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Towards Ecosystem-Based Fishery Management in the California Current System – Predators and the Preyscape: A Workshop

Report to National Fish and Wildlife Foundation

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Cover photo: Pigeon guillemot with rockfish (Photo by R. LeValley), common murre with squid (Photo by R. LeValley) and common murres with anchovies (Photo by R. LeValley).

EXECUTIVE SUMMARY: THE SCIENCE APPLICABLE TO EBFM IN THE CCS

- Most California Current System (CCS) predators are generalists, very few are krill specialists (e.g. blue whales). Owing to the variability inherent in the CCS, predators must engage in prey switching at both temporal (decadal to seasonal) and spatial (region to local) scales;

- There are foraging hotspots in the CCS, and while their general location may be similar from year to year (e.g., Northern Channel Islands to Point Conception, Gulf of the Farallones-Monterey Bay, Cape Blanco to Heceta Bank, Strait of Juan de Fuca), they are subject to temporal (decadal to seasonal) and spatial (meso- to micro-scale) variability in their relative importance, which contributes to the prey switching behavior of the predators;

- While the classic "forage species" are prevalent in predator diets of the CCS (e.g. anchovy, herring, sardine), juveniles of important federal FMP species (e.g., salmon, rockfish, hake) as well as several invertebrates (krill, market squid, octopus) are equally prevalent;

- Where human and "wild" predators coincide, based on experimental evidence, the human fishers are far more efficient in their prey harvesting activities, putting "wild" predators at a disadvantage;

- Current modeling to assess fish stocks generally takes a single-species approach, which fails to incorporate the importance of the temporal and spatial availability of key prey species; however, incorporating these prey species into stock assessment modeling (or other types) presents its own suite of challenges and cannot be based on reserving some portion of the exploited biomass alone, but rather must also address availability to predators (biomass does not equal availability);

- Undertaking further, complex modeling will require the expensive collection of additional data not currently available.

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BACKGROUND

Ecosystem-based fishery management (EBFM), while not mandated by legislation, has become a widespread goal in U.S. fisheries management, and in accord the Pacific Fisheries Management Council has initiated EBFM approaches in the waters of Washington, Oregon, and California (PFMC 2007, 2013), i.e. those of the California Current System (CCS). Forage species have been one of the primary focuses of these efforts and have attracted the attention not only of fishery agencies but NGOs as well (Oceana 2011, Pikitch et al. 2014, PEW 2013). In the past, management policies have given attention to individual forage species deemed to be particularly important to CCS food web dynamics, e.g., anchovy management plan (PFMC 1978), prohibition of a shortbelly rockfish fishery in the groundfish management plan (PFMC 2000, Field et al. 2007), and the recent prohibition on commercial (other than incidental) take of euphausiids (PFMC 2008). More recently, fishery managers have been placing importance on establishing a more complete understanding of predator-prey relationships involving forage fish. In addition, the California Fish and Game Commission has recently (2013) adopted policy guidelines toward progressively incorporating Essential Fishery Information (EFI) for "ecosystem-based management of forage species, including physical factors, oceanographic conditions, the effects of fishing on forage species' dependent predators, the availability of alternative prey, spatio-temporal foraging hotspots for predators, and existing management schemes, including marine protected areas (California Fish & Game Commission 2013). The State of Washington, Department of Fish and Wildlife, has also been active in encouraging such an ecosystem approach in marine fisheries management (http://wdfw.wa.gov/conservation/research/).

Implementation of new fishery policies to facilitate EBFM will be much more complex than current management approaches, which often address single species, and this is particularly true of forage fish efforts which to date have focused primarily on food-web type models (PFMC 2007, 2008). Helpful to some degree is the observation that many predator-prey relationships in the CCS are organized around "hotspots", which are the result of oceanographic and bathymetric conditions that concentrate productivity and create prey-rich environments. This is now a well-investigated phenomenon in the CCS known from remote sensing of ocean properties, summary of at-sea survey data and tracking of individual predators (Etnoyer et al. 2004; Palacios et al. 2006; Sydeman et al. 2006; Nur et al. 2011; Reese et al. 2011; Santora et al. 2011, 2012). Predators are adapted to find and explore these prey rich environments and are themselves concentrated there (Block et al. 2011). Moreover, these hotspots have long been recognized by fishing vessel captains, who concentrate their fishing efforts in them as well (NOAA 2008).

While we know that forage fish and predators, including humans, concentrate at these hotspots, an important and much lesser known finer scale spatio-temporal aspect of use exists --- depending on the dynamics of the forage species, predators may or may not encounter the same forage species in a given year or find that forage in the same mesoscale or smaller location each year. Conversely, during specific times of the year, predators may move to specific locations where they have had high success in previous years. For central-place foraging species that are constrained geographically, such as island-breeding seabirds and pinnipeds or salmon prior to up-river spawning migration, prey switching is the only option; for mobile species or portions of species' populations that are not geographically constrained, moving to where the prey are abundant is the most efficient strategy. This was recently demonstrated in a model of low-trophic level forage species indicating the need for more fine scale analysis (Smith et al. 2011), but has been previously shown empirically by long term investigations of the diet and spatial aspects of seabirds foraging in the Gulf of the Farallones (Ainley & Boekelheide 1990; Ainley et al. 1996a, b), salmon off Oregon (Brodeur et al. 2007) and albacore throughout the CCS (Glaser 2010). As well, dynamics will change as populations of predators change, some possibly out-competing others, e.g., whales and seabirds (Ainley & Hyrenbach 2010) and fishing vessels and seabirds (Bertrand et al. 2005, 2008, 2012; Pichegru et al. 2010, 2011). Finally, some predators are attracted to CCS hotspots not so much for the forage species themselves, but because certain predators, e.g., albacore and salmon, facilitate other predators' access to prey (Ainley et al. 2009). Such a strategy, i.e., going to where other predators are actively foraging, is also among the favorites used by human fishers.

Including forage fish concerns with respect to predators into management, i.e., EBFM, is certainly on the minds of managers (Meyer 1997, Leet et al. 2001, Etnoyer et al. 2004), but achieving it, as just noted, is not as simple as just the development of harvest strategies that account for predator needs by reducing overall take levels by certain amounts (e.g. Cury et al. 2011, Pikitch et al. 2014). To succeed, we will need to better understand the spatio-temporal dynamics of forage fish availability, associated predator movement patterns (including fishing vessels), and predator-to-predator and predator-prey interactions, thus to understand better the complexities in developing management plans (California Fish & Game Commission 2013). While it is true that some portion of a forage fish prey stock should be available to natural predators (Cury et al. 2011, Pikitch et al. 2014), and to some degree this is already being considered in some cases at the state and federal levels, successfully implementing that goal in the CCS requires much additional information on the dynamic spatial and temporal aspects of predator-fishery-prey interactions (see, e.g., Smith et al. 2011).

Towards management of forage fish in the California Current: a workshop

To address these issues, a workshop was held 10-13 September 2013 in Petaluma CA, hosted by Point Blue Conservation Science, to i) gather together the existing information on forage fish and predator dynamics in the California Current; ii) summarize and present that information to a large range of experts in oceanography, fish and fisheries management, seabirds, marine mammals, and ecosystem management; and iii) gather insights from these experts and organize both the information and feedback in a readily available peer-reviewed publication. Important issues considered in the workshop were temporal (seasonal, annual, decadal) and spatial availability of prey complexes and why these patterns of availability occur and change.

A workshop setting was the perfect venue for synthesizing what is known about the dynamics of these forage fish hotspots, how to implement this knowledge into EBFM plans, and what future research priorities should be considered to address uncertainties and unknowns. Important in information transfer was the opportunity of formal and informal interaction among experts in different disciplines. In the selection of presentations, we emphasized three California Current hotspots that are important for marine mammals, birds, and fishes: Channel Islands-Point Conception, Gulf of the Farallones – Monterey Bay, and Cape Blanco – Columbia River plume vicinity (see Nur et al. 2011). However, insights into how predators respond to the preyscape vagaries came as well from research conducted in other eastern boundary currents (Benguela, Peru, Gulf of California; Bertrand et al. 2005, 2008, 2012; Pichegru et al. 2010, 2011; Velarde et al. 2013).

The workshop program can be found in Appendix A and workshop participants in Appendix B. The presentations and the rapporteurs' notes can be found at the following password protected website; approval to access given when password is requested: http://www.pointblue.org/foragefish. To obtain passwords for access contact: marinedirector@pointblue.org.

The presentations or notes cannot be cited or used without written consent of the presenters involved or authors of this document.

STATE OF THE SCIENCE

A brief history of applying ecosystem based-fishery management in the California Current System

Ecosystem based fishery management (EBFM) has a long history and the lack of a clear, direct solution suggests that this is a complex and difficult problem. Herein is a brief summary of its application to the CCS; see Fields & MacCall (Day 1-AM) for a more complete presentation.

Beverton & Holt (1957), the basis for the modern single-species fishery assessment, analyzed the Lokta-Volterra equations specifically to examine the forage fish issue, and so recognition of the forage fish issue started at the beginning of fishery management. Early on, the need for and operational difficulties of EBFM, especially as applied to the CCS, were apparent (Hobson & Lenarz 1977), particularly in regard to issues of data needs, understanding of biological interactions, and socioeconomic aspects of management. By the 1980s, responding to the need for EBFM, the National Marine Fisheries Service initiated several large-scale data collection and modeling projects [Georges Bank (Sissenwine et al. 1984), Northwest Pacific (Laevastu 1995), etc.] to address this need. This response has led to a range of EBFM modeling approaches: single-species assessments that explicitly include climate, predation, etc.; Multispecies Virtual Population Analysis (MSVPA); aggregate biomass models (Ecopath, Ecosim, Ecospace); and End-to-End models (e.g., Brodeur et al. 2011) and other whole ecosystem models (Atlantis).

Among these models, MSVPA (Sparre 1991) is an extension of traditional VPA that partitions instantaneous natural mortality (M) for a given forage species into predation by various predators. This approach has been somewhat successful, but has extensive data requirements and is sensitive to deviations in predator dynamics from the mass-action equations used to represent predator-prey dynamics (Kinzey & Punt 2009). There also have been several aggregate biomass models: Ecopath (Polovina 1985), Ecosim (Walters et al. 1997), and Ecospace (Walters et al. 2000). These models are designed to evaluate various policy alternatives, but the aggregations of species often make them less suitable for tactical management advice.

These latter models also use mass-action predator-prey dynamics and are sensitive to deviations from their assumptions. Full-featured ecosystems models (Atlantis: Fulton et al. 2004, 2011) have a full range of spatial and temporal components and the realistic population dynamics and predator-prey dynamics. Such models have been developed in the California Current, and used to evaluate trade-offs among different fisheries and objectives, including the impacts of fisheries on forage species to food webs (Kaplan et al. 2012, Kaplan et al. 2013). However, parameterizing this type of model also requires extensive data collections and often large numbers of criteria assumptions have to be made, compromising the model integrity. The lack of sophistication in representing predator-prey dynamics, spatio-temporal components, and impact of environmental factors, along with extensive need for data have led to challenges in the interpretation of model results for management, particularly with respect to the appropriate characterization of uncertainty (Link et al. 2012). It is the authors' opinion that models are much cheaper to derive than the collection of realistic data, so individual models for each ecosystem situation (not for individual species) may be the best approach. That way, data collection can be more directed. If there ever is agreement on what models should be used remains an open question.

It is important to note that Federal legislation has not required ecosystem based approaches, although most Fisheries Councils in the U.S. have moved forward toward some level of EBFM. The collapse of the cod stock in the North Atlantic, in particular, forced fishery biologists to recognize the need to consider ecosystem function as part of management. While the collapse of the fishery occurred due to overfishing, the recovery of the cod stock has been hindered by top-down, ecosystem, food web processes (Bundy 2001), thus emphasizing the need for an ecosystem approach to management.

The first instance of including ecosystem considerations in management of US fisheries was the Pacific Fishery Management Council's Northern Anchovy Fisheries Management Plan (FMP) (PFMC 1978) which targeted "maintaining an anchovy population … of sufficient size to sustain an adequate population of predator fish, birds, and mammals". This plan in part recognized recovery needs for Endangered Species Act (ESA) listed predator species, particularly Brown Pelican. It set a cutoff parameter at half of maximum sustainable yield biomass based on relationships between anchovy population size and pelican fledging success (Anderson et al. 1980, 1982), and was sensitive to the foraging range of the pelicans. The northern anchovy fishery is currently small enough that it is no longer actively managed. On the other hand, as a more recent example of applying EBFM, the Eastern Bering Sea walleye pollock catch was reduced from Maximum Sustainable Yield (MSY) due to a shift in spatial distribution, a reduction in forage for juvenile pollock, and increased predation on juvenile pollock by arrowtooth flounder (Lanelli et al. 2006). This management, too, addressed needs for another ESA-listed predator, the western population of northern (Steller) sea lion.

Further incorporation of ecosystem function into FMPs can be expected as scientific justification is established. However, the only current mechanism for including ecosystem function in FMPs, and management control rules occur under the 1996 Sustainable Fisheries Act that enables the reduction of Optimal Yield from MSY for a variety of reasons including ecological factors. Some of the most direct considerations of ecosystem function in FMPs has been the recent prohibition of fisheries on shortbelly rockfish (PMFC and NMFS 2011) and on euphausiids (PFMC 2008) in the CCS in light of overwhelming evidence substantiating their role as major prey of both fished and non-fished predator species. Otherwise, actual incorporation of ecosystem function into existing FMPs is more difficult and does require substantial justification.

