Mr. Phil Anderson, Chair
And Members of the Pacific Fishery Management Council

Dear Mr. Anderson and Council Members,

Please consider the following comments and recommendations on:

Perspectives on Forage Fishes and Protected Species Ecosystem-based Management
Prepared for the FEP Scoping Process

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Overview

Predators on forage fishes in the California Current fall into two management classes, those that can be harvested and those that cannot. The first class is composed of fishes and the second is composed of mammals, birds and reptiles.

The reasons for this separation are historical, emotional, and political and not biological or ecological. Current regulations were enacted over several decades to ensure that none of the harvested species are harvested at unsustainable rates. That sounds simple but in practice it involves a highly sophisticated monitoring, analysis and management structure that must cope with a highly variable physical environment.

On the West Coast, the recent political lawsuits and debates about forage fishes primarily concern the northern stock of sardine and the central stock of anchovy. These two stocks are notorious for their extreme regime scale variations in abundance, and they share this type of variation with closely related stocks and sibling species in the Humboldt, Benguela and Kuroshio Current Systems.

In what follows I will use the input data from a recent ecosystem model to show that the take of the key forage fishes by the U.S. fisheries is insignificant in comparison with their take by either the exploited predators or the protected predators. I will show that one of the protected species, the California sea lion, was approaching carrying capacity when the recent regime shift to low abundance of both the northern stock of sardine and the central stock of anchovy occurred. It is likely that the California sea lion is currently near its carrying capacity; and therefore, unusually high mortality of the young and/or disease outbreaks in the juveniles and adults should be expected to occur in individual years or runs of years when the environmental conditions are unfavorable near their breeding colonies. I will also discuss what is known about the population fluctuations and population biology of the California sardine and northern anchovy. Finally, I will discuss a number of important ecosystem concepts that have been little mentioned in Council documents, but are critical to the development of an optimum ecosystem management regime.

Summary of Comments and Recommendations to enhance the Fishery Ecosystem Plan (FEP)

The pelagic habitat is likely to be one of the first considered for ecosystem-based management because it is the principal source of food for protected mammals and birds.

The lower and middle trophic levels of the pelagic habitat in the California Current are well known to have extreme climatic-dependent variations associated with annual and decadal scale changes in oceanic circulation. Present ecosystem models are incapable of predicting or accounting for these fluctuations.

To date no one has provided a time series of the combined biomass of the species that dominate the food habits of predators on small pelagic fishes.

Present models cannot predict long strings of unusually poor or good recruitment years; that is, they cannot predict regime shifts.

Recent highly complicated ecosystem models have addressed the relationship between forage fishes and the population abundance of protected predator species. Unfortunately, the people carrying out these analyses do not appear to consider the ecosystem effects of predator species on forage fishes. Although they clearly had the model output to assess these affects, they have largely ignored top down effects on forage fishes.

Food habit studies taken in one era will not accurately describe food habits in another. The expected wide variation in food habits is both a problem in the determination of the relative importance of sardine or anchovy to a predator and in evaluation of ecosystem function. Prey switching appears to be much easier for the predators than for modelers and fishermen.

A very recent review of ecosystem models of a number of ocean ecosystems, including the California Current, suggests that doubling fishing on small pelagic fishes has surprising little effect on ecosystems (Olsen et al 2018).

Both bottom up and top down ecosystem analyses should be carried out before any ecosystem-based management is attempted.

Both steady-state and naturally varying environmental-dependent ecosystem models should be developed and assessed before ecosystem-based management is attempted.

Background:

Fifty-two years ago, I started sampling forage fishes on Cannery Row. For my first few years I shared an office with the only other fisheries biologist in the Monterey Bay area, Julius (Julie) Phillips, who started working on sardine with the California Division of Fish and Game in 1926. I note that Julie was the first to sample fish on Cannery Row and I was the last. Thanks to Julie, I was exposed to the entire history of the West Coast fishery for sardine and other forage fishes. This history can be divided into five periods with different population levels of two of the major forage fishes. Each period had a different research focus and political problems.

Period	Sardine	Anchovy
192?-1950	High	Low
1951-1968	Low	Low
1969-1993	Low	High
1994-2010	High	Low[a]
2011-2017	Low	Low[b]

[a] Except for an abrupt population bubble to more than 1.3 MMT in 2005-6.
[b] The most recent CalCOFI larvae based index of the SCC shows a very strong resurgence of the biomass of anchovy (2018 IEA Rep. Figure G.3.1). The 2017 larval index appears to be in the range of that found in the highest years during the peak of the fishery in the 1980s and during the 2005-2006 anchovy population bubble when the anchovy biomass was in excess of 1 MMT. (R.H. Parrish, Management of Northern Anchovy in US Waters, Agenda Item C.4.b., April 2018, Public Comment)

The most recent period began with the transition from a period of high sardine abundance and low anchovy abundance to the second observed period with low abundance of both sardine and anchovy. The transition could be said to have occurred in 2011 at the beginning of a five-year string of sardine recruitment failures (Hill et al 2017). The first period of low sardine and low anchovy lasted for 18 years. Historically, average biomass levels of sardine and anchovy were relatively uncommon, and they principally occurred during regime shifts when biomass levels were either increasing or decreasing.

Sardine and anchovy are not the only important forage species. The classic forage fishes are essentially small, pelagic schooling species. The ‘key’ forage species in the California Current include: sardine, anchovy, herring, saury, osmerid smelts, antherinid smelts, shortbelly rockfish, market squid, the young of two medium-sized pelagic species (Pacific mackerel and jack mackerel) and pelagic juveniles of a wide range of benthic fishes.

Pacific mackerel have had two periods of high abundance, 1928-1944 and 1977-1998, (Hill and Crone 2005), which further complicates evaluation of the abundance of forage species. The variation in the abundance of jack mackerel has decadal variations; however, they can live for more than 30 years, which considerably dampens their population fluctuations. Shortbelly rockfish (the most abundant small pelagic rockfish), while not as well documented as the coastal pelagic species, has large decadal scale variation in its abundance (Field et al 2007). Almost nothing is known about the variability of the saury. The other dominant schooling species, Pacific hake, has relatively less variation in abundance, with total biomass varying from a high of 6.7 MMT in 1985 to a low of 1.7 in 2007; the 2017 total biomass of 5.3 MMT is the highest since 1988 (Berger et al. 2017).

