially occupying specific bathymetric domains. Additionally, these analyses have provided evidence of seasonal and inter-annual variability in seabird / cetacean community structure off southern and central California (Gulf of the Farallones), where we have compiled historical survey data since the mid 1980s (Oedekoven et al. 2001).

Despite the regional differences and the great diversity of predator distributions, which clearly complicates the design of multi-species MPAs for the CCS, our research suggests that certain bathymetric habitats (shelf-breaks, slope) have great ecological importance. In theory, MPAs could be designated to protect predictable foraging aggregations and migration corridors associated with these static bathymetric habitats. For instance, many seabird species, including far ranging migratory species from the southern hemisphere (e.g., sooty shearwater *Puffinus griseus* and pink-footed shearwater *P. creatopus*), and non-migratory locally breeding species (e.g., Cassin's auklet, common murre), are numerous along the shelf-break and the slope. Similarly, cetaceans appear to aggregate along these same bathymetric features. Moreover, seabird and marine mammal communities appear to be more diverse within the shelf-break and slope areas than on the continental shelf, or in the pelagic waters farther offshore. The conservation importance of the shelf-break and continental slope is also highlighted by the occurrence of several rare and highly endangered oceanic species (leatherback turtle *Dermochelys coriacea*, and short-tailed albatross *Phoebastria albatrus*). Therefore, preliminary results suggest that marine reserves could focus on protecting relatively small (100s - 1000s km^2) regions delineated by static bathymetric features.

In summary, our studies underscore a number of essential aspects of pelagic conservation in the CCS. First, large-scale MPA designs will have to account for the substantial spatial and temporal variability of oceanic habitats and species distributions, which vary seasonally and from year to year. Thus, distinct reserve designs will be required to accommodate regional differences in oceanographic processes and food-web structure. Furthermore, because non-breeding birds and mammals are numerically dominant during spring and summer, effective conservation will have to extend protection beyond that afforded to breeding sites and waters adjacent to colonies. From a community-level and biodiversity perspective, providing protection to migratory species in the CCS is essential. Second, seafloor depth appears to influence seabird and cetacean habitat selection, and may therefore provide a convenient means of delineating MPAs in the CCS. Certain species preferentially inhabit specific bathymetric domains, and the overall abundance and diversity of avian and marine mammal predators appears to be higher along regions of strong bathymetric gradients. However, understanding to what extent top predator distributions are determined by "fixed" geographic features (e.g., ocean depth) versus dynamic water mass properties (e.g., temperature, salinity, chlorophyll) associated with these bathymetric habitats remains a critical issue. Future multivariate analyses will characterize cetacean / seabird distribution and abundance with respect to these dynamic (e.g., ocean temperature, salinity and chlorophyll concentration) and static habitat features (e.g., sea floor depth, distance to the shore and the shelf-break). Additionally, replicate surveys of the same areas / regions during different seasons and years will be summarized to further assess the temporal variability of species distributions, wildlife-habitat associations and ocean productivity "hotspots".

Coalition Building

The policy track of P4 has focused on establishing a broad-based coalition, efforts aimed at both synthesizing and sharing data between scientists on pelagic ecosystem functions, and communicating complex scientific material to ocean resource managers and decision makers. As described in the first P4 workshop summary, the effort to enhance the scientific basis for MPA designs in pelagic ecosystems involved compiling existing knowledge of pelagic predator habitat associations and physical-biological linkages (e.g., spatio-temporal variability of plankton distributions, top predator diets), and using this information to define knowledge gaps. In particular, we assessed which taxonomic groups required further study to resolve predator-prey habitat relationships (e.g., squid), and other poorly known aspects of the structure and dynamics of pelagic food webs in the CCS. Another aspect of this work involved asking managers and decision makers to define what types of information they would need to assess the feasibility, ecological implications, and potential stakeholder impacts of different pelagic MPA designs.