The Pacific Fishery Management Council's Pacific Coast Fishery Ecosystem Plan (FEP) (PFMC 2013) represents a substantial recent advancement in the application of ecosystem management in U.S. waters off of the West Coast (www.pcouncil.org/wp-conten t/uploads/FEP_February2013_Draft_for_web.pdf). Offering an attractive example for the CCS, the North Pacific Council, which has a Fisheries Ecosystem Plan for the Aleutian Islands, has been doing an ecosystem considerations chapter for over two decades, has healthier (in general) fish populations than off the Pacific Coast, has a cap on total landings and a prohibition on new forage fisheries, and has some of the most advanced ecosystem models in the world, including the data in many cases to parameterize them (3 decades of time series data on food habits for many key predators).The Pacific Coast Plan itself is an informational document that describes a two stage approach to improve Council management decisions. The first stage is to increase description and consideration of ecosystem function and incorporation into

FMPs. The next step is for stock assessment models to include model sensitivity runs testing hypotheses on ecosystem considerations or impacts on a specific stock. Results could then be used to define alternative states of nature as the basis for the decision tables within current single species stock assessments, explicitly including ecosystem interactions. When implemented, the second stage is to increase the progress toward a whole picture assessment of the CCS Ecosystem. This approach is described in an annual report published by the California Cooperative Fisheries Investigations (Wells et al. 2013). More specifically, "the needs for ecosystem-based fishery management within the Council process are:

1. Improve management decisions and the administrative process by providing biophysical and socio-economic information on CCE climate conditions, climate change, habitat conditions and ecosystem interactions.
2. Provide adequate buffers against the uncertainties of environmental and human-induced impacts to the marine environment by developing safeguards in fisheries management measures.
3. Develop new and inform existing fishery management measures that take into account the ecosystem effects of those measures on CCE species and habitat, and that take into account the effects of the CCE on fishery management.
4. Coordinate information across FMPs for decision-making within the Council process and for consultations with other regional, national, or international entities on actions affecting the CCE or FMP species.
5. Identify and prioritize research needs and provide recommendations to address gaps in ecosystem knowledge and FMP policies, particularly with respect to the cumulative effects of fisheries management on marine ecosystems and fishing communities. "

Just as important is the Plan's FEP Initiatives Appendix (www.pcouncil.org/wp-content/uploads/FEP_Initiatives_Appendix_for_web.pdf), which describes the priority activities for Plan implementation in the first several years. Importantly, Initiative #1 addresses unmanaged forage species:

"FEP Initiative 1 is intended to recognize the importance of forage fish to the marine ecosystem off of the U.S. West Coast, and to provide adequate protection for forage fish. The Council's objective is to prohibit the development of new directed fisheries on forage species that are not currently managed by the Council, or the States, until the Council has had an adequate opportunity to assess the science relating to any proposed fishery and any potential impacts to our existing fisheries and communities.

The Initiatives Appendix also identifies the Bio-Geographic Region Identification and Assessment Initiative: Section 3.1.2 of the FEP identified three large scale bio-geographic regions of the CCE that could be further subdivided into finer scale nested sub-regions to provide the Council with a framework for undertaking finer scale fisheries management actions to implement ecosystem-based management and to facilitate linkages with other government policies and processes. One possibility for defining such spatial divisions could be based upon the functional distributions of species, for example: estuarine habitats, nearshore habitats, inshore demersal habitats, offshore demersal habitats, and pelagic habitats (coastal and offshore)".

Also in California in 2012, a new state policy on forage species adopted by the Fish and Game Commission acknowledges the importance of forage species and sets a course for precautionary management that progressively incorporates ecosystem information into fisheries management. The policy addresses fished and unfished species. The Commission must now operationalize the unmanaged species portion of the policy through new regulations. For managed species, Pacific herring is the focus of attention for implementing the policy.

GENERAL GUIDELINES

Spatio-temporal variation in the prey scape: the challenge of ecosystem based-fishery management in the California Current System

The key to existing as an upper trophic level predator in the CCS is the ability to switch prey at within- and between-seasonal, inter-annual and decadal scales in response to inherent variability in the preyscape and the needs of the predator. Moreover, while several geographically persistent "hotspots" of prey availability do concentrate predators within the CCS-wide scale (see Background), often this may require shifting location within regions as well, which is more of a challenge for central-place foraging species (e.g., pinnipeds, seabirds) than for free-roaming species (e.g., cetaceans, predatory fish). However, even the latter can be severely constrained spatially as a function of various issues, the best example being Chinook salmon needing the limited availability of rivers of suitable size and outflow for spawning.

"Forage fish" have been defined most recently by Pikitch et al. [2014, p 44: "…small or intermediate-sized pelagic species (e.g., sardine, anchovy, sprat, herring, capelin, krill) that are the primary food source for many marine predators, including mammals…., seabirds ….., and larger fish."] or PEW [2013, p 3: "…small open ocean schooling fish that remain at the same level in the food web for their entire life cycle, and due to their size and abundance are important as forage during their adult life-phase"]. While such definitions work at a broad scale in addressing EBFM concerns, for the CCS specifically and its high preyscape variability the definition essentially must be: *the prey species prominent in the diets of CCS predators* (the definition used by Oceana 2011, who then discussed only classical "forage fish"). As noted above, and developed more fully in this section of the report, the species mix composing the preyscape in the CCS is far more complex than the above generalities bespeak, and include not just the classic pelagic, schooling species but also the juveniles of piscine predators (e.g., salmon, rockfish, hake), which themselves may be the subject of intensive fisheries. Managing this scenario cannot be easy, even without including the socio-economic needs of humans, but owing just to the natural history of the system itself.

In fact, a fairly good example of the problem facing CCS predators is illustrated in the "forage fish" net-haul fisheries of the Gulf of California, the predators in this case being fishing vessels

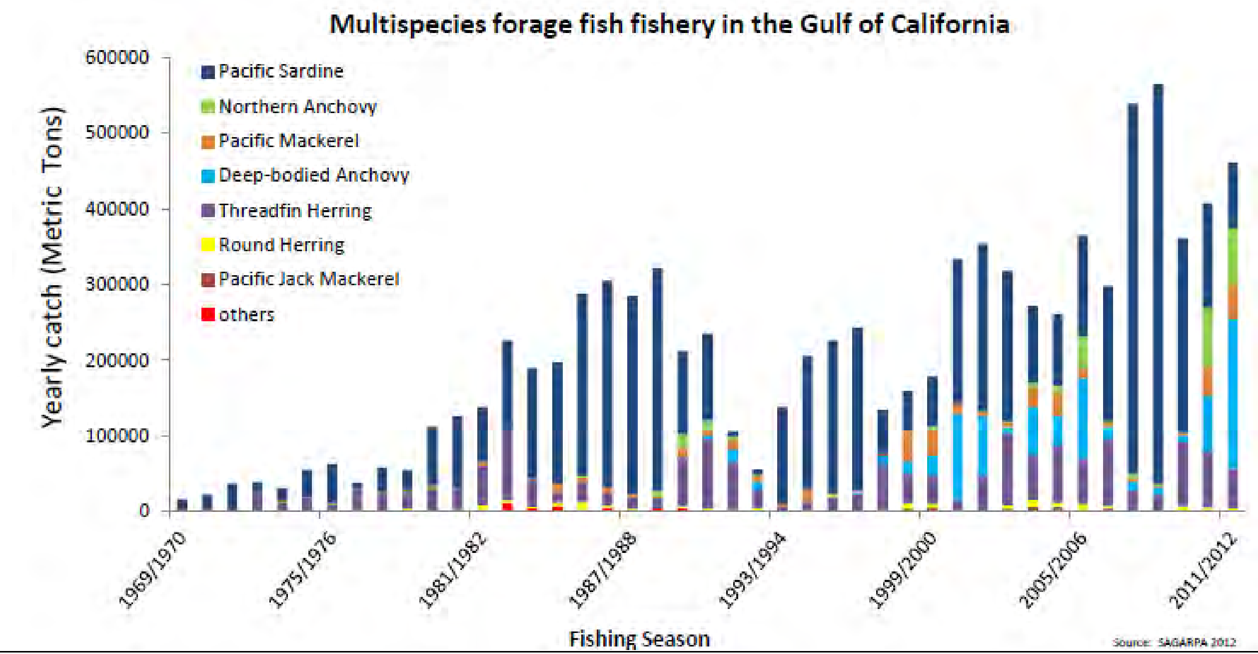


Fig. 1. Variation in the annual tonnage and species composition of the net-haul fisheries of the Gulf of California, 1969-70 to 2011-12.

(Velarde et al., Day 3 - AM). The fishery targets sardines at a somewhat non-conservative level, which are heavily and almost exclusively fished until natural variation intercedes, often related to climate anomalies (El Niño) and perhaps enhanced by heavy fishing pressure. The sardine stock then exhibits dramatic boom-and-bust cycles, and the sardine stock frequently collapses (unlike the conservatively managed stock in the CCS; MacCall, Day 1-AM). Until the sardine stocks recover, to maintain operators' livelihoods the vessels must fish other pelagic species. This is exactly the behavior of natural predators in the CCS, who when populations of preferred forage species decline must switch to alternate prey to maintain at least a low level of productivity (see below) or in extreme cases experience reduced reproduction (Ainley & Boekelheide 1990; Elliott et al., Day 3-AM; Webb & Harvey, Day 3-AM; Velarde et al., Day 3-AM; see also summary in PEW 2013), increased mortality (Nevins et al., Day 3-PM) and ultimately reduced populations (Vilchis et al., Day 3-PM).

In the central and northern CCS (data are sparse for the southern region), based on the diets of the major predatory species (Appendix C), the top ten "forage species" are, in order of rank (Table 1): anchovy (juvenile and adult), rockfish (multiple species, juveniles), squid (mostly market squid, adults), herring (juvenile and adult), smelt (true smelts in the north and central, other smelts in the southern CCS; adults), Pacific hake (juveniles and adults), crustacea (includes shrimp, crab megalopa), flatfish (mostly sanddabs, juvenile and adult), sandlance (adults), and salmon (juveniles). This assemblage does include some of the "classic" forage species, but half of them are the juveniles of predatory, and managed fish species. Krill likely would have ranked higher if winter/early spring data were included in the data presented at the workshop, as well as if species such as blue whales and Cassin's auklets, which are krill specialists (and thus show little spatial or temporal variation), had also been included in the analysis. Sardines may have ranked higher (as well as lanternfish and saury) if sampling had included waters off the shelf, and if the predators had included more of the larger species, such as certain cetaceans (e.g., fin whales).

In the northern CCS, herring replaces anchovies and rockfish which are ranked 1 or 2 in the central CCS. In the north, sandlance and true smelts are ranked higher; sardines and saury are more important in the central CCS than in the north. The juveniles of major groundfish species, such as lingcod and sablefish, are more important as prey in the southern CCS, which is somewhat ironic in that these fish are far more abundant in the north. Not enough data were available for waters south of Point Conception to be included in the regional comparison, as noted above.

Table 1. A ranking of prey species in the diets of 32 predators throughout the CCS (north, central and south; see Appendix C); and a comparison of regional differences between the northern and central portion, among 14 predators *common* to both regions and having sufficient diet data (data were too sparse among overlapping predators to include the southern portion). Data were derived from the presentations at the CCS predator-preyscape workshop, which covered continental shelf and slope waters and mostly the spring-autumn period (no winter). In the regional comparison, the boxed cells note significant regional differences in the ranks attained by respective prey species. Occurrence = Percent of instances by species/sampling area/year in which this prey species was abundant enough to be ranked among the top 10 for respective predator species; weighted score = sum of the ranks weighted by position (rank 1 = 10 points, rank 2 = 9 points, etc.). The data (and literature sources) from which these figures are based are displayed in the next section (spatial variation and temporal variation in preyscape) as well as in the individual workshop presentations. Washington data include waters of the Strait of Juan de Fuca (i.e., to the shores of British Columbia).

	All area of CCS				Washington/Oregon				Central and Northern California			
	Occurrence		Weighted Score		Occurrence		Weighted Score		Occurrence		Weighted Score	
Prey species	%	Rank	Sum	Rank	%	Rank	Sum	Rank	%	Rank	Sum	Rank
Anchovy	13.5	**1**	585	**1**	11.8	**2**	111	**2**	14.8	**1**	204	**1**
Rockfish	12.2	**2**	505	**2**	9.7	**3**	81	**4**	14.2	**2**	189	**2**
Squid	10.9	**3**	454	**3**	9.7	**3**	80	**5**	13	**3**	175	**3**
Herring	7.8	**4**	346	**4**	13.2	**1**	124	**1**	6.5	**4**	76	**5**
Smelt	6.5	**5**	263	**5**	9.7	**3**	97	**3**	4.7	**7**	57	**8**
Hake	5.7	**6**	260	**6**	6.3	**5**	70	**7**	4.1	**8**	62	**7**
Crustacea	3.8	**7**	173	**7**	2.1	**8**	18	**12**	3	**9**	42	**10**
Flatfish	3.8	**8**	164	**8**	2.8	**7**	31	**11**	2.4	**10**	28	**14**
Sandlance	3.6	**9**	148	**9**	9	**4**	79	**6**	1.8	**11**	25	**15**
Salmon	3.6	**10**	136	**10**	6.3	**5**	38	**8**	5.9	**5**	69	**6**
Sardine	3.4	**11**	146	**11**	0.7	**10**	5	**17**	4.1	**8**	51	**9**
Sculpin	3.4	**12**	129	**13**	1.4	**9**	15	**14**	1.8	**10**	14	**19**
Krill	3.2	**13**	136	**10**	4.2	**6**	37	**9**	3	**9**	39	**11**
Saury	3.0	**14**	133	**12**	2.8	**7**	13	**15**	5.3	**6**	77	**4**
Midshipman	2.3	**15**	91	**14**	0.7	**10**			1.8	**10**	18	**17**
Tomcod	2.1	**16**	87	**15**	4.2	**6**	34	**10**	1.2	**12**	15	**18**
Surfperch	1.7	**17**	62	**17**	1.4	**9**	16	**13**	1.8	**10**	15	**18**
Octopus	1.7	**18**	67	**16**	0.7	**10**	3	**18**	1.2	**12**	19	**16**
Mackerel	1.5	**19**	55	**19**					1.8	**10**	19	**16**
Cusk-eel	1.5	**20**	56	**18**					1.2	**12**	33	**13**
Sablefish	1.1	**21**	41	**20**					3	**9**	35	**12**
Lingcod	1.1	**22**	39	**21**					3	**9**		
Croaker	0.6	**23**	14	**24**	1.4	**9**	8		0.6	**13**		
Lanternfish	0.6	**24**	17	**23**	1.4	**9**	10	**16**				
Prickleback	0.4	**25**	9	**25**								
Lamprey	0.4	**26**	18	**22**	0.7	**10**	10	**16**				
Pipefish	0.4	**27**	18	**22**								

Spatial/geographic variation in the preyscape: regional perspective

A number of species that have been sampled widely in the CCS illustrate well the latitudinal change in diet. In the case of fish, Pacific albacore (Fig. 2), its major prey off Oregon and Washington during the 2000s are anchovies, hake and crustacea; off California, sauries and hake predominate; and off Baja California, anchovies and sardines are important. Where the high energy anchovies are consumed in large proportion, results of bioenergetics models indicate that albacore actually swim faster than when they are in transition zones (Glaser, Day 2-PM).