Market squid, which live less than one year, do not build up large populations of animals recruited from several years of good environmental conditions. Instead squid abundance depends upon much shorter time scales, and its population has sharply declined repeatedly during El Niño years and then recovered quickly when ‘normal’ circulation patterns returned. Pelagic crabs (*Pleuroncodes planipes*) are important only in the southern portion of the California Current, and their abundance in California is essentially the reverse of that of market squid, abundant during warm-water El Niño periods and rare otherwise. Little information is available for this species.

To date no one has provided a time series of the combined biomass of the species that dominate the food habits of predators on small pelagic fishes.

The variations in abundance of the northern stock of sardine, Pacific mackerel, and the central stock of anchovy are well documented from population assessments, egg and larval abundance and examination of paleo-sediments. It is clear that all three stocks will have huge variations in biomass at decadal time scales, with or without fishing. Extensive single species simulation models (Hurtado-Ferro and Punt 2014) have confirmed that the sardine management model, developed by Larry Jacobson and myself, is an effective way to manage the northern stock of sardine. The decades-long development of highly sophisticated population assessment models for sardine demonstrate that biomass can be assessed accurately enough to utilize the present harvest control rule (Hill et al 2017). However, present models cannot predict long strings of unusually poor or good recruitment years; that is, they cannot predict regime shifts. The Pacific Fisheries Management Council followed the harvest control rule and closed the directed sardine fishery when the estimated biomass fell below the established 150,000 mt CUTOFF.

Recent highly complicated ecosystem models have addressed the relationship between forage fishes and the population abundance of protected predator species. Unfortunately, the people carrying out these analyses do not appear to consider the ecosystem effects of predator species on forage fishes. Although they clearly had the model output to assess these affects, they have largely ignored top down effects on forage fishes. For example, fisheries on predator species have significantly lowered their biomass, and this would have resulted in an increase the biomass of the forage species they preyed on. In contrast, the increased biomass of protected predator species has certainly been a factor in decreasing the biomass levels and increasing the natural mortality rates of the key forage species.

Evaluation of the relationships between forage fishes and their predators is severely affected by the fact that during some periods there can be more than 100 times as many anchovy as sardine and in other periods the opposite may occur. Predator food habit studies taken during periods of both low and high abundance of anchovy and sardine are simply not available for many predators, primarily due to the decadal scale and El Niño scale variation in the abundance of the major forage species. Food habit studies taken in one era will not accurately describe food habits in another. The expected wide variation in food habits is both a problem in the determination of the relative importance of sardine or anchovy to a predator and in evaluation of ecosystem function. Prey switching appears to be much easier for the predators than for modelers and fishermen.

One principal 'problem' addressed by researchers during the current period is the allocation of forage fishes between protected species and commercial fisheries. This 'problem' has occurred in spite of evidence that protecting marine mammal and bird species in the area regulated by the Pacific Fisheries Management Council has greatly increased their population sizes. This increase has occurred in spite of low sardine abundance from 1958-88 and low anchovy biomass from 1989-2004 and 2007-15.

For example, there are now more than 12 times as many California sea lions as there were in 1966 when I started sampling forage fishes, and more than 120 times as many as when Julie Phillips started in 1926.

To address what I believe are the necessary factors that need to be evaluated in the fishery management of the California Current, I will first focus on an ecosystem approach including the above 'key' forage species and protected marine mammals and birds (Part 1). I will then go into more depth with a case-history approach based on the California sea lion (Part 2). Finally, I will present information on the present state of sardine and anchovy stocks and discuss a number of important ecosystem concepts that have been little mentioned in Council documents, but are critical to the development of an optimum ecosystem management regime (Part 3).

Part 1: Ecosystem Perspective

Ecosystem model estimates of consumption of forage fish by protected species.

There are several ways to estimate the volume of forage fishes taken by predators. Knowledge of the population size and the annual food consumption allows a direct calculation of the forage taken by a predator. If the biomass by species is available, the annual forage can be divided into the major species and species groups. The development of ecosystem models allows the calculation of the amount of forage species consumed; however, to date none of the recent California Current ecosystem models have been focused on a top-down analysis. The input estimates of biomass and consumption per unit body weight used in the ecosystem models can be used to estimate average total forage consumption of species or species groups, and if the species composition of the diets used in the ecosystem model is available, the forage by species or species group can be calculated.

Koehn et al. (2016) developed a species-rich California Current Ecopath model that contains 27 piscivorous fish species and species groups, 15 marine mammal species and species groups and 18 marine bird species and species groups. This model is "intended to represent the most recent state of the ecosystem, averaged over 2000-14", including the fisheries. Their Table 1 gives the biomass and consumption-to-biomass ratio for all of the species in the model, and their diet matrix is available in their supplemental information. The Koehn et al model does not include jack mackerel, antherinid smelts or pelagic red crabs; however, it does include a number of juvenile species groups that are important forage species for a wide range of animals. The most serious lack on the predator side is the absence of the 'trans-boundary species' (tropical tunas, bonito, barracuda and yellowtail) that are of great importance in the southern portion of the California Current. The absence of spatial resolution makes it difficult to evaluate the fairly different fauna assemblages in the northern and southern halves of the California Current, and the northern fauna are better represented than the southern.

I have used the information from the Koehn et al (2016) model and average 2000-14 U.S. landings to show the relative consumption of the "key" forage species by major faunal groups (Table 1). As used here, the "key forage fishes" include sardine, anchovy, herring, other forage fishes (saury, osmerid smelts, shortbelly rockfish and sandlance), juvenile fishes (rockfish, flatfish, hake, roundfish), Pacific mackerel and, although not a fish, market squid. I have also separately included euphausids (krill), as a reference, due to their importance as forage.

The total vertebrate predator consumption of the 'key forage fishes' is 8.77 MMT, and they take and additional 52.48 MMT of euphausids. Fishes take the majority, 54%, of the annual consumption of the key forage species (4.75 MMT) and euphausids, 94%, (49.09 MMT). Mammals take 2.89 MMT of the key forage fishes and 3.13 MMT of euphausids; birds take 1.13MMT and 0.26 MMT. In contrast, the U.S. fishery takes 0.17 MMT and 0 MMT of euphausids (Table 1). The Koehn et al. (2016) model has no invertebrate take of the key forage species, and I have not included the fisheries in Canada and Mexico.