Two specific efforts are underway within the "coalition building" framework: (1) assembling an interdisciplinary Pelagic Working Group (PWG) to review the current state of knowledge for key pelagic species and habitats, to summarize the threats and conservation opportunities for pelagic species, and to prioritize research and management needs [3]; and (2) establishing an advisory board of stakeholders — including scientists, funding sources, management agencies, conservation groups and resource users— to establish research projects addressing the priorities delineated by the PWG.

Results of January 2002 Workshop - In January 2002, PRBO sponsored, in conjunction with the National Fish and Wildlife Foundation (NFWF) and NOAA's

[3] Workshop report available online at http://www.prbo.org/marine/p4_report_0505.pdf.

National Center for MPA Science (NMPAC), the first PWG workshop. This meeting brought together key researchers and agency managers from Canada, Washington, Oregon and California to explore the scientific basis of pelagic MPAs and no-take reserves. The PWG was given the tasks of: (1) Assessing the current state of knowledge of pelagic systems from biological, geophysical, and oceanographic perspectives; (2) Identifying processes and habitat features that make certain productive areas and top predator foraging grounds predictable in time and space; (3) Defining threats to pelagic organisms and their habitats; (4) Developing a consensus statement concerning the potential role of MPAs and MRVs to protect pelagic organisms and habitats.

The PWG considered the following issues:

- Identification of bathymetric and hydrographic features (e.g., upwelling plumes, seamounts) associated with high biological productivity ("hotspots") in the CCS.
- Assessment of linkages between offshore and nearshore processes / species, and the relevance of these connections to marine conservation in the CCS.
- Determining whether currently available scientific knowledge justifies the implementation of a precautionary marine reserve network to protect krill (euphausiids), a major component of the marine food-web in the CCS.
- Improving the collection and integration of physical and biological data in monitoring and research programs to better assess the status of key indicator species.

Scientists from a cross-section of marine science disciplines presented data on physical oceanography, cetaceans, turtles, seabirds, forage fish, and zooplankton. The workshop highlights include the following:

(i) At-sea surveys are of great value to resource managers because they allow us to place biological observations of predator / prey aggregations in an oceanographic context, including habitat variables such as salinity and ocean temperature.

(ii) Geographical Information Systems (GIS) and seafloor mapping confirm that the distribution and abundance of pelagic predators and their prey are frequently associated with bathymetric features (e.g., canyons, shelf-breaks, and slopes).

(iii) Static seafloor features are often associated with dynamic and recurring hydrographic processes (e.g., temperature fronts, upwelling). Thus, there appear to exist some linkages between static and dynamic habitats, even in pelagic systems.

(iv) Physical / biological coupling associated with these habitat features influences the predictability of productivity and foraging "hotspots" and links pelagic food web dynamics with oceanographic variability.

(v) Resource managers should incorporate natural variability into MPA designs because environmental change (e.g., El Niño, climate change) are known to affect pelagic species distributions and marine food web structure.

In summary, the PWG concluded that understanding linkages between pelagic organisms and their physical environment is essential to protect marine top predators and their prey resources. In particular, it is essential to pinpoint those time periods and localities where the transfer of energy to top predator occurs. For example, tight physical-biological coupling may be particularly important during stressful conditions (e.g., El Niño) if pelagic organisms aggregate within restricted areas of high productivity. In turn, predator / prey aggregations may be particularly vulnerable to anthropogenic impacts during these stressful periods. Moreover, an understanding of wildlife-habitat associations can help resource managers categorize taxa according to their common habitats and potential threats. Based on these commonalities, MPAs could protect a variety of pelagic organisms susceptible to similar threats (e.g., coastal gillnets that take Common Murres off British Columbia and central California, also kill harbor porpoise *Phocoena phocoena*).