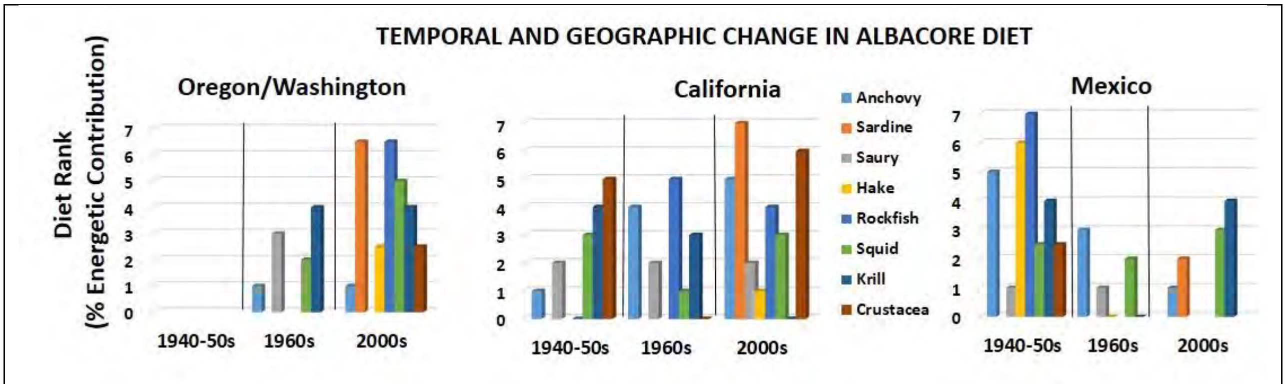


Fig. 2. Temporal and geographic variation in the diet of albacore tuna in the CCS; data from Brodeur et al. (Day 1-PM) and Glaser (Day 2-PM). Note: shortest bar is the highest rank!

Among Chinook salmon (Fig. 3), herring is important in the north, especially in later years, replaced by anchovies as the primary target in the central CCS. Crustacea, including crab megalopa, are important in the central CCS, while krill and squid seem more important off Oregon and Washington.

Similar variation is apparent among seabirds (Fig. 4). Brandt's cormorant is a species that feeds on or just above the bottom in sandy or muddy substrates (not rocky). Flatfish (sanddabs) are prevalent in the diet in all sampling areas, but other species vary though not in a spatially consistent manner. For instance, cusk-eel and tomcod are included in the diet in the Gulf of the Farallones but not elsewhere, and squid become more prevalent in the diet towards the south. In the case of the common murre, one of the most abundant CCS seabirds and which feed mid-water anywhere over the shelf, herring, sandlance and smelt replace anchovies and rockfish as latitude increases; krill appear to be more important in the north. As for pigeon guillemot, a species that feeds on or near the bottom in rocky habitat, sculpins, rockfish and flatfish (sanddabs) are the main prey in the Gulf of the Farallones, with sanddabs, silversides and anchovies being more important near Pt Conception.

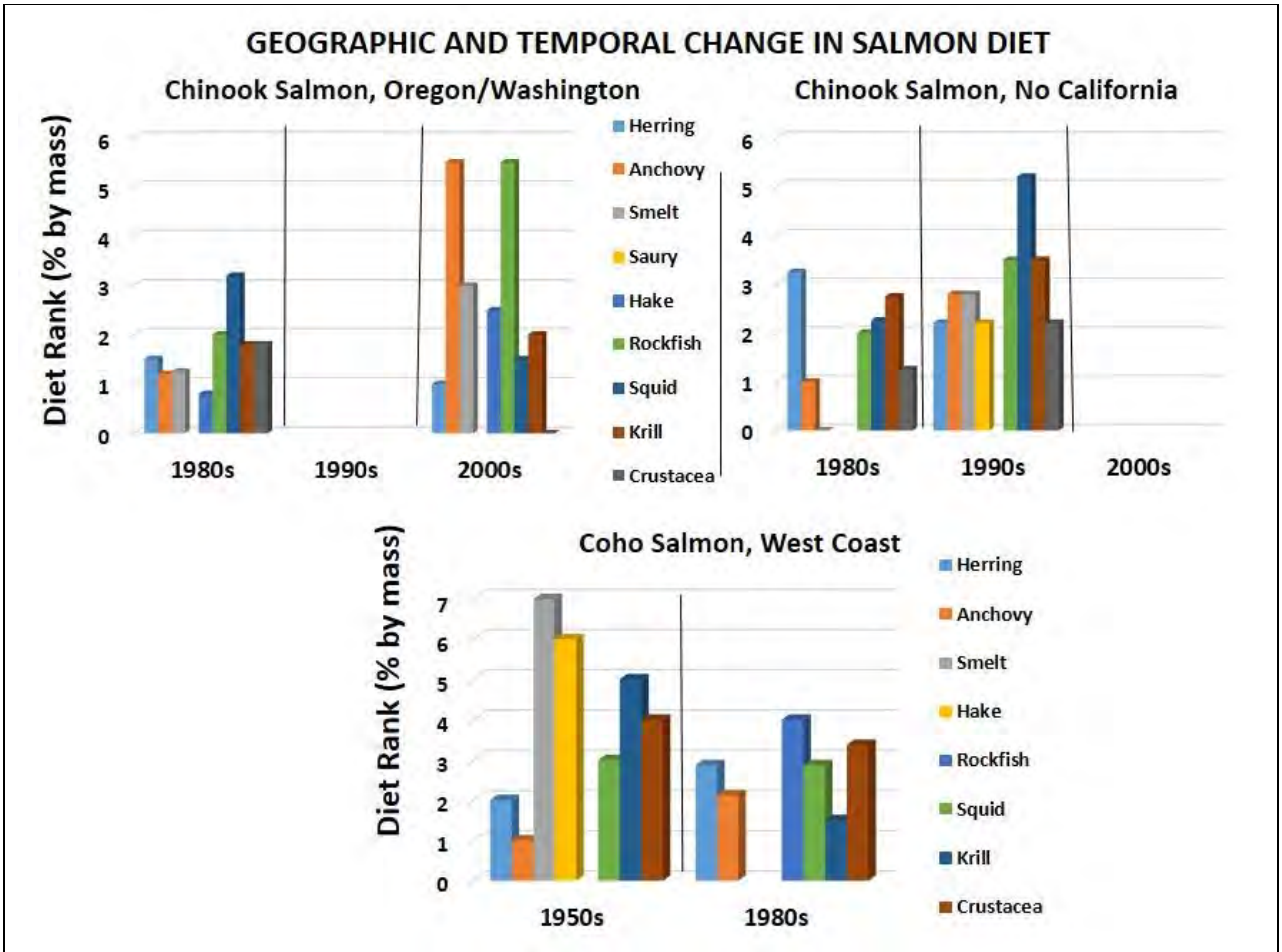


Fig. 3. Geographic and temporal variation in the diet of Chinook and Coho salmon in the CCS; data from Brodeur et al. (Day 1-PM) and Adams et al. (Day 2-AM). Note: shortest bar is the highest rank!

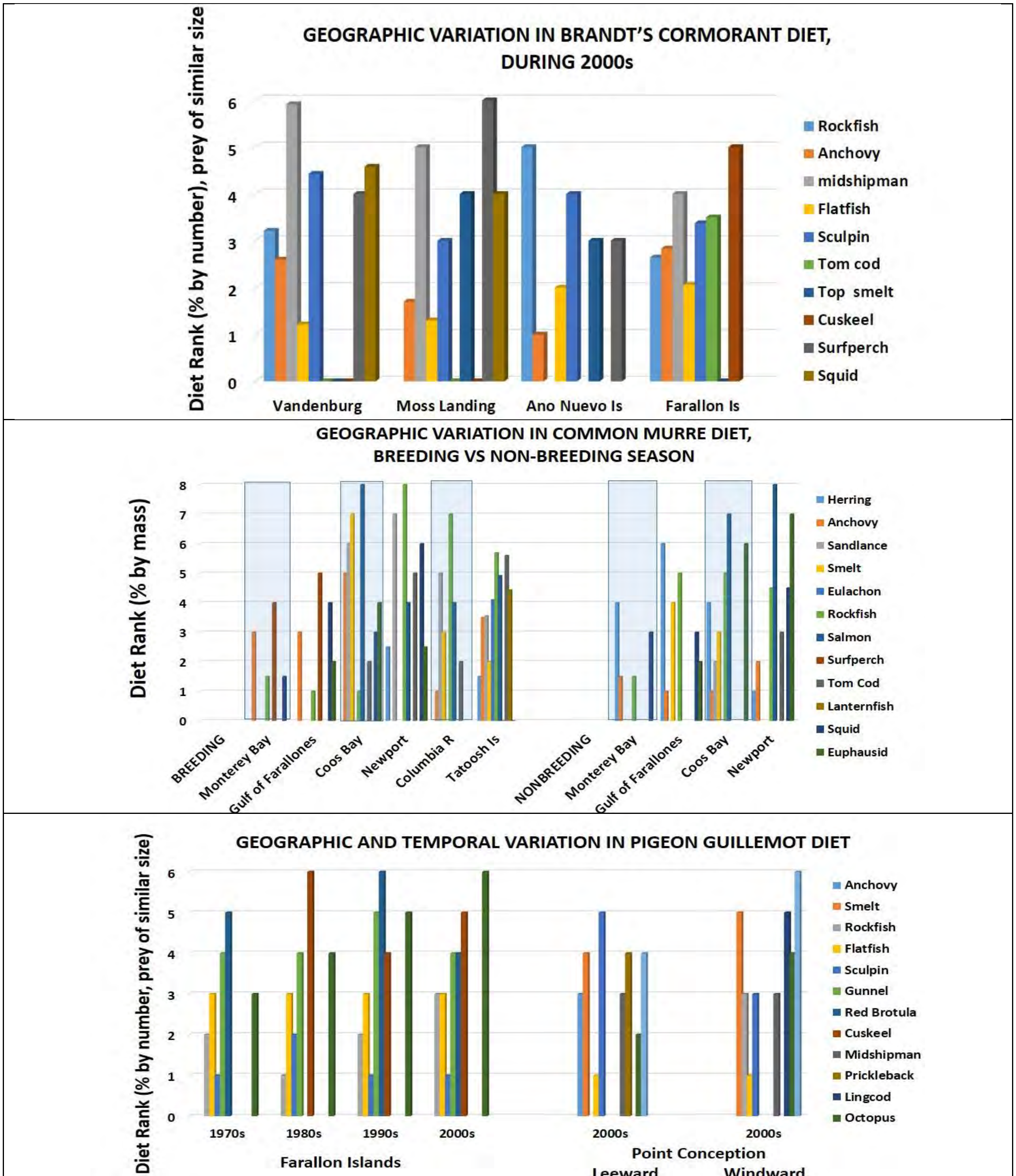


Fig. 4. Geographic variation in the diet of three seabird species in the CCS: top, Brandt's cormorant; middle, common murre; and bottom, pigeon guillemot (data from Ainley et al., Day 1-PM; Elliott et al., Day 3-AM; Webb & Harvey, Day 3-PM; and Suryan & Gladics, Day 3-AM. Note: shortest bar is the highest rank!

Among pinnipeds (Fig. 5), sufficient data for comparison were available for California sea lions and harbor seals, the sea lion occurring throughout shelf waters and the seal in mostly coastal habitat. Pacific hake and market squid are important diet components everywhere for the sea lion, but diet appears to be more complex in the south and central CCS than in the north. The locally resident harbor seal appears to be more of a bottom feeder, with octopus, market squid and sanddabs being important depending on area. As in the sea lion, the diet is less complex in the north. Herring is a major dietary component north of central California.

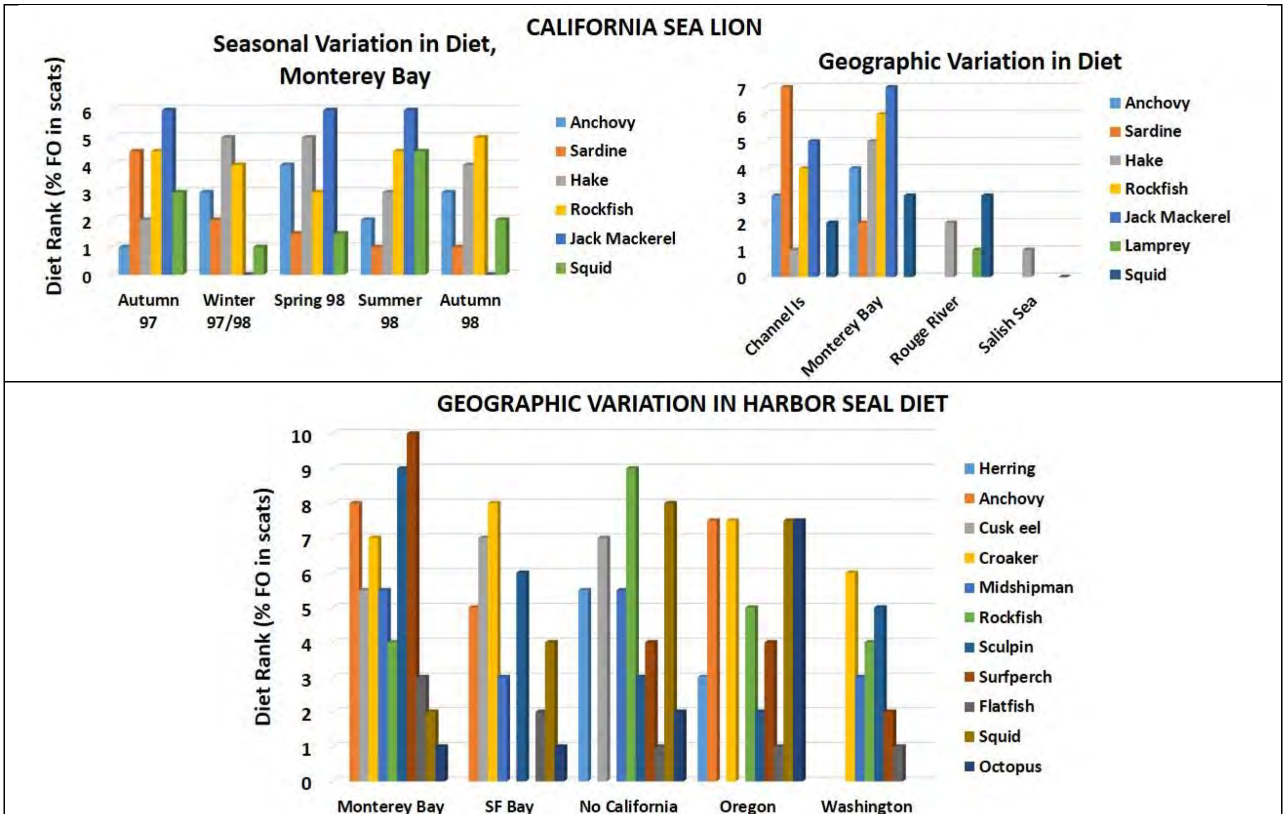


Fig. 5. Seasonal and geographic variation in the diet of California sea lions and harbor seals in the CCS; data are from Harvey (Day 1-PM) and Lowry (Day 3-PM). Note: shortest bar is the highest rank!