The take of the key forage species by the U.S. fishery is 2.0% of that taken by the fishes, mammals and birds. Fishes take 27.5 times as much of the key forage fishes as the U.S. fishery; mammals take 16.7 times as much, and birds take 6.6 times as much. Clearly, competition between predators is far more important than competition between predators and the fishery.

It should also be noted that the large fishes that take the key forage species are those most likely to be fished to levels well below their unfished biomass levels. Therefore, the unfished take of key forage species by the presently exploited fishes would be expected to be somewhere between 20-40% higher than the 4.75 MMT figure. The total pristine population biomass of the marine mammals and birds is unknown, but it is possible that, at pristine population levels, the marine mammals and birds would take more of the key forage species than do the fishes. Based on the 2000-14 Koehn et al (2016) data, fishes take 14 times more euphausids than the combined take of euphausids by mammals and birds, and fishes take 10 times more euphausids than key forage fishes.

Table 1. Annual consumption (mt) of forage by major faunal groups and average (2000-14) U. S. landings. (Calculated from Koehn et al. 2016: Table 1 and supplemental data).

Key Forage Species	TOTAL	Fishes	Mammals	Birds	Fishery	Fishery %
Sardine	918,256	379,032	530,061	9,163	76,754	8.4%
Anchovy	1,318,094	633,862	429,545	254,687	8,095	0.6%
Herring	913,513	709,657	136,559	67,297	1,829	0.2%
Other for. fish	1,322,808	906,608	220,288	195,911	16	0.0%
Juvenile fishes	2,887,172	1,691,576	842,913	352,682	0	0.0%
Market squid	1,309,632	406,604	650,128	252,901	80,460	6.1%
Pacific mackerel	100,146	23,915	75,512	718	5,860	5.9%
Total	**8,769,620**	**4,751,254**	**2,885,006**	**1,133,360**	**173,014**	**2.0%**
Euphausids	52,478,145	49,085,682	3,132,986	259,478	0	0.0%

Marine Mammals:

To examine the take of the key forage species by individual species and species groups, the take by marine mammals is arrayed by species (Table 2). More than half of the marine mammal consumption of the key forage species is taken by California and Stellar sea lions (0.85 MMT) and dolphins (0.73 MMT). Humpback whales take (0.37 MMT), porpoises take (0.33 MMT), and elephant seals take (0.23 MMT).

Seals and sea lions take 1.33 MMT of the key forage species; porpoises and dolphins take 1.06 MMT; whales take 0.49 MMT and the U.S. fishery takes 0.17 MMT. It is clear that, with the exception of the humpback and minke whales, the key forage species are only a minor portion of the diet of baleen and sperm whales. Baleen whales take 3.13 MMT of euphausids, which are a prohibited species for fisheries.

The marine mammal take of sardine is nearly 7 times that of the fishery. The mammal take of market squid is 8 times, Pacific mackerel is 13 times, anchovy is 53 times and herring is 75 times the take of the corresponding fisheries (Table 2). Note that the model combines the northern and central stocks of anchovy. and it does not include the southern stock of sardine.

Table 2. Biomass (mt) and consumption of key forage species by marine mammals. (Calculated from Koehn et al. 2016: Table 1 and supplemental data).

Key Forage Species	Sardine	Anchovy	Herring	Other forage fishes	Juvenile fishes	Market squid	Pacific mackerel	**Total Key Species**	Euphausids
Orcas (transient)	0	0	0	0	0	0	0	**0**	0
Orcas (residential)	82	0	1,022	17	0	0	307	**1,428**	0
Porpoises	33,160	87,135	9,682	51,313	11,618	135,544	968	**329,419**	0
Humpback	189,449	94,725	42,626	0	42,626	0	0	**369,426**	568,347
Minke	4,012	6,018	1,404	3,611	1,003	0	201	**16,250**	23,071
Fin	22,822	22,822	22,822	22,822	0	0	0	**91,288**	712,044
Sperm whale	11,866	0	0	1,870	0	0	0	**13,736**	0
Harbor Seals	0	50,677	16,892	65,156	14,479	12,066	0	**159,270**	0
Sea lions	178,889	41,741	29,815	52,325	360,760	163,982	22,361	**849,874**	0
Juvenile Elephant seals	0	1,480	0	0	81,916	145,080	0	**228,476**	0
Adult Elephant Seals	0	0	0	1,160	0	2,008	0	**3,168**	4,686
Fur seals	5,589	35,768	12,295	16,319	2,235	16,766	0	**88,973**	0
Blue whale	0	0	0	0	0	0	0	**0**	1,816,909
Gray whale	0	0	0	0	0	0	0	**0**	7,929
Dolphins	84,192	89,179	0	5,694	328,275	174,682	51,676	**733,698**	0
Total	**530,061**	**429,545**	**136,559**	**220,288**	**842,913**	**650,128**	**75,512**	**2,885,006**	**3,132,986**
Fishery (2000-14) Ave.	76,754	8,095	1,829	16	0	80,460	5,860	**173,014**	0

Marine Birds:

The take of the key forage species by birds (1.13 MMT) is 6.5 times larger than that taken by the fishery (0.17 MMT).

The majority of the 1.13 MMT consumption of the key forage fishes in the California Current (Table 3) is taken by three species groups; common murre (0.44 MMT), shearwater (0.22 MMT) and Western/Glaucous gulls (0.14 MMT). Some of the most abundant species (Cassin's auklet and Leach's storm petrel) do not eat most of the key forage fishes and instead consume euphausids and other species. Probably due to their larger size, sardine and Pacific mackerel are not eaten by most marine birds: those fishes are only significant in the diet of brown pelican.

Table 3. Biomass (mt) and consumption of key forage species by marine birds.
(Calculated from Koehn et al. 2016: Table 1 and supplemental data).