CONCLUSION: ECOSYSTEM APPROACH TO PELAGIC CONSERVATION

It is our contention that a broad-based conservation approach for the CCS is crucial to preserve essential ecological processes and services, and to protect economic and cultural resources for future generations. Within this marine conservation framework, the design of offshore / pelagic MPAs to protect mobile vertebrates represent major conservation challenges as well as opportunities because these species frequently exploit dynamic habitats whose location, extent and shape changes through time. In particular, the far ranging nature of many marine top predators and the inherent variability of their oceanic ecosystems will require the coupling of MPAs with other management actions. In addition to the establishment of MPAs to protect the foraging grounds and migration routes of top marine predators, broader ecosystem-level effects must also be considered. Additional research is needed to assess the ecological benefits of offshore MPAs to non-target species, nearshore ecosystems and species, local and regional fisheries. Evidence of indirect ecosystem-level benefits and fisheries enhancement effects will greatly advance the political will to implement MPAs in pelagic systems.

ACKNOWLEDGEMENTS

We would like to thank the many partners and contributors whose support has made this initiative and paper possible, including the National Fish and Wildlife Foundation, the National Marine Protected Areas Center, the Packard Foundation, the Pelagic Working Group, and Michael Dunn of Canadian Wildlife Service.

REFERENCES

Agardy, M.T. 1994. Advances in marine conservation: the role of marine protected areas. Trends in Ecology and Evolution 9: 267-270.

Barlow, J., Hill, P. S., Forney, K.A., & DeMaster, D.P. 1998. U.S. Pacific marine mammal stock assessments: 1998. NMFS-SWFSC-258.

Briggs, K.T., Tyler, W.B., Lewis, D.B., & Carlson D.R. 1987. Bird communities at sea off California. Studies Avian Biology 11:1-74.

Croll, D.A., Tershy, BR., Hewitt, R.P., Demer, D.A., Fiedler, P.C., Smith, S.E., Armstrong, W., Popp J.M., Kiekhefer T., Lopez, V.R., Urban, J. & Gendron, D. 1998. An integrated approach to the foraging ecology of marine birds and mammals. Deep-Sea Research II 45:1353-1371.

Duffus, D.A., & Dearden, P. 1995. Whales, science and protected area management in British Columbia, Canada. (pp. 53-61). In: Agardy, T. (Ed.), The science of conservation in the coastal zone. Gland, Switzerland: IUCN.

Fulton, J.D., & LeBrasseur, R.J. 1985. Interannual shifting of the Subarctic Boundary and some of the biotic effects on juvenile salmonids. (pp. 237-252). In: Wooster, W.S. & Fluharty, D.L. (Eds.), El Niño North: El Niño effects in the subarctic Pacific Ocean. Seattle: University of Washington Press.

GLOBEC. 1992. Eastern boundary current program: report on climate change and the California Current System. Davis: University of California.

Julian, F., & Beeson, M. 1997. Estimates of marine mammal, turtle, and seabird mortality for two California gillnet fisheries: 1990-1995. Fishery Bulletin 96:271-284.

Johnson, D.H., Shaffer, T., & Gould, P.G. 1993. Incidental catch of marine birds in the North Pacific high seas driftnet fisheries in 1990. International North Pacific Fisheries Commission Bulletin 53(III):437-483.

Halpern, B.S. & Warner, R.R. 2002. Marine reserves have rapid and lasting effects. Ecology Letters 5:361-366.

Hooker S.K., Whitehead, H., & Gowans, S. 1999. Marine protected area design and the spatial and temporal distribution of cetaceans in a submarine canyon. Conservation Biology 13: 592-602.

Hooker S.K., Whitehead, H., & Gowans, S. 2002. Ecosystem consideration in conservation planning: energy demand of foraging bottlenose whales (*Hyperoodon ampullatus*) in a marine protected area. Biological Conservation 104: 51-58.

Hyrenbach, K.D., Forney K.A. & Dayton, P.K. 2000. Marine Protected Areas and Ocean Basin Management. Aquatic Conservation: Marine and Freshwater Ecosystems 10:437-458.

McKinnell, S., & Waddell, B. 1993. Associations of species caught in the Japanese large- scale pelagic squid driftnet fishery in the Central North Pacific Ocean: 1988-1990. International North Pacific Fisheries Commission Bulletin 53(III):91-146.