Finally, ample data are available to look at geographic variation in the diet of two porpoise species, Dall's and harbor porpoise (Fig. 6). Differences in diet between the two species reflects the more coastal occurrence of the harbor porpoise, e.g., hake is less important than for Dall's porpoise, which has a less complex diet. For both species, herring and pollock are prevalent in the diet in the north (Salish Sea) but not the south; squid are important especially in the north.

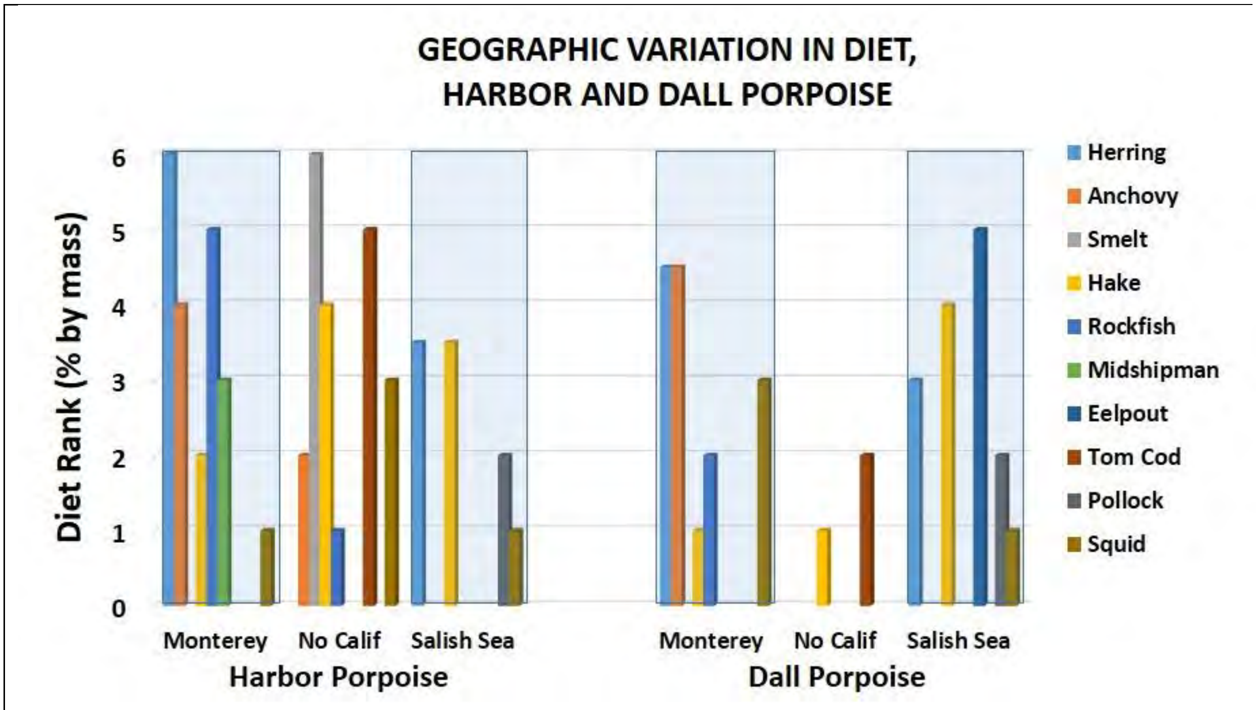


Fig. 6. A comparison of geographic variation in the diets of harbor and Dall's porpoise in the CCS; data from Ainley et al. (Day 1-PM). Note: shortest bar is the highest rank!

Spatial/geographic variation in the preyscape: sub-regional perspective

If prey availability varied only at the latitude/regional scale then applying EBFM might be easily tractable in the CCS. However, diet as a reflection of prey availability in the CCS can vary dramatically for a particular species as a function of location within a "hot spot" (see also Santora et al., Day 1-AM; Reese & Brodeur, Day 2-PM). The best examples of this come from the Gulf of the Farallones and studies of Chinook salmon (Adams et al., Day 2-AM), Brandt's cormorants (cf. Elliott et al., Day 3-AM; Webb & Harvey, Day 3-PM), common murres and rhinoceros auklets (Ainley et al., Day 1-PM). In the case of Chinook salmon and common murres, when foraging in outer shelf waters, their diet is dominated by krill and juvenile rockfish, but when occurring more coastally they feed on herring and anchovies. Brandt's cormorant diet is dominated by sanddabs and rockfish as well when foraging in outer shelf waters, but when foraging near the coast anchovies become much more prevalent in their diet.

One of the best studied predators in the CCS, in terms of spatial resolution of diet during summer, is the rhinoceros auklet (actually a puffin). The rhinoceros auklet is known to prey heavily on krill during the early spring; however, during the summer, especially when they feed their chicks, their diet is mainly fish (Fig. 7). Colonies and respective sampling occur in both inner, coastal locations (Año Nuevo, Gulf of the Farallones; Protection Island, inner Salish Sea), as well as outer coast and outer shelf locations, where it feeds more along the shelf break (Farallon Islands; Destruction Island, near Cape Flattery, outer Salish Sea). Where the auklet feeds along the shelf break, like the albacore (Glaser, Day 2-PM), the Pacific saury is the principal prey species, and this is especially prevalent among Gulf of the Farallones auklets where foraging often is truly offshore. Sauries are minimally, if at all, represented in the diet where the species is feeding over the shelf, even its outer reaches (Año Nuevo, Destruction Island). In the inner, coastal locations, the auklets prey predominantly on anchovies and sandlance, and juvenile salmon become a regular prey item.

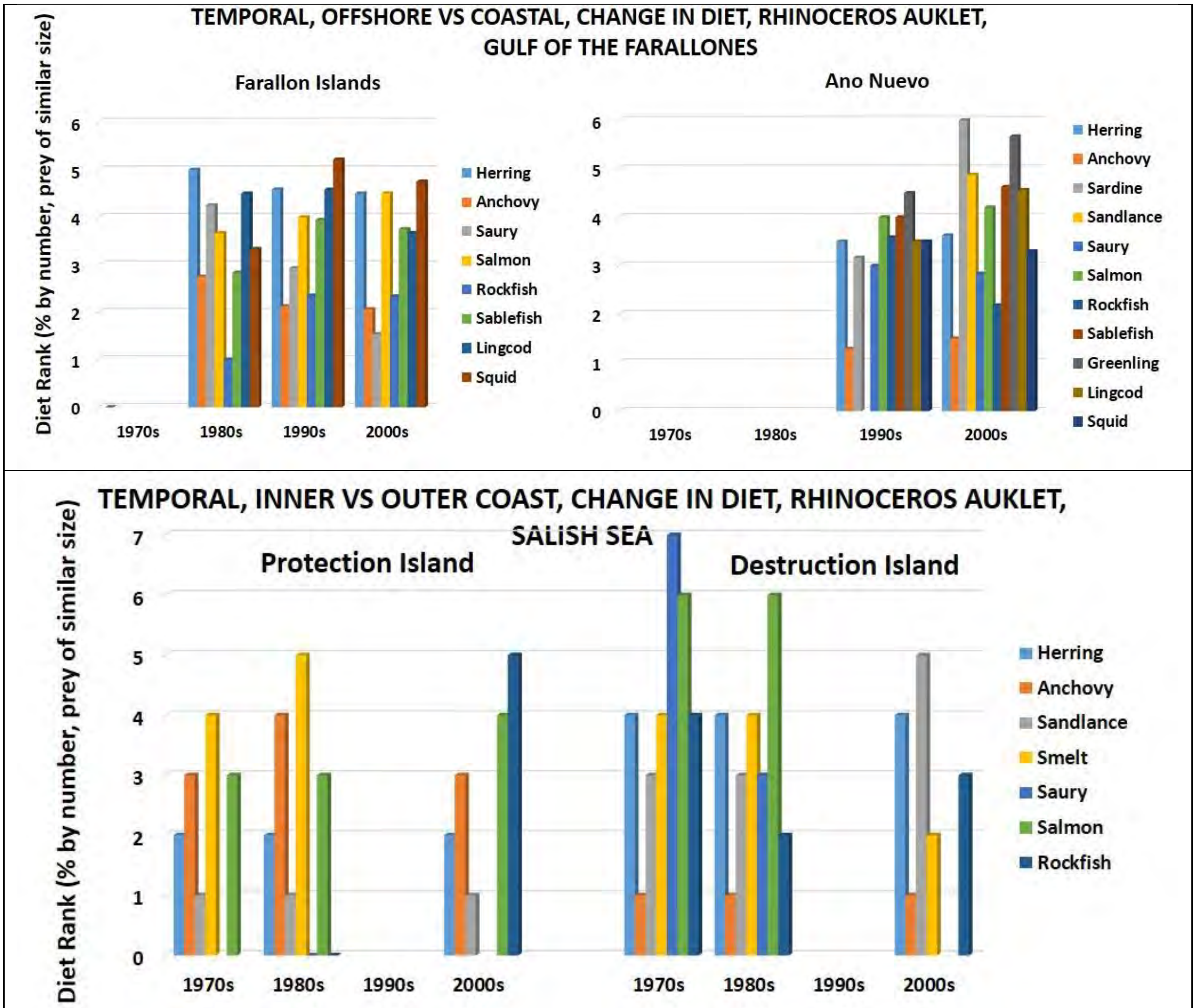
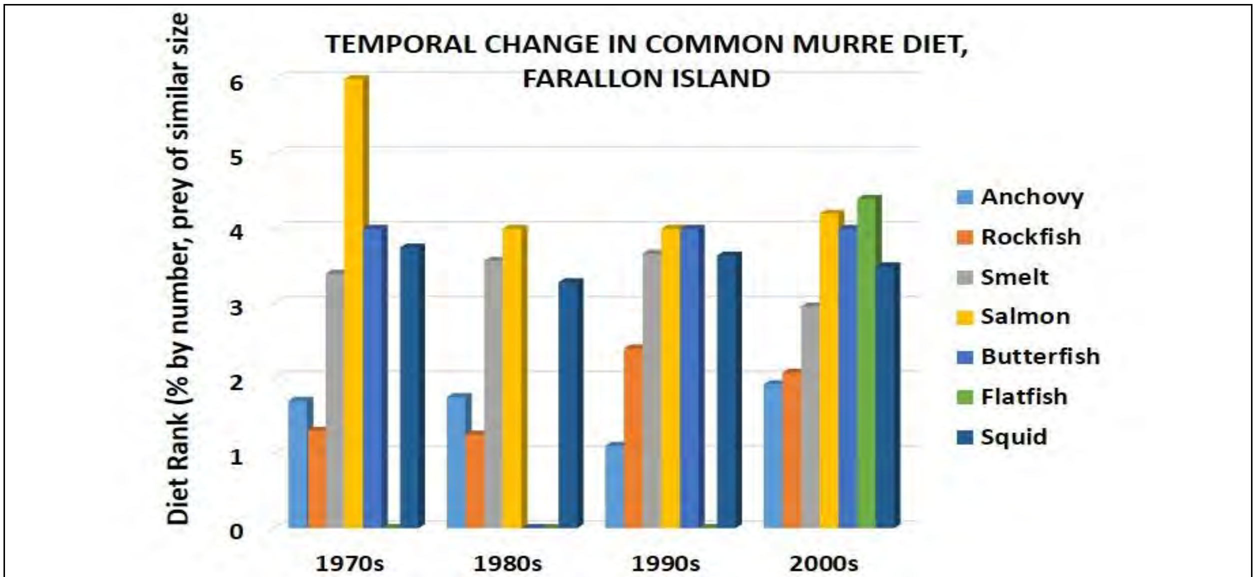
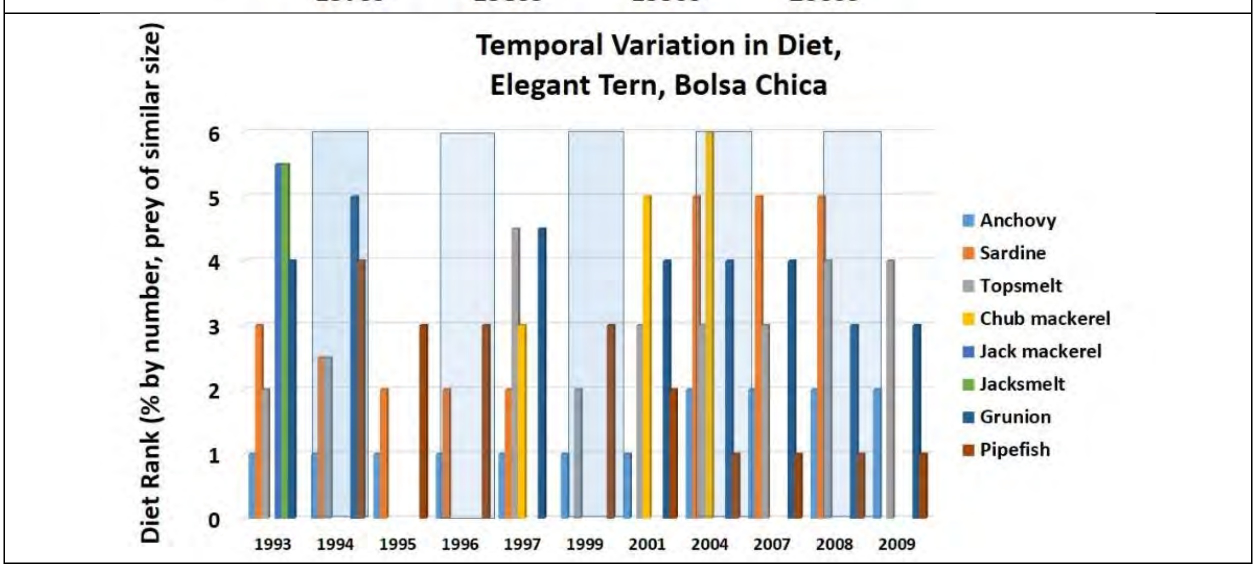


Fig. 7. Temporal and geographic variation in the diet of rhinoceros auklet in the CCS; data from Ainley et al. (Day 1- PM). Note: shortest bar is the highest rank!