Key Forage Species	Sardine	Anchovy	Herring	Other forage fishes	Juvenile fishes	Market squid	Pacific mackerel	**Total Key Species**	Euphausids
Common Murre	0	103,082	37,845	55,896	180,706	64,824	0	**442,353**	4,452
Cassin's auklet	0	0	0	0	0	0	0	**0**	128,496
Rhinoceros auklet	0	8,724	3,643	20,400	8,306	3,212	0	**44,285**	5,207
Tufted Puffin	0	239	0	14,310	12,463	183	0	**27,195**	1,669
California gull	0	23,671	0	0	0	30,772	0	**54,442**	0
Western/Glaucous gull	0	22,027	20,949	61,394	18,653	16,216	0	**139,239**	1,312
Black-legged kittiwake	0	2,113	0	0	0	10,830	0	**12,943**	337
Albatross	0	0	0	2,411	0	0	0	**2,411**	0
Northern Fulmar	0	0	0	0	741	3,174	0	**3,914**	1,058
Shearwater	0	52,885	449	31,633	16,907	121,926	0	**223,799**	43,671
Leach's S. Petrel	0	0	0	0	28,899	0	0	**28,899**	72,247
Brandt's cormorant	0	10,741	1,907	1,032	57,546	996	0	**72,222**	0
Double crested cormorant	0	7,156	541	1,210	6,119	0	0	**15,025**	0
Pelagic cormorant	0	0	0	2,607	13,700	0	0	**16,307**	0
Marbled murrelet	168	1,307	956	1,567	626	770	0	**5,394**	1,028
Pigeon Guillemot	0	0	0	447	7,221	0	0	**7,668**	0
Caspian tern	446	1,729	1,008	1,928	79	0	0	**5,190**	0
Brown Pelican	8,549	21,013	0	1,077	718	0	718	**32,074**	0
Total	**9,163**	**254,687**	**67,297**	**195,911**	**352,682**	**252,901**	**718**	**1,133,360**	**259,478**
Fishery (2000-14) Ave.	76,754	8,095	1,829	16	0	80,460	5,860	**173,014**	0

Consumption rates are higher for marine mammals than fishes, due to the fact that mammals are warm blooded and need more energy. Marine birds, due to their small size and increased energy output, have much higher energy requirements than marine mammals. For example, salmon consume 5.3 times their body weight per year, dolphins consume 32.3 times their weight and California gulls consume 193.9 times their weight (Kuehn et al. 2016)

Any comparison between the consumption of marine mammals, birds and fishery yields in the California Current ecosystem should account for the fact that migratory species, such as the grey whale and shearwaters, take a major portion of their annual consumption outside of the California Current Ecosystem. For example, the Koehn et al (2016) data show that shearwaters take about 47% of their diet outside of the California Current (Table 4).

Based on the biomass and consumption values given in Koehn et al. (2016), the total consumption of the fishes in their model is 104.90 MMT of which 103.17 MMT is taken from the California Current. The respective values for mammals are 25.46 MMT and 17.37 MMT and those for birds are 2.30 MMT and 2.01 MMT (Table 4). About 32% of the forage taken by the marine mammals and 23% of that taken by marine birds is taken outside of the California Current Ecosystem.

Table 4. Biomass, consumption per-unit body weight and total forage consumption of marine birds (Calculated from Koehn et al. 2016: Table 1 and supplemental data).

	Biomass mt	Consumption Per Body wt.	Cal. Current Consumption	Total Consumption
Common Murre	3,270	169.50	549,255	554,265
Cassin's auklet	1,230	266.90	269,725	328,287
Rhinoceros auklet	280	202.20	54,702	56,616
Tufted Puffin	180	181.10	32,565	32,598
California gull	650	193.90	72,042	126,035
Western/Glaucous Gulls	960	168.65	157,751	161,904
Black-legged kittiwake	130	216.20	13,729	28,106
Albatross	750	124.25	18,021	93,188
Northern Fulmar	240	199.70	24,016	47,928
Shearwater	3,640	182.75	354,190	665,210
Leach's S. Petrel	600	407.90	243,112	244,740
Brandt's cormorant	730	138.10	85,327	100,813
Double crested cormorant	360	147.00	37,023	52,920
Pelagic cormorant	260	142.60	31,563	37,076
Marbled murrelet	30	255.10	6,741	7,653
Pigeon Guillemot	100	205.90	15,791	20,590
Caspian tern	90	189.90	16,397	17,091
Brown Pelican	270	120.70	32,074	32,589
Marine Birds	**13,770**		**2,014,026**	**2,607,609**

Part 2. Case History: California Sea Lion.

The starvation of California sea lion pups in Southern California rookeries in the last couple of years has had extensive exposure in the press. This has contributed to the present advocacy to reduce the fisheries on small pelagic fishes, based on undocumented claims that fishing may be responsible for this unusual mortality. Apparently, the advocates hope that a reduction in commercial fisheries will increase the nutrition, size and survival rate of sea lion pups.

Before addressing this issue, however, it is necessary to review the food habits and history of the California sea lion population.

Food habits:

The California sea lion (hereafter 'sea lion') is an opportunistic predator that "feeds on whatever is most convenient" (Bonnot 1928). Sea lions consume a very wide variety of fishes and invertebrates and, as will be seen, the most common species in their diet are among the key forage fishes described above.

In recent decades, sea lion food habit studies have been based on sampling scat and spewings. Lowry and Carretta describe the difficulty of using these sampling methods. In addition to their concerns, the limitations of this method of sampling are seen in early food habit studies of sea lions in California; "Between July 20 and August 16 twelve sea lions were killed (yearlings, two-year olds and old cows). Seven contained giant squid. One was full of octopus, four were empty, except for a few remains of pens and beaks of squid." (Bonnet 1928). Evidence of large squids is very unlikely to occur in scat samples, and it is possible that the recent abundance of Humboldt squid went largely unnoticed in sea lion food habit studies.

The food habit studies by Lowry and Carretta (1999: their Table 3) were taken over an extensive time period (1981-95) and include periods with high and low anchovy and sardine abundance; however, they only list the eight most abundant species and their values are frequency of occurrence not mass.