Moser H.G., & Smith P.E. 1993. Larval fish assemblages of the California Current region and their vertical and horizontal distributions across a front. Bulletin of Marine Science 53(2):645-691.

Murray, S.N., Ambrose, R.F., Bonshack, J.A., Botsford, L.W., Carr, M.H., Davis, G.E., Dayton, P.K., Gotshall, D., Gunderson, D.R., Hixon, M.A., Lubchenco, J., Mangel, M., MacCall, A., McArdle, D.A., Ogden, J.C., Roughgarden, J., Starr, R.M., Tegner, M.J. & Yoklavich, M. 1999. No-take reserve networks: sustaining fishery populations and marine ecosystems. Fisheries 24 (11):11-25.

NCEAS. 2001. Scientific consensus statement on marine reserves and marine protected areas. Santa Barbara: National Center for Ecological Analysis and Synthesis. Available online at: www.nceas.ucsb.edu

Oedekoven, C.S., Ainley, D.G. & Spear, L.B. 2001. Variable responses of seabirds to change in marine climate: California Current, 1985-1994. Marine Ecology Progress Series 212:265-281.

Russ, G.R. & Alcala, A.C. 1998. Natural fishing experiments in marine reserves 1983-1993: roles of life history and fishing intensity in family responses. Coral Reefs 17:399-416.

Sherman, K. & Duda, A.M. 1999. Large marine ecosystems. Fisheries 24(12): 15-26.

Stehn, R.A., Rivera, K.S., Fitzgerald, S., & Wohl, K.D. 2001. Incidental catch of seabirds by longline fisheries in Alaska. (pp. 61-78). In: Melvin, E.F. & Parrish, J.K. (Eds.), Seabird Bycatch: Trends, Roadblocks and Solutions. Anchorage: University of Alaska Sea Grant.

Sydeman, W.J., & Allen, S.G. 1999. Pinniped population dynamics in central California: correlations with sea surface temperature and upwelling indices. Marine Mammal Science 15: 446-461.

Sydeman, W.J., Hester, M.M., Thayer, J.A., Gress, F., Martin, P., & Buffa, J. 2001. Climate change, reproductive performance and diet composition of marine birds in the southern California Current System, 1969-1997. Progress in Oceanography 49:309-329.

Wahl, T.R., Morgan, K.H., & Vermeer, K. 1993. Seabird distribution off British Columbia and Washington. (pp. 39-47). In: Vermeer, K., Briggs K.T., Morgan, K.H. & Siegel-Causey, D. (Eds.), The status, ecology, and conservation of marine birds of the North Pacific. Ottawa: Canadian Wildlife Service.

Table 1. Conceptual framework of ecological criteria for marine zoning.

	Species Conservation	**Food-Web Conservation**	**Ecosystem Conservation**
Metrics	Distribution Aggregation	Ocean productivity Prey biomass Predator density	Species richness Species diversity Endemism
Habitats	Breeding grounds Foraging areas Migration corridors	Productivity "hotspots" Foraging areas	Multi-species aggregations
Processes	Breeding Feeding Migration	Upwelling regions Convergence zones Foraging areas	Ecotones Shared prey resources

Table 2. Conceptual framework for focal species selection for marine zoning.

	Definition	**Rationale**	**Example**
Protected Species	Taxa afforded national or international protection due to their conservation status	Direct conservation benefits Legal basis for MPA establishment	Taxa listed under IUCN, MMPA, COSEWIC, ESA, and other criteria
Endemic Species	Taxa that occur exclusively in the California Current System	High biogeographic importance	Ashy Storm-petrel, Xantus' Murrelet, Black-vented Shearwater
Locally-breeding Species	Taxa that breed in the California Current System	At-sea distribution data can be integrated with diet and telemetry studies at breeding colonies	Cassin's Auklet, Common Murre, Rhinoceros Auklet, California Sea Lion, Northern Elephant Seal
Indicator Species	Taxa whose distributions are indicative of specific water masses (e.g., 12 ^{o}C water, subarctic), certain physical processes (e.g., upwelling), prey aggregations (e.g., krill), or ocean habitats (e.g., frontal systems)	Bio-indicators of specific oceanic habitats, physical processes, and prey resources exploited by other predators that are more difficult to study (e.g., tuna, salmon)	Water masses Bathymetric habitats Krill aggregations Squid distributions Upwelling fronts Convergence zones