Temporal variation in the preyscape

Patterns evident in a number of predator diet investigations in the CCS reflect changes in the availability of certain prey species at a decadal scale. One of the best examples is provided by juvenile rockfish, which before the collapse of the stocks due to over-fishing in the mid-1980s (Field & MacCall, Day 1-AM; Ralston, Day 2-AM) were of major importance in the diet of Chinook salmon (Fig. 3), pigeon guillemots (Fig. 4), Brandt's cormorants (Elliott et al., Day 3-AM), rhinoceros auklets (Fig. 7), and common murres (Fig. 8). In accord with decreasing abundance of anchovies in the CCS, especially in the south (MacCall, Day 1-PM), the occurrence of this prey species has declined in the diets of elegant and least terns (Fig. 8). In the case of elegant terns, pipefish appear to have replaced the anchovy. As for least terns, the diet has become much more diverse than previously observed.





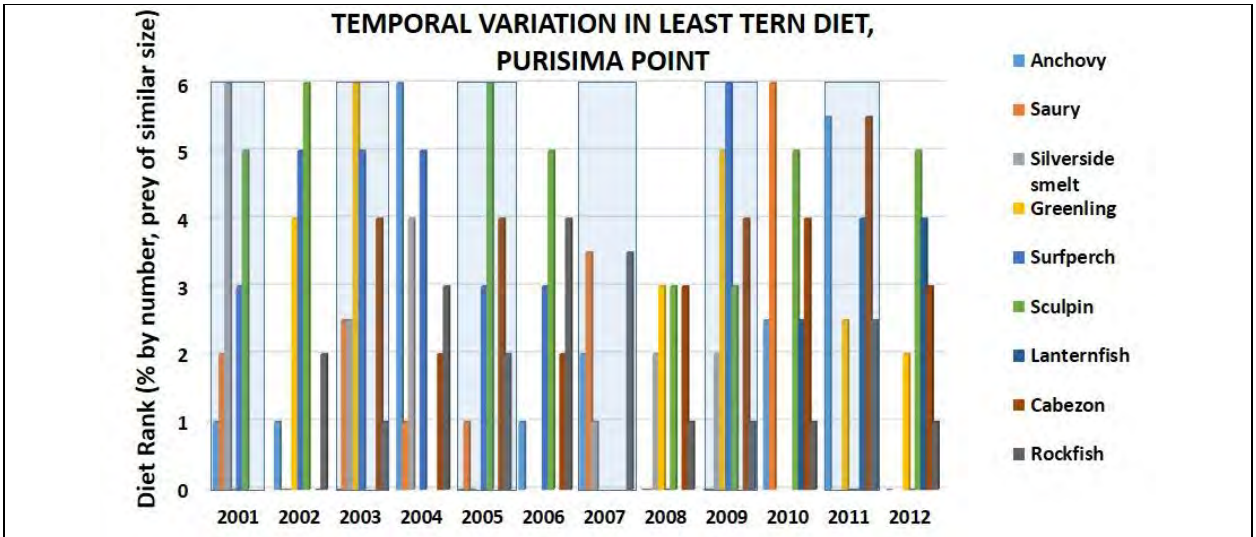
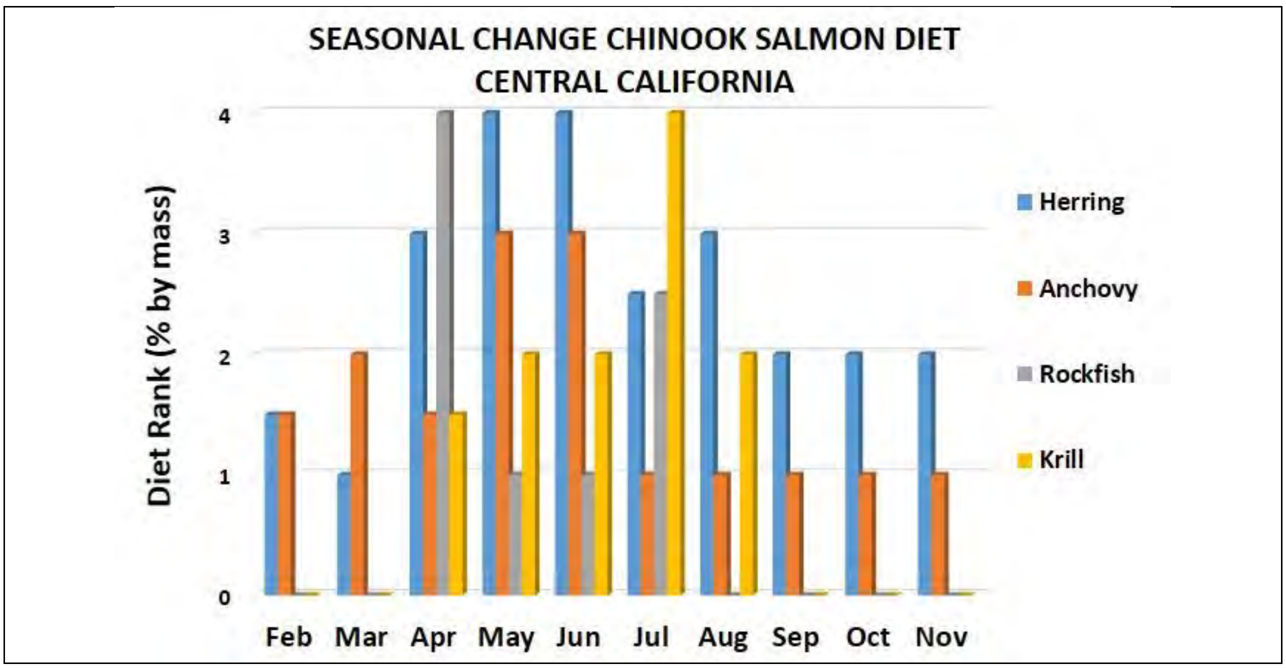


Fig. 8. Decadal change in the diets of common murre in the central CCS (top), and of elegant (middle) and least terns (bottom) in the southern CCS; data from Ainley et al. (Day 1-PM) and Horn (Day 3-AM). Note: shortest bar is the highest rank!



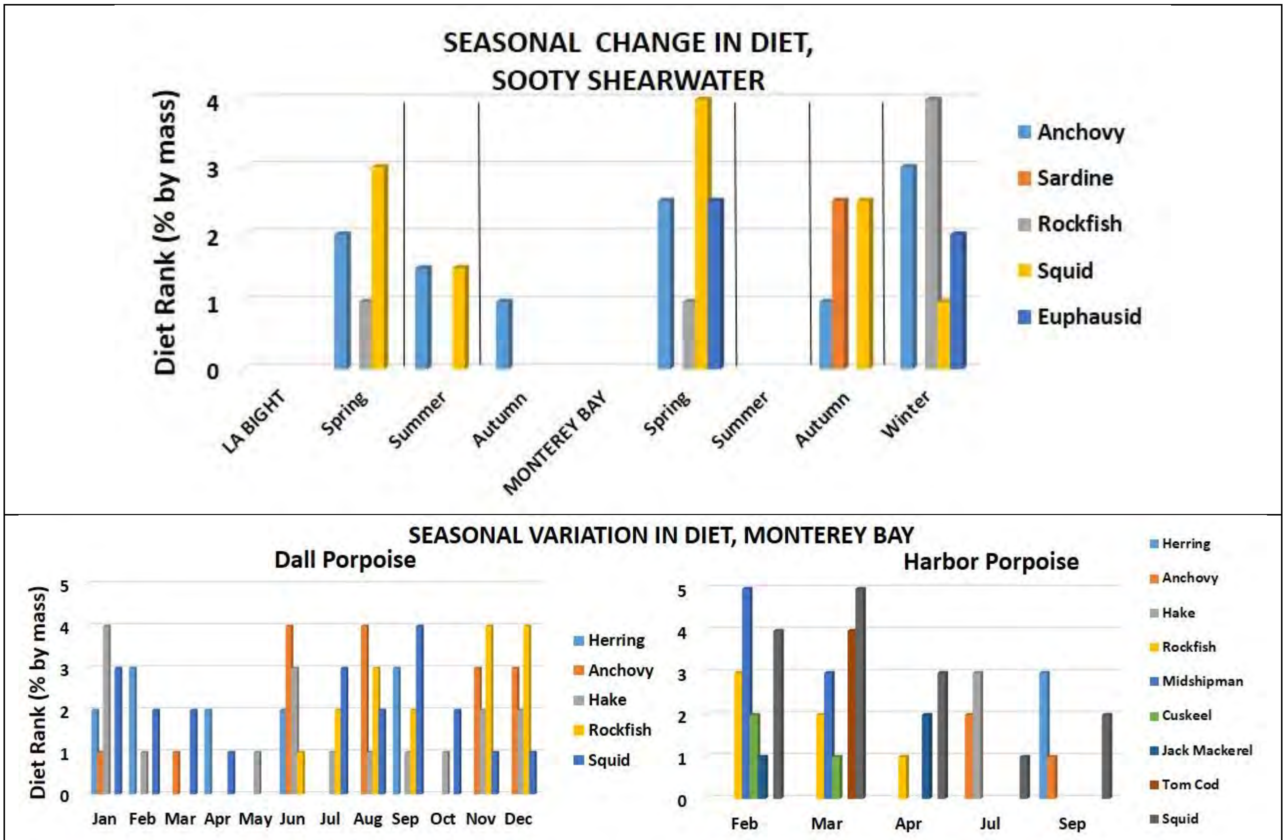


Fig. 9. Seasonal variation in diet of Chinook salmon (top), sooty shearwaters (middle) and porpoise (bottom) within sub-regions of the CCS; data from Adams et al. (Day 2-AM), and Ainley et al. (Day 1-PM). Note: shortest bar is the highest rank!

Diet among predators can also vary dramatically within year, i.e., seasonally, and within a sub-region like the Gulf of the Farallones or Monterey Bay. Good examples of this are illustrated by Chinook salmon, sooty shearwaters, and harbor porpoise (Fig. 9), as well as common murres (Ainley et al., Day 1-PM). In all cases, late in the summer, these predators are switching to energy-dense anchovies: in the case of the salmon and shearwater, prior to annual, long-distance migration: in the case of the murre to provide food for chicks during their most rapid growth period and while the adults are molting, and for the porpoise, perhaps during their gestational period. Earlier in the year, diets more likely reflect availability of prey. For example, juvenile rockfish disappear from diets as the rockfish grow and settle to the bottom. This phenomenon may also explain the reduced take of rockfish by Dall's porpoise as well (Fig. 9).

Trends in the forage base and effects on the preyscape

The attributes of the classic "forage species," reviewed in the workshop --- herring (Weinstein & Hay, Day 1-PM), market squid (Zeidberg, Day 1-AM), anchovies and sardines (MacCall, Day 1-PM; McClatchie, Day 2-AM), true smelt (Adams, Day 2-AM), and krill (Santora et al., Day1-AM; Shaw et al., Day 1-AM; Wells et al., Day 2-PM) --- essentially confirmed the idea that high abundance and a schooling nature were of utmost importance --- see also PEW 2013 (which contains vignettes for the classic forage species). Easy availability and high energy density are the two most important traits of a forage species, classic or not (Weinstein & Hay, Day 1-PM; Adams, Day 2-AM; Glaser, Day 2-PM).

In most spawning areas along the CCS, herring are decreasing in abundance (Weinstein & Hay, Day 1-PM), with the species spawning largely confined these days to the Salish Sea and vicinity (plus the now somewhat isolated SF Bay). Factors behind the decrease appear to be climate variability, pollution and overfishing, more so in the past. Eulachon, the most abundant CCS true smelt are ESA-listed owing to anthropogenic factors, primarily climate variability (Adams, Day 2-AM). True smelt along the California coast exhibit severely reduced abundance. The reasons are unclear, but probably are due to climate change and spawning habitat (beaches) degradation; however, their status and trends are not closely monitored. Anchovies and sardines also appear to be disappearing owing to natural, cyclic factors (MacCall, Day 1-PM; McClatchie, Day 2-PM), though identifying specific environmental factors remains elusive (Mendelssohn, Day 1-AM). Market squid appear to be cyclic in abundance, and the take by humans has been increasing (perhaps as a replacement for the other, decreasing “forage fishes”; Zeidberg, Day 1-AM, and see as an example, not including squid, Fig. 1).

The changes such as those just reviewed do not bode well for CCS predators, as alternate prey are required for switching. Without the ability to switch, predator numbers will decrease (Vilchis et al., Day 3-PM), owing to decreased reproductive output (Elliott et al., Day 3-AM; Velarde et al., Day 3-AM; Suryan & Gladics, Day 3-AM) as well as direct mortality (Nevins et al., Day 3-PM). These trends also do not bode well for food web modeling (Zeidberg, Day 1-AM; Reese & Brodeur, Day 2-PM) given the apparent transitory state of predator-prey relationships in the CCS; nor for predictive modeling (Lyday et al., Day 3-PM); and nor do they make easy using the more modern, indirect techniques of food web analysis, i.e., stable isotopes, to characterize species diets or foraging behavior, e.g., for whales (Fleming, Day 3-PM; Palacios et al., Day 3-PM) or for seabirds (Suryan & Gladics, Day 2-AM).

How the decrease in the classic forage species will ripple down in the food web remains unknown without concerted and repetitive sampling. On the one hand, there might be less competition for prey (Daly, Day 2-PM), but on the other the increase in jellyfish, which compete directly with small fish for prey, may compensate (Brodeur et al., Day 2-PM). Does the prevalence of juvenile fish of species like sablefish, lingcod, etc. in the diets of predators in the central-northern portion of the CCS (Table 1) reflect the decreasing availability of classic forage species? Is the fact that one can predict salmon spawning-run size in the Sacramento River system by the amount of krill in the Gulf of the Farallones region (Wells et al., Day 2-PM) also a reflection of the seeming simplification of the forage base that appears to be underway? Krill abundance in this area does appear to be doing well, if the recent (re-)invasion of large whales into central California waters is any indication (Ainley & Hyrenbach 2010). Adult Chinook salmon diet at least in central California has only been investigated into the early 1990s, covering a time in which anchovies and rockfish juveniles still ranked with krill as major diet components (Brodeur et al., Day 1-PM; Adams et al., Day 2-AM). Whether that is the case now, remains to be seen. The food web of the CCS needs to be diverse for a reason, as the system has a wide range of states. One group of prey may do well under one set of ocean conditions, but not well under another, while another group of prey may have the opposite response. As noted, predators can meet these wide range of ocean conditions by switching from one group of prey to another. However, as these prey systems become simplified this becomes less possible, and may facilitate an increased "boom or bust" type of predator abundance cycle as only a few prey are sustaining the system. When conditions are good for the prey left in the simplified system, predators will do well but when conditions are bad for remaining prey, predator abundance will crash (Ainley & Boekelheide 1990, and references therein; PEW 2013, and references therein; Elliott et al., Day 3-AM; Webb & Harvey, Day 3-AM; Velarde et al., Day 3-AM; Nevins et al., Day 3-PM; Vilchis et al., Day 3-PM). This type of dramatic swing in abundance leads to unstable conditions that can cause extinction and are difficult for fishery management.