TABLE 3
Frequency of Occurrence of Common Prey Found in California Sea Lion Scat Collected Seasonally at San Clemente (n = 2,543) and San Nicolas Islands (n = 2,980), and in Summer at Santa Barbara Island (n = 736), 1981–95

		San Clemente Island		San Nicolas Island		Santa Barbara Island	
Scientific name	Common name	n	%	n	%	n	%
Engraulis mordax	Northern anchovy	1,155	45.4	897	29.4	360	48.9
Loligo opalescens	Market squid	895	35.1	1,323	44.3	315	42.7
Merluccius productus	Pacific whiting	631	24.8	931	31.2	290	39.4
Trachurus symmetricus	Jack mackerel	631	24.8	659	22.1	147	19.9
Sebastes jordani	Shortbelly rockfish	328	12.8	423	14.1	100	13.5
Pleuroncodes planipes	Pelagic red crab	301	11.8	244	8.1	72	9.7
Scomber japonicus	Pacific mackerel	264	10.3	463	15.5	59	8.0
Sardinops sagax	Pacific sardine	122	4.7	371	12.4	73	9.9

Male sea lions differ from the females in that they typically spend a major portion of their lives in central California and further north. Males will therefore have somewhat different food habits than females. Food habits of sea lions in Central California are similar to those in Southern California (Weise and Harvey 2008); however, herring, spiny dogfish and salmon are added and pelagic red crabs are absent. Weise's (2000) Figure 9 visually demonstrates two important concepts. 1. Sea lions consume a very wide range of species but their diet is dominated by a small number of schooling and pelagic species. 2. Sea lions rapidly shift their feeding habits depending upon the availability of dominant forage species. These Central California food habit studies were carried out in 1998-9 and therefore they include only a regime with high sardine and low anchovy abundance.

Weise and Harvey (2008) pointed out that California sea lions "consume almost exclusively commercially important prey species," and they concluded, "it was clear that they were plastic specialists concentrating their efforts on a handful of prey species in each season and switching prey with ocean climate shifts and seasonal movement of prey."

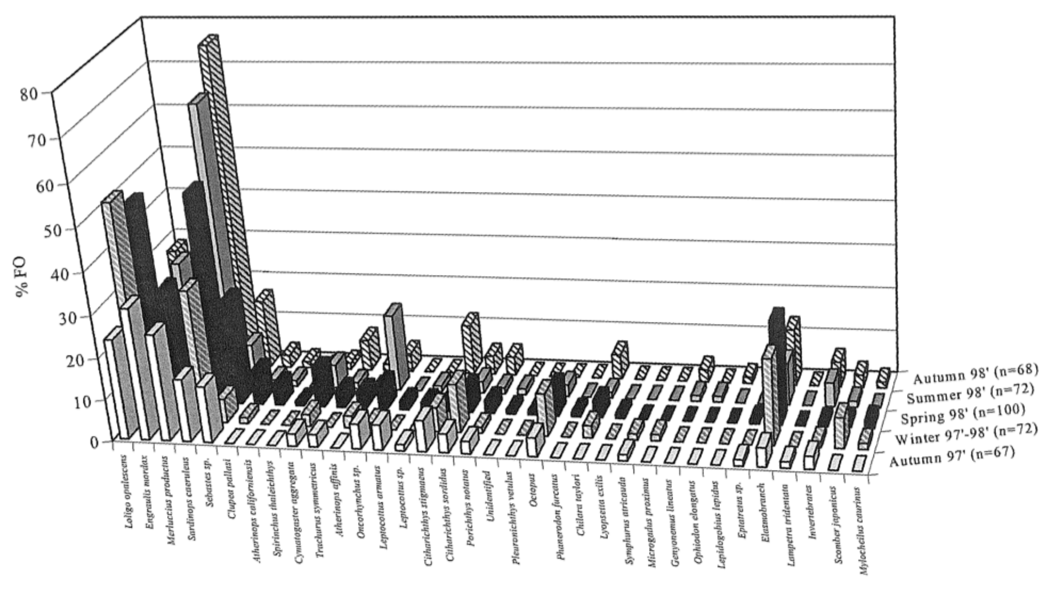

Figure 9. Comparison among seasons of percentage frequency occurrence of prey species identified in California sea lion fecal samples collected in Monterey Bay, California in 1997 and 1998.

95

History of the California Sea Lion Population:

California and Stellar sea lions were highly over-exploited in the late 19th century and early 20th century, resulting in severe population declines. During the 1860 to 1870 period about 9,000–15,000 were harvested per year; by 1907 the estimated sea lion population in California was low and remained low until about 1930 (Cass 1985). For those with a strong stomach, Bonnot (1928) provides a description of the treatment of sea lions at that time. As late as WWII, sea lions were considered to be a nuisance. In an attempt to decrease sea lion harassment of the sardine purse-seine fishery, soldiers from Fort Ord were employed to machine gun sea lions hauled out near Point Sur (Julie Phillips pers. comm.).

Bonnot (1928) also provided information on the early counts of the numbers of sea lions in rookeries and haul out sites and observations on the diet of sea lions. For example, "(7 and 8) July 16. Two cows a mile south of Point Pinos. Both feeding on giant squid. Stomach, (1) contained two quarts, and (2) a gallon of chewed flesh and arms of giant squid."

The State of California started making sea lion counts in the rookeries and haul out grounds in 1927 (Bonnet 1928). The 1927 survey counted 941 California sea lions, 6,348 Stellar sea lions and 320 harbor seals; the 1928 survey found 1,429, 4,994 and 350 respectively. The five breeding season surveys between 1927 and 1938 had very similar statewide totals

(6,273 to 7,861); however, the numbers in Southern California (mostly California sea lions) increased gradually and those in Northern California (mostly Stellar sea lions) were relatively stable ((Bureau of Marine Fisheries 1946). All of the counts before 1946 were made by boat and would now be considered minimum population estimates, as sea lions at sea were not counted. Sea lions became protected species in 1972 with the passage of the federal Marine Mammal Protection Act, and annual aerial surveys of the rookeries began in the mid-1970s. The first aerial survey was made in 1946, when 7,338 sea lions were found in Southern California and 5,168 in Northern California (Bureau of Marine Fisheries 1946).

It is disappointing that, given the recent concern about the sea lions in Southern California, the last available value for pups born is from 2011 (Carretta et al. 2017). It is also discouraging that survey data must be estimated from a figure rather than being able to use the actual numbers obtained in the surveys.

To make the early population counts comparable to recent population estimates, I have increased the pre-1972 population counts by the ratio of total population size/survey count (i.e. 296,750/153,337 = 1.935) found in the most recent stock assessment (Carretta et al. 2017). Recent population estimates are based on counts of pups on the breeding islands in Southern California, and total numbers are estimated by multiplying the number of pups (Table 1) by 4.317 (Carretta et al. 2017). The most recent estimate (2014) is 340,000 California sea lions on the Southern California breeding colonies (McClatchie et al. 2016); however, the documentation of that estimate is not given.

In addition, there are breeding colonies on both the Pacific and Gulf coasts of Baja California, and males from the Pacific coast colonies spend a significant portion of their lives in U.S. waters (Carretta et al. 2017). Lowry and Maravilla-Chavez (2005) estimated the Pacific Baja California population to be about 81,000 in 2000 (i.e. between 75,000 and 87,000).