Table 3. Focal seabird species considered in this study. The plus (+) and minus (-) signs indicate presence and absence within the three survey regions: British Columbia, Central California, and Southern California. Bycatch refers to fisheries known to take these taxa in the North Pacific (Johnson et al., 1993, Julian & Beeson 1997, Stehn et al. 2001).

	Occurrence						
Species	**BC**	**central CA**	**southern CA**	**Status**	**Indicator**	**Bycatch**	**Other Threats**
Ashy Storm-petrel	-	+	+	concern endemic	breeding		land predators oil spills
Black-footed Albatross	+	+	+	concern		longline	plastic ingestion
Black-legged Kittiwake	+	+	+		subarctic	longline	
Black-vented Shearwater	+	+	+	endemic	coastal subtropical		land predators
Buller's Shearwater	+	+	+		subtropical water mass	gillnet longline	
Brown Pelican	+	+	+	concern endemic	subtropical		habitat degradation
Cassin's Auklet	+	+	+	concern	breeding euphausiid aggregations	gillnet	land predators oil spills
Common Murre	+	+	+	concern	breeding salmon prey	gillnet	oil spills
Cook's Petrel	+		+		subtropical		
Fork-tailed Storm-petrel	+	+	+		breeding subarctic	gillnet	
Laysan Albatross	+	+	+	concern	breeding	longline	plastic ingestion
Leach's Storm-petrel	+	+	+		breeding pelagic	gillnet	land predators
Marbled Murrelet	+	+	-	concern	breeding	gillnet	habitat degradation
Pink-footed Shearwater	+	+	+	concern	subtropical	gillnet	land predators chick harvest
Phalaropes	+	+	+		convergences		oil spills
Rhinoceros Auklet	+	+	+		breeding	gillnet	oil spills land predators
Short-tailed Albatross	+	+	-	concern		longline	plastic ingestion
Sooty Shearwater	+	+	+	concern		gillnet longline	chick harvest
Xantus' Murrelet	+	+	+	concern endemic	breeding subtropical	gillnet	oil spills land predators

Table 4. Marine mammal and sea turtle species considered in this study. The incidence of bycatch refers to fisheries known to take these taxa in the North Pacific (McKinnell & Waddell 1993, Barlow et al. 1997, Julian & Beeson 1997). The plus (+) and negative (-) signs indicate presence and absence within the three survey regions: British Columbia, Central California, and Southern California.

	Occurrence						
Species	**BC**	**central CA**	**southern CA**	**Status**	**Indicator**	**Bycatch Incidence**	**Other Threats**
Blue Whale	+	+	+	concern	Euphausiid aggregations		ship strikes
Fin Whale	+	+	+	concern			ship strikes
Minke Whale	+	+	+	concern		gillnet	ship strikes
Humpback Whale	+	+	+	concern		gillnet	ship strikes
Bottlenose Dolphin	+	+	+		shelf and shelf-break	gillnet	
Common Dolphin	-	+	+		subtropical	gillnet	
Dall's Porpoise	+	+	+		subarctic	gillnet trawls	
Short-finned Pilot Whale	+	-	+	concern	squid distributions	gillnet squid seine longline	
Risso's Dolphins	+	+	+		squid distributions subtropical	gillnet squid seine longline	
Sperm Whale	+	+	+	concern	pelagic	gillnet	ship strikes
White-sided Dolphin	+	+	+		cold-water	gillnet	
Northern Fur Seal	+	+	-		pelagic	gillnet	
Leatherback Turtle	+	+	-	concern	pelagic	gillnet longline	ship strikes
Green Turtle	-	-	+	concern	subtropical	gillnet longline	

FIGURES

Figure 1. The three oceanographic domains of the CCS (thick lines), showing the research vessel tracks surveyed as part of the P4 initiative (thin lines). (A) Region 1: Line P survey, British Columbia; (B) Region 2:NMFS Rockfish Survey, Central CA; (C) Region 3: CalCOFI grid, Southern California.