Going forward in applying ecosystem based-fishery management in the California Current System

To reiterate what was said in the Introduction to this report:

> In the past, management policies have given attention to individual forage species deemed to be particularly important to California Current System (CCS) food web dynamics, e.g., anchovy management plan…., shortbelly rockfish management plan….., and the recent prohibition on large-scale commercial take of euphausiids….. ***More recently, changes in national fishery policy places importance on establishing a more complete understanding of predator-prey relationships involving forage fish***. In addition, the California Fish and Game Commission has recently adopted policy guidelines toward progressively incorporating ***Essential Fishery Information (EFI) for "ecosystem-based management of forage species, including physical factors, oceanographic conditions, the effects of fishing on forage species' dependent predators, the availability of alternative prey, spatio-temporal foraging hotspots for predators, and existing management, including marine protected areas*** …..

In that regard, and as revealed in this workshop, implementation of these new fishery policies to facilitate EBFM will be much more complex than current single-species approaches and simple food web type models illustrate. There have been substantial efforts to investigate approaches to implement EBFM and the current situation is testament to the fact that this is not simple nor an easy problem to resolve. The focus of current legislation on single species fishery management remains, and there needs to be legislation clarification of what these more general statements about EBFM mean.

The three major points from this workshop, incorporating the finer elements identified above (Major Conclusions Resulting from the Workshop, P. 4), are as follows:

1. **Who eats whom?** Even single-species predator-prey relationships are complicated not just by how much of each prey the predator is feeding, but temporal and spatial variability as well. When multiple predators are considered, the complexity increases even more. Understanding these multiple predator prey interactions is essential for implementing EBFM. Species-specific research provides the building blocks for management, but this needs to be expanded to other species and their interactions with the prey. We learned that there are not a large number of specialists in the CCS preyscape; instead, any specialization may have to do with habitat types, such as bottom or mid-water, inshore or offshore. Four or five main species constitute the forage base, and they have different levels of importance to different predators. Knowing that generalists dominate the CCS and that there are a limited number of prey is a good place to start, but additional complexity comes from the seasonality and spacing of the prey that affect their availability.
2. **Spatial/temporal hotspots:** We have information for the ecologically important hotspots, including both predators and prey. The issue of scale was identified as important, in that there are a wide range of scales used in research, but depending on the questions being asked, there is a need for localized *and* wide-scale research on par with the scale of both the predators and the fisheries.
3. **Harvest control**: We learned a great deal about the preyscape from the declines in predator populations or aspects of natural history (e.g., population size, breeding success, recruitment) when in conjunction with knowing spatio-temporal aspects of foraging behavior, including diet, and this is where we see the greatest effects on the fishery and ecosystem dynamics. There is a need for people to recognize that many declines, e.g., anchovy-sardine, are natural occurrences, and we can (and have) also overfish(ed) during these periods to exacerbate declines (Lindegren et al. 2013). There are other declines that are not natural, e.g. rockfish, although these stocks are now recovering due to more rigorous management. Like all models, stock assessments often include a lot of uncertainty and are far from perfect, but when informed by data they provide essential information when the stock is on a downward curve, and often why, which is critical to management, and information about how predators are faring could be useful.

Major information gaps identified in this workshop

- Better understanding of the nature of predator-prey interactions on various forage fishes. When does feeding change, where does feeding change, where do feeding locations change from and to, and equally important why do these changes occur?
- A better understanding of extreme oceanic events (El Niño, etc.), since the changes that occur during these events reveal how these predator-prey interactions operate;
- Spatially and temporally explicit prey species abundance or, better, availability thresholds, revealed among predators, as early indicators of change, as a function of prey biomass;
- Effects of commercial take and climate change on defining these thresholds, towards establishing Integrated Ecosystem Assessments (IEAs);
- Data at different scales for the novel, real-time applications (matching resources with who is using those resources, including humans), i.e., the simultaneously determined foraging ambits of predators;
- Information on smelt, saury, sandlance and myctophid populations and their importance in the diets of predators;
- Information on the nearshore environment and the species who inhabit it (e.g., herring, sandlance, smelt);
- Importance of juvenile fish to the foodweb (e.g., salmon, rockfish, sablefish, lingcod); information on these early life stages is sparse for many species;
- Energetic values of prey to distinguish whether energy density or prey availability is the important factor used by a predator to 'choose' its diet, which changes seasonally;

How to fill these gaps?

Mining of existing data and integrated investigation is needed to address these gaps. Long time series of prey and predator data are available for the central portion of the CCS but have yet to be merged and synthesized as an integrated preyscape. In addition, monitoring of different parts of the ecosystem at the same time is needed to understand how changes in one part of the system impact other parts. This type of integrated investigation is essential to develop the understanding of what level of prey species abundance would constitute thresholds and how these levels of prey abundance change in response to natural oceanographic variation and to harvesting. This is along the lines of what was accomplished in the Northern California Current GLOBEC program, which emphasized the mid-trophic levels (i.e., prey) and relationships to predators, i.e., salmon, seabirds, mammals. Real-time, coincident surveys and process studies were accomplished for forage species as well as predators, along with the standard oceanographic investigation. Such investigations should be carried out where there are hotspots both of predators/fisheries as well as institutions, with their resources, geared to be undertaking the task; otherwise, if too remote, then effort and data gaps appear. The two prime examples would be the Gulf of the Farallones/Monterey Bay (GoF/MB) and the Columbia River Plume/Heceta Bank (CRP/HB) areas. Clearly, they are predator hotspots as a function of prey availability and also have on-going fisheries for forage fish. In addition they represent the transition in the prey assemblage that dominates predator diets (see Table 1). In the GoF/MB, long term predator work is being carried out by Point Blue Conservation Science (predators: Farallon Islands; ACCESS Partnership cruises), Oikonos Ecosystem Knowledge (predators: Año Nuevo), NMFS-Santa Cruz (rockfish and other species assessment, salmon research), UC Santa Cruz (pinnipeds predators Año Nuevo), NMFS-PFEG Monterey (sardines, anchovies), as well as efforts and resources from UC Davis-Bodega Marine Lab, UC Santa Cruz-Long Marine Lab, and Moss Landing Marine Lab. In the CRP/HB region, long term fisheries work, including predators and prey, is being carried out by NMFS-Newport, with close cooperation of Oregon State University and University of Washington (mammals, seabirds, forage fish). In both areas, work on cetaceans by Cascadia Research Cooperative has been accomplished.

Incorporating information into fishery management plans

Typically, the PFMC conducts a stock assessment, and the control rule comes later; it is the control rule where our work could be useful, particularly spatio-temporal data, as fully emphasized in this report. Important aspects of predator-prey interactions would be incorporated into control rules so that critical ecosystem function would be protected. It was noted that there is no control rule for predators, such as salmon at least from an ocean ecosystem perspective, so this would be something useful to accomplish in the interests of EBFM. The PFMC's primary tool for incorporating this information into FMPs are actions through the Pacific Ecosystem Plan and the Ecosystem Advisory Team. This process will provide the mechanism for ongoing communication between both this workshop and ecosystem research with the PFMC.

MANAGEMENT APPLICATIONS

1. Importance of key species interactions

Observation: Predators, whether fish or fowl, need to have the ability to switch prey, i.e., other prey need to be abundantly available even if predators can change foraging area (or breeding site) in order to cope with variability in the CCS preyscape. Evidence indicates that this has to be considered on decadal, interannual, and seasonal time scales, much as the behavior of human fishers (who fish different resources in different seasons, years, etc.). For example, following the decline of the Pacific sardine fishery in the 1950s, sardines disappeared from the diets of many key predators (whales, sea lions, salmon), despite the fact that those populations themselves were stable or increasing (Hannesson et al. 2009, their appendix A). Adding to the complexity are the seasonal migrations within the CCS of predatory species such as salmon, Pacific hake, market squid, tuna, sea lions and cetaceans, as well as migrations of forage species, such as sardines.

Policy application: The combination of temporal and spatial variability of ocean processes inherent in the CCS, these predator-prey interactions, and complex species natural history characteristics leads to an extremely complex situation. The challenge associated with ecosystem modeling to inform EBFM are substantial, and include a perceived need to develop spatially-explicit regional models with the appropriate resolution by species and life history stage. The ability to identify key interactions and timeframes, through directed research, will be the answer to designing a successful EBFM regime. New types of sampling will be needed to provide the understanding necessary for effective EBFM.

Recommendation: A 'State of the Ecosystem Report' that compiles current data, strongly integrates physical and biological series, and applies it to managed species is needed. This report and research program might well be modeled after that of the North Pacific Fisheries Management Council.

2. Composition of the CCS "forage fish" preyscape

Observation: "Forage fish" species include not only the "traditional ones", e.g., anchovy, sardines, herring, smelt and market squid, but also importantly include juveniles of various groundfish (e.g., rockfish, hake, lingcod, sablefish, flatfish), salmon, and Dungeness crabs, as well as adult krill, hake, saury, sand lance, and mesopelagic fish. For large predators, such as marine mammals or large fish (e.g., billfish, sharks, halibut), forage fish might include the subadults or even adults of predatory fish, such as salmon, hake and rockfish. All factors being equal, prey selection by predators is heavily weighted toward energy density of the prey, but in the case of central-place foraging predators with a restricted feeding radius, high levels of prey nearby often overrides aspects of energy density.

Policy application: Effective EBFM has the problem of dealing in an integrated way with fisheries both on predatory fish and the forage fish upon which they depend, as well with recovery of depleted stocks of both fish and predators (including non-fish species). To the extent that such specific ecosystem needs can be quantified or characterized, they should be incorporated into Fishery Management Plans (FMPs), and precautionary approaches to address uncertainty need to be incorporated into overharvested or depletion recovery scenarios. One approach should be to identify the most important forage species (plural) for a given managed predator fish fishery, quantify the prey biomass necessary to maintain the predator population at sustainable levels (incorporating some level of uncertainty), and protect (at a minimum) that forage biomass from fishing pressure. Moreover, it should be recognized that prey availability to predators represents much more than just maintaining a certain biomass level of the prey, i.e., it is not just a linear relationship (biomass is not the same as availability). In addition to the need for forage biomass/availability estimates, similar assessments are needed for other predator fish species. As a third priority or goal, add to that the forage biomass/availability needed for the numerically important, or legally protected (ESA listed) unexploited predators. Also see 3.

Recommendation: The spatio-temporal patterns of occurrence and interactions of main prey for each managed species need to be identified. Juveniles of managed species, such as rockfish, need to be addressed appropriately through harvest guidelines. Other marine wildlife's prey requirements need to be considered as well.

3. Importance of real-time fish stock assessments

Observation: We know from investigations of, e.g., anchovy, sardine and true smelts, that forage species' abundance can vary dramatically at both annual and decadal time scales owing to both intense food web (including human fishing) and climatic pressures, independent of factors that affect landings. However, the temporal scales at which these resources respond to these pressures remain uncertain. It appears that these resources experience extended periods during which any harvest would accelerate the ongoing decline in abundance, as well as periods when harvest would have little effect.

Policy application: The length and overall impact of the swings in abundance exhibited by forage species are a necessary challenge to assess in real time, as indicated by anchovies and sardines, but miscalculation can lead to severe depletion and/or delay of recovery until environmental conditions improve. Because of this uncertainty and realizing that we lack all that we'd like to know about what affects abundance, no fishery on such forage species can be classed as "sustainable" in the conventional sense of being able to support some level of harvest indefinitely. Ultimately, the sustainability of fisheries on forage species will require increasing accuracy in real time assessments, an improved understanding of the mechanisms that lead to variable productivity in such populations over time and space, and an overall precautionary and adaptive approach to setting harvest quotas.

Recommendation: Annual stock assessments are needed to compensate for extreme spatio-temporal variability in forage availability throughout the CCS. All approaches to assessing annual forage fish availability should be considered, including physical oceanography derived indices and variation in predator abundance and distribution.

4. The lag in ecosystem responses to change

Observation: The CCS preyscape is changing, as reflected in seasonal, interannual and decadal variation in predator diet, as well as in shifts in predator locations (e.g., Brandt's cormorant shifting from the Farallones to adjacent coastal locations).

- Some of these changes are beyond human control, e.g., sardine – anchovy cycling; sardine spawning habitat moving farther offshore; change in market squid spawning location;
- Some changes are due to other human-caused reduction, e.g., decreased salmon owing to decreased spawning habitat; and
- Other changes are due to recoveries from exploitation, e.g., rockfish, cetaceans, and the increased consumption of forage species involved.

Policy application: The high level of variability of the CCS preyscape causes time lag challenges for effective EBFM. As with #3, this significant uncertainty calls for a precautionary and adaptive approach to setting harvest quotas. It also calls for attention to address possibly conflicting management goals, e.g., exploitation of forage based on current stock assessments in the face of ongoing increases in predator populations (e.g., California Current marine mammals) or attempts to increase the abundance and productivity of predator populations (e.g., threatened or endangered salmon. In these cases a cushion built into Fishery Management Plans might well be effective).

Recommendation: Annual stock assessments should anticipate lags in species responses to human pressure and climate variability at appropriate spatio-temporal scales in the CCS. The demographic capacities of prey species are particularly important for rebuilding stocks.

5. The spatio-temporal foraging overlap between humans and wildlife

Observation. When human and natural predators compete for the same prey at the same time, the natural predators *always* lose. We have seen this in real time in anchovy-sardine systems of the Benguela/Agulhas and Humboldt current systems, as well as in the Gulf of California, but not yet in the CCS, where directed local study that includes both human and wild predators has yet to be conducted. In the CCS, however, this phenomenon has been demonstrated at a decadal scale, e.g., fishery depletion of rockfish or disappearance of salmon (to varying degree exacerbated by climate variability); this has led to shortages of juveniles of these species as prey, and predators responded by switching to other prey, thereby shifting the forage pressure to other species.