The original California sea lion surveys in 1927-30 show that the population size of the California portion of the California sea lion population was about 2,800, and the most recent estimate is 340,000 (Table 5). The 2014 California population estimate is more than 120 times larger than the 1928 estimate. So there were more than two orders of magnitude less sea lions when the original sardine fishery began.

Contrast this situation with the very closely related Japanese sea lion. It, too, was driven to low levels in the late 1800s and early 1900s by unregulated exploitation. It went extinct in 1974.

California sea lion population growth rate from 1930 until 1938 averaged 9.3% per year even though sea lions were still being harvested or killed, and the rate between 1938 and 1946 dropped to 8.6%. Sea lions became protected species in 1972 and the population grew at a rate of 5.8% from 1975 to 2000. The rate decreased to 4.3% between 2000 and 2008 and to 2.3% between 2008 and 2014 (Table 5). The drop off in the population growth rate is entirely consistent with a population approaching carrying capacity.

Unfortunately, due to the absence of current survey information, it is not possible to determine if the population has reached or exceeded carrying capacity and has ceased growing.

Table 5. California Sea Lion Population Trends. Pup counts multiplied by 4.317, CDF&G survey counts multiplied by 1.935 and forage based on 4.563 mt per sea lion. (Survey and pup counts from Bonnot 1928, Cass 1946, Carretta et al. 2013, McClatchie et al. 2016 and Lowry and Maravilla-Chavez 2005.)

	Pup counts	Survey counts	Population estimates	Forage Consumption mt	Annual Growth
USA					
1928	-	1,429	2,800	13,000	9.3%
1938	-	3,882	7,500	34,000	8.6%
1946	-	7,338	14,000	65,000	6.8%
1966 a	-	-	28,000	128,000	-
1975	12,000	-	52,000	236,000	5.8%
2000	49,000	-	212,000	965,000	4.3%
2008	68,740	-	297,000	1,353,000	2.3%
2014	-	-	340,000	1,550,000	
Baja California					
2000			81,000	369,000	
2018 Projection (+2.3%/yr)					
US from 2008			373,000	1,699,000	
Baja from 2000			122,000	556,000	
TOTAL in 2018			**494,000**	**2,256,000**	

a Estimated with 6.8% annual growth from 1946-66.

Based on information from Sea World[1], Demer et al (2015) estimated that California sea lions consume an average of 12.5 kg of forage per sea lion per day, (4.563 mt per year) and that 300,000 sea lions would consume about 1.37 MMT of forage per year. Based on 10% of their diet being sardine, they estimated that California sea lions consumed 0.14 MMT of sardine per year. Using the 4.563 mt yr[1] value, the total consumption of forage by California sea lions during the beginning of the original sardine fishery in 1928 was about 0.01 MMT (Table 5). By 1975 the amount of forage consumed by the California sea lion population had risen to 0.24 MMT and by 2008 it was 1.35 MMT. The most recent U.S. population estimate available, 340,000 California sea lions (McClatchie et al. 2016), would consume 1.55 MMT of forage.

The calculations derived from the Koehn et al 2016 data, which include the entire California Current Ecosystem and both sea lion species, give values about double that estimated by Demer et al. (2015) for the Southern California region. That is, a total marine mammal consumption of 2.87 MMT forage fishes and 0.53 MMT of sardine with 0.18 MMT of sardine consumed by sea lions (Table 2).

Neither the Demer et al. (2015) nor the Koehn et al (2016) estimate of the consumption of forage fishes by sea lions include the Baja Pacific Coast populations. In 2000 the U.S. population of California sea lions was about 212,000 and the Pacific Baja population was about 81,000 (Table 5). This implies that their total populations, and forage consumption by California sea lions, should be increased by about 38%.

The California Current population of California sea lions includes both the US breeding colonies and the Pacific coast of Baja colonies. To estimate the 2018 population size, the 81,000 California sea lions in Baja in 2000 and the recent US estimate must be projected. To make this projection I increased the 2000 Baja California and 2008 California population estimates by the most recent growth rate in California (i.e. +2.3%/yr). This results in a 2018 population estimate of 494,000 California sea lions that consume 2.25 MMT of forage per year (Table 5). This does not include the consumption by Stellar sea lions.

Part 3: Present State of the Sardine and Anchovy Stocks:

Sardine:

A time series of the commercial landings of the northern stock of sardine and the central stock of anchovy is available back to 1928, when 190,663 mt of sardine and 162 mt of anchovy were landed in California. The first observed period of high sardine abundance and its collapse is very well known; the second observed period of high sardine abundance was brought to a close by low recruitment success from 2006 to 2010 followed by near complete reproductive failure from 2011 to 2016 (Figure 34 from (Hill et al 2017). Note that an unknown proportion of the total landings is from the southern (Baja) stock.

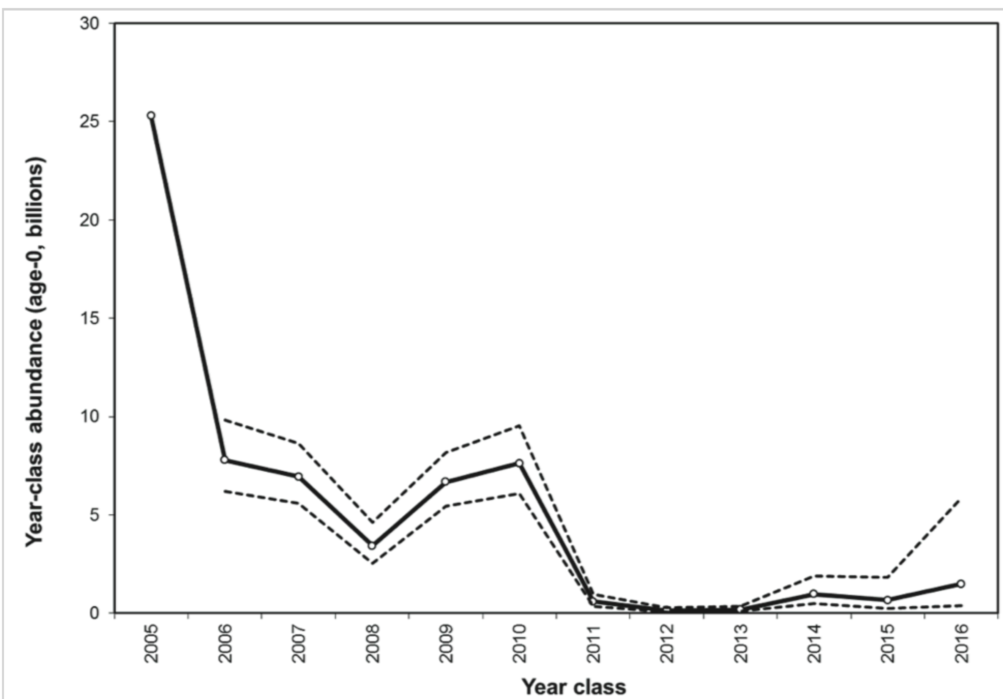

Figure 34. Recruit (age-0 fish, billions) abundance time series (±95% CI) for model ALT.