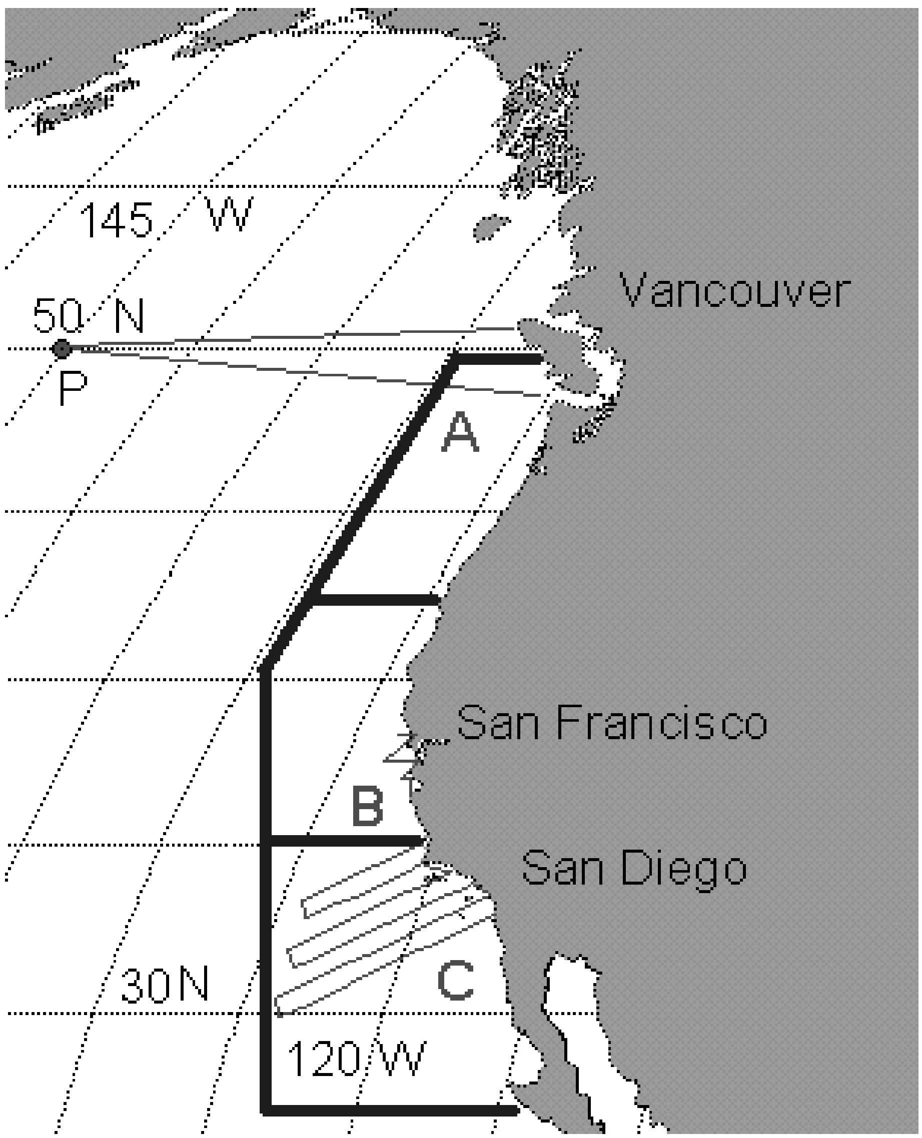

Figure2. Spatial and temporal scales addressed by P4 research objectives.