Policy application: Research is needed in the CCS to gauge the real-time spatio-temporal aspects of foraging by both predators and fishing vessels. Ultimately, zoning or smaller geographic scale harvest control rules might be one approach for areas where central-place foragers with restricted spatial options are prevalent (seabirds, pinnipeds). Such controls have been instituted in the past, e.g., in the anchovy management plan. Access by managers and enforcement personnel to high resolution VMS (Vessel Monitoring System) data would be critical to adjust or maintain the boundaries of spatial planning.

Recommendation: Incompatibilities of simultaneous foraging by vessels and predator species as they adjust to the availability of forage fish need to be addressed to avoid conflict. More than just the stock size needs to be considered in managing the spatio-temporal aspects of foraging by vessels and predators.

6. Spatial aspects of foraging locations

Observation: The preyscape is composed of small scale hotspots, both predictable and ephemeral, existing within larger hotspots. The larger hotspots in the CCS are (see, e.g., Nur et al. 2011): Straits of Juan de Fuca, Columbia River mouth, Cape Blanco, Cape Mendocino northwards, Cordell Bank-Gulf of the Farallones-Monterey Bay, Point Conception-Northern Channel Islands, and southern Channel Islands. These preyscape hotspots are also hotspots for commercial fishing. As examples of further partitioning, within the Cape Blanco hotspot, a smaller hotspot area exists at Heceta Bank (Brodeur et al., Day 1-PM); within Gulf of the Farallones, smaller hotspots are at Cordell Bank, Pioneer Canyon, Ascension Canyon (Santora et al., Day 1-AM). The large scale hotspots are formed by processes associated with topographic features, such as capes, banks etc.; smaller scale hotspots are seasonally ephemeral and are related to upwelling, plumes, jets etc. The importance of some of these hotspots to avian predators may depend on the proximity of other features that are important to the predators e.g., proximity of suitable nesting habitat.

Policy application: If any zonal or geographically controlled harvest options for fishery management are contemplated, attention must be given to these hotspots. An example has been the closing of Cordell Bank to trawling to preserve an area of high productivity and natural, under-sea beauty, and perhaps more important from a direct management perspective, to help to rebuild depleted rockfish stocks.

Recommendation: Research to identify small scale hotspots associated with topographic features would help to reduce human pressure on the preyscape important to managed species. This might best be handled by a multiagency consortium.

7. Predators and their prey are not necessarily full time residents.

Observation: In the CCS, robust predator and forage populations are, in some cases, dependent upon processes outside of the CCS itself, in addition to local ocean processes. Examples include: (i) enhanced survival of salmon in the CCS is affected by robust body condition of smolts upon entering the ocean, which is affected by freshwater/river spawning habitat quality; (ii) a number of species that populate the CCS during certain seasons come from elsewhere, i.e., most importantly, the Gulf of California (e.g., several species of cetaceans, pinnipeds, and seabirds) as well as from the west (e.g. turtles, albacore, albatrosses and shearwaters); and (iii) proximity of suitable nesting habitat for seabirds is a process outside the CCS upon which predators and forage fish depend.

Policy application: CCS fishery managers need to be aware of these 'peripheral' issues to achieve management goals. There needs to be better communication between the management councils and the organizations that manage species that cross international or marine-estuarine borders. One example is the reduction of vessel collisions by altering traffic patterns with cetaceans, which are attracted to swarming krill hotspots. What results is a *de facto* spatial management, i.e., fishing vessels likely avoid areas of heavy ship traffic.

Recommendation: We recommend that fisheries managers and scientists work together to address issues that occur across political boundaries, perhaps through PICES (North Pacific Marine Science Organization).

REFERENCES

Ainley, D.G. & R. J. Boekelheide (eds.). 1990. Seabirds of the Farallon Islands: Ecology, structure and dynamics of an upwelling system community. Stanford University Press, Palo Alto.

Ainley, D.G., K.D. Dugger, R.G. Ford, S.D. Pierce et al. 2009. The spatial association of predators and prey at frontal features in the northern California Current: Competition, facilitation, or merely co-occurrence? Marine Ecology Progress Series 389:271–294.

Ainley, D.G. & K. D. Hyrenbach. 2010. Top-down and bottom-up factors affecting seabird population trends in the California current system (1985–2006). Progress in Oceanography 84: 242-254.

Ainley, D.G., L.B. Spear & S.G. Allen. 1996a. Seasonal and spatial variation in the diet of Cassin's Auklet reveals occurrence patterns of coastal euphausiids off California. Marine Ecology Progress Series 137: 1-101.

Ainley, D.G., L.B. Spear & S.G. Allen. 1996b. Temporal and spatial variation in the diet of the Common Murre in California. Condor 98: 691-705.

Anderson, D.W., F. Gress & K.F. Mais. 1982. Brown pelicans: influence of food supply on reproduction. Oikos 39: 23-31.

Anderson, D.W., F. Gress, K.F. Mais & P.R. Kelly. 1980. Brown pelicans as anchovy stock indicators and their relationships to commercial fishing. CalCOFI Reports 21: 54-61.

Bertrand, S., J.M. Burgos, F. Gerlotto & J. Atiquipa. 2005. Levy trajectories of Peruvian purse-seiners as an indicator of the spatial distribution of anchovy (*Engraulis ringens*). ICES Journal of Marine Science 62: 477–482.

Bertrand, A., F. Gerlotto, S. Bertrand, M. Gutierrez et al. 2008. Schooling behaviour and environmental forcing in relation to anchoveta distribution: an analysis across multiple spatial scales. Progress in Oceanography 79: 264–277.

Bertrand, S., R. Joo, C.A. Smet, Y. Tremblay et al. 2012. Local depletion by a fishery can affect seabird foraging. Journal of Applied Ecology 49: 1168–1177.

Beverton, R.J.H. & S.J. Holt. 1957. On the Dynamics of Exploited Fish Populations, Fishery Investigations Series II, Volume XIX, Ministry of Agriculture, Fisheries and Food, FAO, Rome.

Block, B.A., I.D. Jonsen, S.J. Jorgensen, A.J. Winship et al. 2011.Tracking apex marine predator movements in a dynamic ocean. Nature 475: 86-90.

Brodeur, R.D., E.A. Daly, R.A. Schabetsberger & K.L. Mier. 2007. Interannual and interdecadal variability in juvenile coho salmon (*Oncorhynchus kisutch*) diets in relation to environmental changes in the northern California Current. Fisheries Oceanography 16: 395–408.

Brodeur, R.D., J.P. Fisher, R.L. Emmett, C.A. Morgan & E. Casillas. 2005. Species composition and community structure of pelagic nekton off Oregon and Washington under variable oceanographic conditions. Marine Ecology Progress Series 298: 41–57.

Brodeur, R.D., J.J. Ruzicka & J.H. Steel. 2011. Investigating alternate trophic pathways through gelatinous zooplankton and planktivorous fishes in an upwelling ecosystem using end-to-end models. Interdisciplinary Studies on Environmental Chemistry—Marine Environmental Modeling & Analysis, Eds., K. Omori, X. Guo, N. Yoshie, N. Fujii, I. C. Handoh, A. Isobe and S. Tanabe, pp. 57–63. TERRAPUB.
Bundy, A. 2001. Fishing on ecosystems: the interplay of fishing and predation in Newfoundland-Labrador. Canadian Journal of Fisheries and Aquatic Science 58: 1153-1167.
California Fish and Game Commission. 2013. Policy statement, forage fish management. Sacramento CA.
Cury, P.M., I.L. Boyd, S. Bonhommeau, T. Anker-Nilssen et al. 2011. Global seabird response to forage fish depletion—one-third for the birds. Science 334: 1703-1706.
Etnoyer, P., D. Canny, B. Mate & L. Morgan. 2004. Persistent pelagic habitats in the Baja California to Bering Sea (B2B) ecoregion. Oceanography 17: 90–101.
Field, J., E. Dick & A. MacCall. 2007. Stock assessment model for the shortbelly rockfish, *Sebastes jordani*, in the California Current. NOAA-TM-NMFS-SWFSC-405, La Jolla CA.
Fulton, E.A., A. D.M. Smith & C.R. Johnson. 2004. Biogeochemical marine ecosystem models I: IGBEM–A model of marine bay ecosystems. Ecological Modelling 174: 267–307.
Fulton, E.A., J.S. Link, I.C. Kaplan, M. Savina-Rolland et al. 2011. Lessons in modelling and management of marine ecosystems: the Atlantis experience. Fish and Fisheries 12: 171-188.
Glaser, S.M. 2010. Interdecadal variability in predator-prey interactions of North Pacific albacore in the California Current System. Marine Ecology Progress Series 414: 209-221.
Hannesson, R., S. Herrick & J. Field. 2009. Ecological and economic considerations in the conservation and management of the Pacific sardine (*Sardinops sagax*). Canadian Journal of Fishery and Aquatic Science 66: 859-868.
Hobson, E. & W. Lenarz. 1977. Report of a colloquium on the multispecies fisheries problem, June 1976. Marine Fisheries Review 39: 8-13.
Kaplan, I.C., I.A. Gray & P.S. Levin. 2012. Cumulative impacts of fisheries in the California Current. Fish and Fisheries, doi: 10.1111/j.1467-2979.2012.00484.x.
Kaplan, I.C., C.J. Brown, E.A. Fulton, I.A. Gray et al. 2013. Impacts of depleting forage species in the California Current. Biological Conservation 40: 380–393.
Kinzey, D. & A.E. Punt. 2009. Multispecies and single-species models of fish population dynamics: comparing parameter estimates. Natural Resource Modeling 22: 67-104.
Laevastu, T., R. Marasco & D. Alverson. 1995. Exploitable Marine Systems: Their behavior and management. Blackwell Wiley, London.
Leet, W.S., C.M. Dewees, R. Klingsbeil & E.J. Larson. 2001. California's living marine resources: a status report. California Department of Fish & Game, Sacramento CA.
Lindegren, M., D.M. Checkley, T. Rouyer, A.D. MacCall & N.C. Stenseth. 2013. Climate, fishing, and fluctuations of sardine and anchovy in the California Current. Proceedings of the National Academy of Sciences 110(33): 13672-13677.

Link, J.S., S. Gaichas, T.J. Miller, T. Essington et al. 2012. Synthesizing lessons learned from comparing fisheries production in 13 northern hemisphere ecosystems: emergent fundamental features. Marine Ecology Progress Series 459: 293-302.

Llanelli, J., S. Barbeaux, T. Honkalehto, S. Kotwicki et al. 2006. Assessment of Alaska Pollock Stock in the Eastern Bering Sea. *In*: Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pac. Fish. Mgmt. Council, Anchorage, AK, section 1:35-138.

Meyer, R.M. (ed.) 1997. Forage fish in marine ecosystems. Alaska SeaGrant, AK-SG-97-01.

NOAA (National Oceanic & Atmospheric Administration). 2008. Cordell Bank, Gulf of the Farallones, and Monterey Bay national marine sanctuaries, Final Environ Impact Statement. Washington DC. http://montereybay.noaa.gov/research/techreports/trnccos2007.html.

Nur, N., J. Jahncke, M.P. Herzog, J. Howar et al. 2011. Where the wild things are: predicting hotspots of seabird aggregations in the California Current System. Ecological Applications 21: 2241–2257.

Oceana. 2011. Forage fish: feeding the California Current large marine ecosystem. Washington, DC.

Palacios, D.M., S.J. Bograd, D.G. Foley & F.B. Schwing. 2006. Oceanographic characteristics of biological hot spots in the North Pacific: a remote sensing perspective. Deep Sea Research Part II 53:250–269.

PEW. 2013. The State of the Science: Forage Fish in the California Current. Washington DC.

Pichegru, L., D. Grémillet, R.J.M. Crawford & P.G. Ryan. 2010. Marine no-take zone rapidly benefits endangered penguin. Biological Letters, doi: 10.1098/rsbl.2009.0913.

Pichegru, L., P.G. Ryan, R. van Eeden, T. Reid et al. 2011. Industrial fishing, no-take zones and endangered penguins. Biological Conservation, http://dx.doi.org/10.1016/j.biocon.2011.12.013

Pikitch, E., P.D. Boersma, I.L. Boyd, D.O. Conover et al. 2014. The global contribution of forage fish to marine fisheries and ecosystems. Fish & Fisheries 15: 43-64.

PFMC (Pacific Fishery Management Council). 1978. Northern anchovy fishery management plan. Federal Register, 43 (141), Book 2:31655-31879.

PFMC. 2000. Pacific Coast Groundfish Fishery Management Plan; Amendment 12. Portland OR.

PFMC. 2007. Staff White Paper Development of an Ecosystem Fishery Management Plan. Pacific Fishery Management Council, Portland OR.

PFMC. 2008. Management of krill as an essential component of the California Current ecosystem. Amendment 12 to the Coastal Pelagic Species Fishery Management Plan. Pacific Fishery Management Council, Portland OR.

PFMC. 2013. Pacific Coast Fishery Ecosystem Plan for the U. S. Portion of the California Current Large Marine Ecosystem. Portland OR.

PFMC and NMFS (National Marine Fisheries Service). 2011. Proposed Harvest Specifications and Management Measures for the 2011-2012 Pacific Coast

Groundfish Fishery and Amendment 16-5 to the Pacific Coast Groundfish Fishery Management Plan to Update Existing Rebuilding Plans and Adopt a Rebuilding Plan for Petrale Sole; Final Environmental Impact Statement. Pacific Fishery Management Council, Portland, OR. February 2011. http://www.pcouncil.org/wp-content/uploads/1112GF_SpexFEIS_100806-FINAL_feb21_.pdf

Polovina, J. 1985. An approach to estimating an ecosystem box model. Fish Bull. US. 83: 457-460.

Reese, D.C., R.T. O'Malley, R.D. Brodeur & J.H. Churnside. 2011. Epipelagic fish distributions in relation to thermal fronts in a coastal upwelling system using high-resolution remote-sensing techniques. ICES Journal of Marine Science, doi:10.1093/icesjms/fsr107.

Santora, J.A., W.J. Sydeman, I.D. Schroeder, B. Wells & J. Field. 2011. Mesoscale structure and oceanographic determinants of krill "hot spots" in the California Current implications for trophic transfer and conservation. Progress in Oceanography 91: 397-409.