It is significant that the Gulf of California sardine stock declined sharply at the same time as the northern stock; landings fell from a peak of 528,094 mt in the 08/09 season to 4,455 mt in the 14/15 season (Alvarez et al. 2017). It appears that the environmental factor that was responsible for the second observed collapse of the California sardine is geographically large enough to alter sardine abundance from British Columbia to the Gulf of California.

The original estimate of natural mortality (M=0.4) for sardine was made from the extensive information on the age structure in the early fishery (Murphy 1966). This value was used until very recently, when information showed that the recent natural mortality rate has increased substantially. Based on the size structure of sardines sampled in 2003-13, Zwolinski and Demer (2013) estimated the natural mortality rate to be M=0.52, with larger values for both young sardines and old sardines. The most recent biomass assessment uses a natural mortality rate that is 50% higher (M=0.6) than that observed in the 1930s and 1940s (Hill et al. 2017).

During the late 1930s, at the peak of the early sardine fishery, estimates based on the above Demer et al. (2015) method of calculating total consumption of forage fishes by the U.S. portion of the California sea lion population was 0.034 MMT, this rose to 1.35 MMT in 2014 and the projected 2018 consumption estimate for the combined California and Pacific Baja populations is 2.25 MMT. This estimate does not include the California Current population of Stellar sea lions.

Anchovy:

The spawning biomass of the northern stock of anchovy was at a very low level (i.e. about 0.02 MMT) when the CalCOFI egg and larvae surveys started in the early 1950s. It rose to over 0.5 MMT by the late 1950s and then to about 2.0 MMT in the mid-1960s (MacCall et al. 2015). In the mid-1960s, California anchovy landings began increasing, and the combined California and Ensenada catch was above 50,000 mt from 1967 until 1989. The California portion of the landings peaked at 143,800 mt in 1975. Weak 1974 and 1975 year-classes severely reduced the age composition from a dominance of 2 and 3 year olds and substantial catches of older fish to a fishery dominated by ages 0 and 1 (Mais 1981).

The California fishery fell below 20,000 mt in 1983 and it has never reached that level again. The Baja California fishery, which includes an unknown portion of the southern anchovy stock, peaked at 258,745 mt in 1981 (Alvarez et al. 2017). The combined fisheries peaked at 310,856 mt in 1981 and fell from 84,259 mt in 1988 to 3,215 mt in 1989.

With the exception of the 2005-6 anchovy bubble discussed later, the central anchovy stock has been at low population levels for nearly three decades, and this appears to be closely associated with the survival rate of anchovy eggs and early larvae. Fissel et al (2011) found "that egg densities were highly variable while larval densities have been persistently low since 1989. Recruitment estimation suggests that poor environmental conditions have potentially contributed to the low productivity. Mortality estimation reveals through an increasing egg mortality rate that low larval densities were primarily the result of high mortality during the pre-yolk-sac period."

The decrease in the early life history survival rate is clearly seen in Figure 1. It is clear that environmental conditions affecting the survival rate of eggs and early larval stages are the primary reason for the low population of anchovy in Southern California. Oddly, the 2005-6 anchovy bubble does not appear to have been associated with an increase in the survival of larvae as measured by the surveys.

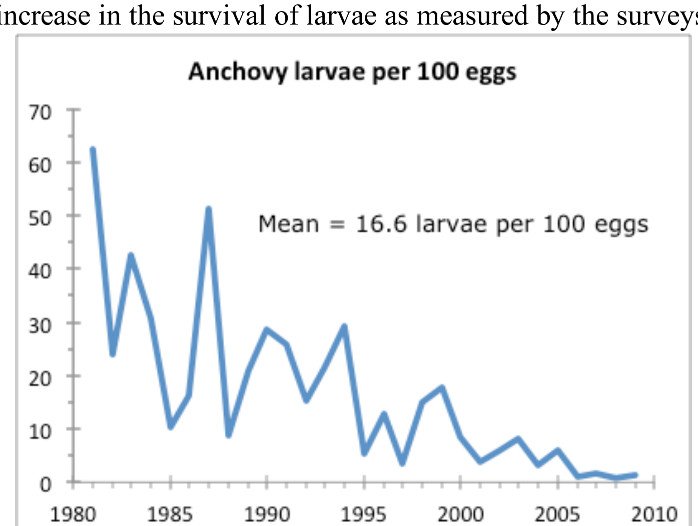

Figure 1. Mean number of anchovy larvae per 100 eggs (from Table 1 Fissel et al 2011)

The 2005-6 Anchovy Population Bubble:

The 2005-6 anchovy outbreak was one of the most interesting 'natural experiments' to occur in the California Current in recent years. The spawning biomass of the central stock of anchovy had been in the 0.1-0.4 MMT range since the decline of the previous anchovy regime in 1989 when it suddenly increased to a 2005 peak of 2.0 MMT (MacCall et al 2016) or 1.36 MMT (Fissel et al 2011). The outbreak appears to have been a single year-class, probably 2003, which must have been the result of extremely high reproductive success. This enormous year-class produced the highest spawning biomass recorded (Fissel et al 2011) or one of the highest (MacCall et al 2016).

The MacCall et al (2016) study shows the spawning biomass in 2003 was about 0.15 MMT, this increased to about 0.6 MMT in 2004 and to a peak of about 2.0 MMT in 2005. The drop in spawning biomass from 2005 to 2006 was about 0.75 MMT and the drop from 2006 to 2007 was about 1.0 MMT.