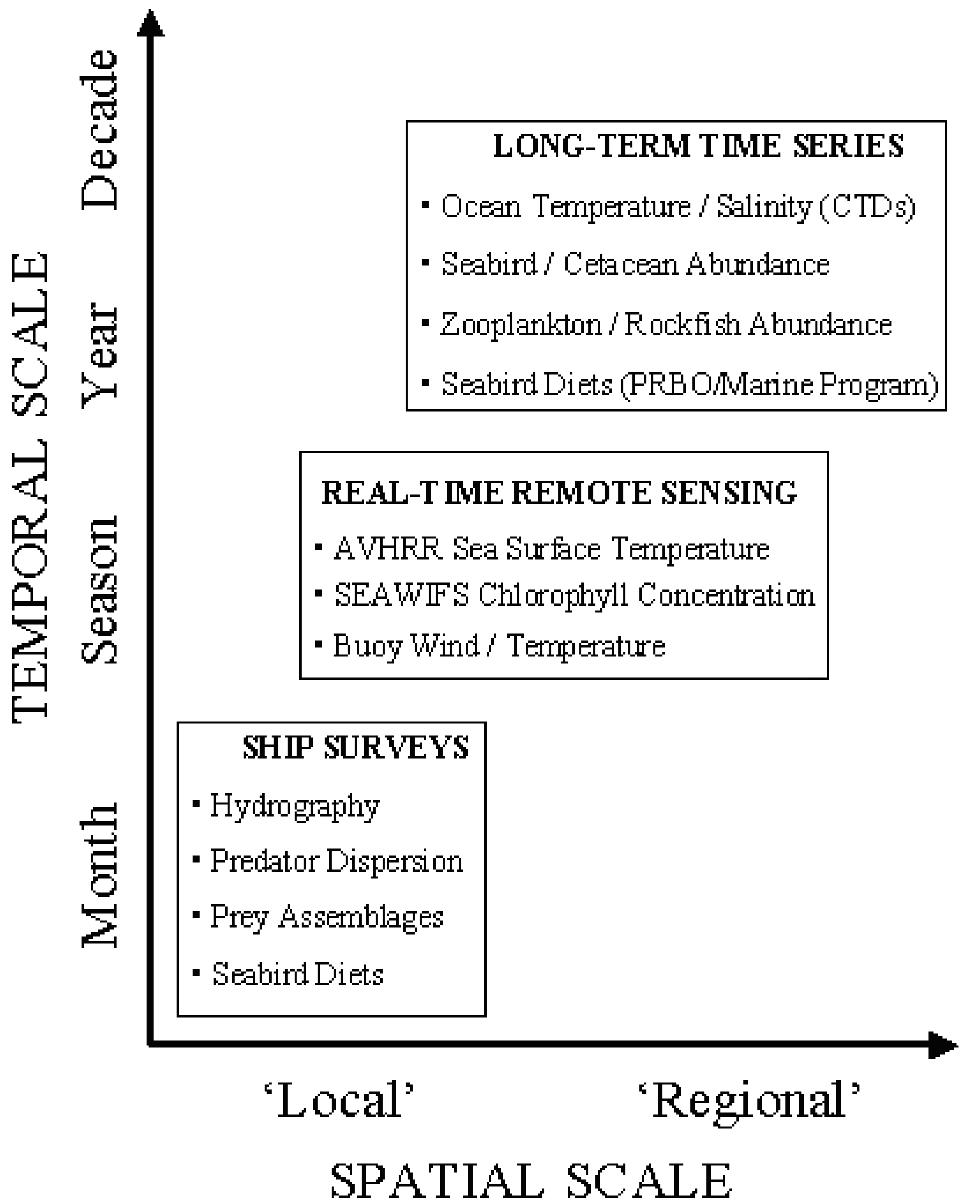

Figure 3. Marine birds are valuable bio-sensors of lower trophic –level food-web constituents. Dietary overlap between common murres breeding at the Farallon Islands and king salmon commercially-caught off central California (1980 – 1994).