Santora, J.A., J.C. Field, I.D. Schroeder, K.M. Sakuma et al. 2012. Spatial ecology of krill, micronekton and top predators in the central California Current: implications for defining ecologically important areas. Progress in Oceanography 106: 154-174.

Sissenwine, M., B. Brown, M. Grosslein & R. Hennemuth. 1984. The multispecies fishery problem: a case study of Georges Bank. Lecture Notes in Biomathematics 54: 286-309.

Smith, A.D.M., C.J. Brown, C.M. Bulman, E.A. Fulton et al. 2011. Impacts of fishing low–trophic level species on marine ecosystems. Science 233: 1147-1150.

Sparre, P. 1991. Introduction to multispecies virtual population analysis. ICES Marine Science Symposia 193: 12–21.

Sydeman, W.J, R.D. Brodeur, C.B. Grimes, A.S. Bychkov & S. McKinnell. 2006. Marine habitat ''hotspots'' and their use by migratory species and top predators in the North Pacific Ocean. Deep-Sea Research 53, special issue.

Velarde, E., E. Ezcurra & D.W. Anderson. 2013. Seabird diets provide early warning of sardine fishery declines in the Gulf of California. Scientific Reports 3: 1332 | DOI: 10.1038/srep01332

Walters, C., V. Christensen& D. Pauly. 1997. Structuring dynamic models of exploited ecosystems from trophic mass balance assessments. Review in Fish Biology and Fisheries 7: 139–172.

Walters, C., D. Pauly & V. Christensen. 2000. Ecospace: prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. Ecosystems 2: 539–554.

Wells, B.K., I.D. Schroeder, J.A. Santora, E.L. Hazen et al. 2013. State of the California Current 2012-13 No such thing as an "average" year. CalCOFI Reports 54: 27-71, http://calcofi.org/publications/calcofireports/v54/Vol_54_StateOfCurrent_37-71.pdf.

Appendix A

Program of the Workshop

(see next 4 pages)

Point Blue Conservation Science (*formerly PRBO*)
3820 Cypress Drive Suite 11
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Conservation Science for a healthy planet.

PREDATORS AND THE CALIFORNIA CURRENT PREYSCAPE

First Day, Sep. 10 (Tuesday)

8:00 - 9:00 Breakfast (Provided - 1 hour)
Choice of fruit, granola, yogurt, pastries, bagels, spreads, coffee, tea, milk, juice.

Introduction and Review Papers

9:00 - 9:10 Welcome and Introduction by David Ainley.

9:10 - 10:00 J. Field & A. MacCall: A historical perspective on the evolution of ecosystem-based fisheries management in the California Current system.

10:00 - 10:30 R. Mendelssohn, et al.: State-space analysis of environmental data in the California Current System and the implications for forage fish.

10:30 - 11:00 J. Santora, et al.: Spatio-temporal scales of multispecies predator-prey hotspots: developing unified “trophic hotspots” in the California Current System.

11:00 - 11:30 Break

Summary of Prey Natural history from Predator's Perspective

11:30 - 12:00 W. Peterson, et al.: Interannual variations in the abundance of krill derived from an 18 year time series of biweekly sampling off central Oregon.

12:00 - 12:30 L. Zeidberg: California market squid as an important prey in the California Current System.

12:30 - 13:30 Lunch (Provided - 1 hour)
Choice of assorted sandwiches, chips, fruit, and drinks.

13:30 - 14:00 A. MacCall: Sardines and anchovies as forage in the California Current Sytem.

14:00 - 14:30 A. Weinstein: Characteristics of Pacific herring as a prey item in the California Current System.

14:30 - 15:00 S. Ralston: Review of juvenile rockfish in the California Current System.

15:00 - 15:30 Break

15:30 - 16:00 P. Adams: True smelt: data-poor nearshore coastal pelagic species that are both harvested and important forage fish.

Existing Information on Predators and Prey - Foraging Dynamics

16:00 - 16:30 R. Brodeur, et al.: Pelagic and demersal fish predators on juvenile and adult forage fishes in the northern California Current: spatial and temporal variations in feeding.

16:30 - 17:00 D. Ainley, et al.: Upper level predators and the California Current System preyscape: a review of spatio-temporal aspects of diet and foraging behavior.

17:00 - 18:00 Synthetic discussion - Day 1.
Discussion moderated by Pete Adams

18:00 - 20:00 Wine / Beer / Dinner (Provided)
Choice of pasta, garlic bread, green salad and drinks.

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Second Day, Sep. 11 (Wednesday)

8:00 - 9:00 Breakfast (Provided - 1 hour)
Choice of fruit, granola, yogurt, pastries, bagels, spreads, coffee, tea, milk, juice.

Invited papers

9:00 - 10:00 S. Bertrand: Foraging by seabirds and (anchovy) fishing vessels in the Peru Current System.

10:00 - 11:00 L. Pichegru: Experiments on seabird foraging effort and commercial anchovy take in the Agulhas Current System.

11:00 - 11:30 Break

Contributed papers - Fish

11:30 - 12:00 P. Adams, et al.: Ocean diet cycle of adult Chinook salmon in the Gulf of the Farallones, California.

12:00 - 12:30 C. Barceló, et al.: Factors affecting the yearly and seasonal community structure of pelagic forage fish and predators in the northern California Current System.

12:30 - 13:30 Lunch (Provided - 1 hour)
Choice of chicken/veggie enchiladas, beans, rice, chips, green salad, and drinks.

13:30 - 14:00 B. Wells, et al.: An ecosystem perspective for quantifying the dynamics of juvenile Chinook salmon and prey in the central California coastal region.

14:00 - 14:30 S. Glaser: Rare predation events: the contribution of uncommon prey to juvenile North Pacific albacore diet.

14:30 - 15:00 R. Brodeur, et al.: Seasonal and interannual variability in the spatial overlap between forage fishes and large medusa in the northern California Current region.

15:00 - 15:30 Break

15:30 - 16:00 E. Daly, et al.: Diet variability of forage fishes in the northern California Current region.

16:00 - 16:30 D. Reese & R. Brodeur: Species associations and redundancy in relation to biological hotspots within the northern California Current region.

Contributed papers - Seabirds

16:30 - 17:00 L. Harvey, et al.: Relationships between California Brown Pelican nesting parameters, prey distributions, and oceanographic conditions, 1986-2005.

17:00 - 18:00 Synthetic discussion - Day 2
Discussion moderated by Pete Adams and David Ainley

18:00 - 20:00 Wine / Beer / Dinner
Grilled creole chicken, mango papaya salsa, rice, green salad and drinks.

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Third Day, Sep. 12 (Thursday)

8:00 - 9:00 Breakfast (Provided - 1 hour)
Choice of fruit, granola, yogurt, pastries, bagels, spreads, coffee, tea, milk, juice.

Contributed papers – Seabirds (continued)

9:00 - 9:30 M. Raphael, et al.: Spatio-temporal dynamics of Marbled Murrelet hotspots during nesting in nearshore waters along the Washington to California coast.

9:30 - 10:00 R. Suryan & A. Gladics: Effects of environmental variation on diets and stable isotope signatures of a piscivorous seabird in a coastal upwelling system.

10:00 - 10:30 E. Phillips, et al.: The influence of the Columbia River Plume on density distributions of forage fish and seabird predators.

10:30 - 11:00 Break

11:00 - 11:30 M. Horn: The Elegant Tern, a non-selective, shallow-diving forager, as an indicator of prey availability in the Southern California Bight: a multi-decadal study

11:30 - 12:00 E. Velarde, et al.: Seabird diets provide insight into small pelagic fish availability to fisheries in the Gulf of California.

12:00 - 12:30 M. Elliott, et al.: Changes in forage fish community as indicated by the diet of the Brandt's Cormorant in the California Current System.

12:30 - 13:30 Lunch (Provided - 1 hour)
Choice of assorted sandwiches, potato salad, and drinks.

13:30 - 14:00 L. Webb: Spatio-temporal variability of forage fishes in the Monterey Bay region revealed by the diet of a piscivorous seabird, Brandt's Cormorant.

14:00 - 14:30 N. Vilchis, et al.: Risks to top-level predators reveal change in a marine ecosystem

14:30 - 15:00 S. Lyday: Shearwaters as ecosystem indicators: connecting predators in the California Current System.

15:00 - 15:30 Break

Contributed papers - Marine Mammals

15:30 - 16:00 A. Fleming: The temporal variability of humpback whale diet deduced from stable nitrogen and carbon isotopic signatures, 1999-2010.

16:00 - 16:30 M. Lowry. Temporal and spatial differences in the diet of California sea lions at San Clemente Island and San Nicolas Island during 1981-2007.

16:30 - 17:00 D. Palacios, et al.: Using habitat models to infer the large-scale distribution and movement behavior of eastern North Pacific blue whales from satellite tagging data and remote sensing.

17:00 - 18:00 Synthetic discussion - Day 3
Discussion moderated by David Ainley

18:00 - 20:00 Wine / Beer / Dinner
BBQ chicken, pasta salad, Suzanne salad, corn bread and drinks.

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PREDATORS AND THE CALIFORNIA CURRENT PREYSCAPE

Fourth Day, Sep. 13 (Friday)

8:00 - 9:00 Breakfast (Provided - 1 hour)
Choice of fruit, granola, yogurt, pastries, bagels, spreads, coffee, tea, milk, juice.

Discussion and Synthesis

9:00 - 12:30 California Current ecosystem based management: the future
Discussion moderated by David Ainley and Pete Adams.

How can management address the importance of forage species to the food web in the context of extreme natural variability?

- Considering examples both within and beyond the CCS, what is the most successful forage fish management strategy, and what elements led to its success?
- Are there examples of successful management of fisheries on spawning prey? (e.g. squid, herring, eulachon, etc.) How do we manage them properly to ensure that there will be enough to maintain the stock?
- Noting that prey size can be important in prey selection by predators, is there evidence for the existence of any forage species specialization within the CCS?

Do we have answers to the above central question? What questions could research help answer regarding spatio-temporal forage fish issues into CCS management?

- Would an intensively studied prey-predator (including fishing vessels) 'hotspot' help move forward forage fish management? Why? What are the best candidates for such an area within the CCS ecosystem? [Major CCS hotspots: N Channel Is – Pt Conception, Gulf of Farallones, Heceta Bank-Columbia R plume]
- Do forage fish in the CCS meet the definition of the 'waist' in a Wasp Waist Ecosystem?
- How do we identify the impacts of climate change on predator-forage fish interactions? And how do we separate these effects from fishery effects?

Given how forage fish populations vary in space and time, how effective are the static National Marine Sanctuaries and MLPA in managing and protecting these species?

How will the spatio-temporal variations in forage fish populations be incorporated into existing fishery management for CCS?

12:30 - 13:30 Lunch (Provided - 1 hour)
Choice of pizza, green salad, and drinks.

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Appendix B

Workshop participants

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Appendix C

Ranking analysis

The 32 predators used in the ranking analysis, and the time periods in which annual data were available; * indicates use in the regional comparison between central and northern portion of CCS (diet data that overlapped the southern portion with the central or northern portion were insufficient for comparison.

	SHARKS	Brodeur et al., Day 1-PM	
1	Spiny Dogfish	Oregon/Washington	2000s
2	*Blue Shark	Oregon	1980s
			2000
		California	1980s
3	Thresher Shark	West Coast	1990s
4	Soupfin Shark	Oregon	1980s
			2000s
5	*ALBACORE	Glaser, Day 2-PM	
		Oregon/Washington	1960s
			2000s
		California	1940-50s
			1960s
			2000s
		Baja California	1940-50s
			1960s
			2000s
	SALMON	Brodeur et al., Day 1-PM; Adams et al., Day 2-AM	
6	Coho Salmon	West Coast	1950s
			1980s
7	*Chinook Salmon	Oregon/Washington	1980s
			2000s
		Northern California	1980s
			1990s
	GROUNDFISH	Brodeur et al., Day 1-PM	
	Rockfish	West Coast	2000s
8	Black		2000s
9	Chilipepper		2000s
10	Yellowtail		2000s
11	Yelloweye		2000s
12	Rougheye		2000s

13	Bocaccio		2000s
14	Lingcod	Oregon	2000s
15	Sablefish	West Coast	1990s
16	Hake	West Coast	1990s
17	*Halibut	Oregon	2000s
18		California	1990s
	PINNIPEDS	Harvey, Day 1-PM	
19	*California Sea Lion	Salish Sea	1970s
		Oregon	1980s
		Monterey Bay	1990s
		Channel Islands	1970s-80s
			1990s
			2000s
20	*Northern Sea Lion	Vancouver	1960s
		Northern California	2000s
21	Pribilof Fur Seal	Vancouver	1960s
		Channel Islands	1980s
22	*Harbor Seal	Washington	1970s
		Oregon	1980s
		Northern California	1980s
		Monterey Bay	1990s
	PORPOISES	Ainley et al., Day 1-PM	
23	*Harbor Porpoise	Salish Sea	1980s
		Northern California	1970s
		Monterey Bay	1970s
24	*Dall's Porpoise	Salish Sea	1990s
		Northern California	1970s
		Monterey Bay	1970s
	SEABIRDS	Ainley et al., Day 1-PM; Elliott et al., Day 3-AM; Webb & Harvey, Day 3-PM; Suryan & Gladics, Day 3-AM; Horn et al., Day 3-AM	
25	Brandt's Cormorant		
		Farallon Is	1970s
			1990s
			2000s
		Año Nuevo Is	2000s
		Monterey Bay	2000s
		Pt Conception	2000s
26	*Sooty Shearwater	Columbia River	2000s
		Monterey Bay	1970s
		LA Bight	1980s
27	*Common Murre	Salish Sea	1990s

			2000s
		Columbia River	1980s
		Newport	2000s
		Coos Bay	1980s
		Farallon Islands	1970s
			1980s
			1990s
			2000s
		Monterey Bay	2000s
28	*Rhinoceros Auklet	Salish Sea	1970s
			1980s
			2000s
		Destruction Is	1970s
			1980s
			2000s
		Año Nuevo	1990s
			2000s
		Farallon Is	1980s
			1990s
			2000s
29	Pigeon Guillemot	Farallon Is	1970s
			1980s
			1990s
			2000s
		Pt Conception leeward	2000s
		Pt Conception windward	2000s
30	Elegant Tern	LA Bight, Bolsa Chica	1900s
			2000s
31	Least Tern	LA Bight, Purisima Pt	2000s
32	*Marbled Murrelet	Salish Sea	1970s
		Oregon	1990s
		Northern California	1980s
		Santa Cruz	1990s
		Monterey Bay	1910s