It should be noted that both the MacCall and Fissel estimates of spawning biomass are minimum estimates of the anchovy population size because they do not include young, non-spawning anchovies, anchovies that spawned south of the US-Mexican Border and anchovies spawning inshore of the egg and larvae surveys. Age 0 and age 1 anchovies are concentrated in shallow coastal water (Parrish et al. 1985).

U.S. landings of anchovy in 2005 were 11,180 mt,, and 12,791 mt were landed in 2006; this small fishery would have had no measureable effect on a population of 1-2 MMT.

So what caused the 1.75 MMT two-year drop in the abundance of the anchovy stock?

The obvious answer is: something ate them!

According to MacCall et al (2015) "It is reasonable to expect that abundance could recover quickly again if and when favorable conditions return. However, other factors such as predation may be currently limiting population growth. Major anchovy predators, such as California sea lions and humpback whales, have recovered from their very low abundances during the 1950s (Carretta et al., 2014; Calambokidis and Barlow, 2004), and may now be consuming a larger fraction of the anchovy population, especially under the presently low abundances and nearshore concentrations."

It would be interesting to see if any of the present ecosystem models could reproduce the prey switching necessary to describe the collapse of the anchovy population bubble of 2005-6.

The decline of the central anchovy stock continued after 2006 and the spawning biomass estimates from the egg and larvae survey in 2009 reached the extremely low levels that had occurred in the early 1950s (MacCall et al (2016).

Natural Mortality Rate.

The major cause of natural mortality in forage fishes is predation, and as seen in the above analysis of the Koehn et al (2016) information, 52% of the predation of anchovy is from protected mammals and birds and 48% is from fishes; there is no take by invertebrates. These values are, of course, averages of the 2000-14 period, and they give no estimate of the range of predation rates when anchovy are at low and high abundance. As seen above, the minimum spawning biomass of the central stock of anchovy (i.e. egg and larvae estimates of spawning biomass in US waters) varied from around 2.0 MMT to 0.02 MMT in the 2000-14 period (MacCall et al 2016).

It is highly likely that there has been a larger increase in the natural mortality rate of the central stock of anchovy than that observed in the northern stock of sardine. This is partially due to the fact that the central anchovy stock's distribution closely overlaps that of the California sea lion. In addition, anchovy has the highest frequency of occurrence in the sea lion diet and sardine has the 8th most frequent (Table 3 from Lowry and

Carretta 1999). The central stock of anchovy remains in the Southern California area and is preyed upon all year; in contrast, older sardine migrate northwards in the late spring and return in the early winter. The abundance of sardine in Southern California is at a minimum in the spring to late fall, when marine mammals and birds that breed and raise their young in Southern California are the most in need of forage. The natural mortality rate of anchovy is not well established, and different authors have used different values. MacCall (1974) found that natural mortality increased with age and suggested that M=1.06 (an annual rate of 65% per year) was the best single estimate. Jacobson et al (1994) 'assumed' a rate of M=0.8 based on the longevity of the species.

Protected species are a major source of predation mortality of the northern anchovy, and their take heavily outweighs that taken by the U.S. Fishery (Table 6).

Table 6. Average (2000-14) annual take (mt) of northern anchovy by protected species and species groups vs. that taken by the U.S. fishery. (Calculated from Koehn et al. 2016: Table 1 and supplemental data).

Common murre	103,082	California gull	23,671
Humpback whale	94,725	Fin whale	22,822
Dolphins	89,179	Western/Glaucous gull	22,027
Porpoises	87,135	Brown Pelican	21,013
Shearwater	52,885	Brandt's cormorant	10,741
Harbor seals	50,677	Rhinoceros auklet	8,724
Sea lions	41,741	**U.S. Fishery**	**8,095**
Fur seals	35,768	Minke whale	6,018

If the anchovy natural mortality rate increased by 50%, as observed in sardine, the present natural mortality would be M=1.2 with the Jacobson et al (1994) estimate or M=1.59 with the MacCall estimate. This would give an annual mortality, in the absence of a fishery, of either 69.9% per year or 79.6% per year, and age 1 anchovy would account for 70% or 80% of the entire population.

When age zeros are added, it is clear that, if the higher mortality rates are valid, the present anchovy population is heavily dominated by ages 0 and 1. Much of this biomass is not measured because it is inshore of the current egg-larval survey grid. Further, current egg-larval surveys, which were designed for sardine, are not suitable to measure peak anchovy spawning because survey timing falls only in January, at the beginning, and April, the end of the spring spawning period for the central stock. The northern stock, which may at times dominate the anchovy biomass in Central and Northern California, is not included in the egg-larvae biomass estimates. The last problem is that current surveys stop at the U.S. border and do not extend into Mexico, where a significant proportion of the central anchovy stock lives.

DISCUSSION

As noted in my comments related to the NOAA Fisheries Ecosystem-Based Fishery Management Western Road Map Implementation Plan (WRIP, Agenda Item C.1.b), the subject that has been largely missing from the forage fish vs. fishery controversy, as well as discussion about how to achieve real ecosystem-based fishery management, is: What is the carrying capacity of the California Current for sea lions and other protected marine animals? Should management treat protected species that are near carrying capacity the same as it does protected species that have healthy populations but are well below carrying capacity, and how should management of threatened species differ from protected species that have healthy populations?

The expected symptoms of a population of mammals at carrying capacity include reduced reproductive output, decreased growth and survival of young animals, delayed sexual maturity, increases in disease or parasites and decreased size and survival of adults. There have been recent increases in California sea lion pup mortality and reduced pup growth rates, as well as increased incidence of leptospirosis observed in central California and Oregon, leading to the suggestion that the population is approaching carrying capacity (McClatchie et al. 2016).

Is a population under stress from being close to or above present carrying capacity as healthy as a population at 60% of carrying capacity and not under stress?

Certainly anyone familiar with the California Current Ecosystem is aware of the extreme climatic dependence of sardine and anchovy populations. Clearly environmental variation causes large decadal and El Niño scale changes in the carrying capacity of the California Current for anchovy, sardine, as well as other key forage species and the animals that prey on them.

In conclusion, as noted in my WRIP comments, it is apparent that during the present environmental regime, competition between protected species is far more important than competition between protected species and the U.S. fishery for forage fishes. Information documenting this competition, and analyses calculating the trade-offs between competing predators and fisheries, which are needed to achieve true ecosystem-based management, should be included in the Fishery Ecosystem Plan,

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