

MEASURES TO PROHIBIT FISHING FOR KRILL IN THE ECONOMIC EXCLUSIVE ZONE OFF THE WEST COAST

**AMENDMENT 12 TO THE COASTAL PELAGIC SPECIES FISHERY MANAGEMENT
PLAN**

**ENVIRONMENTAL ASSESSMENT, REGULATORY IMPACT REVIEW & REGULATORY
FLEXIBILITY ANALYSIS**

**SUBMITTED BY:
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COVER SHEET
Measures to Prohibit Fishing for Krill in the Exclusive Economic Zone off the West Coast

**Environmental Assessment
and
Proposed Amendment 12 to the
Coastal Pelagic Species Fishery Management Plan**

Prepared by: Southwest Region, National Marine Fisheries Service (NMFS), and Pacific Fishery Management Council

Abstract: The Pacific Fishery Management Council (Council) proposes to amend its Coastal Pelagic Species Fishery Management Plan (CPSFMP) to ensure the protection of krill and the resources which depend on or are sensitive to the abundance and availability of krill off the West Coast. The proposed action described in this amendment would:

Add krill to the management unit species of the CPSFMP
Establish a “prohibited harvest” category of management unit species in the CPSFMP
Place all species of krill that occur in the EEZ off the West Coast in the “prohibited harvest” category and thus prohibit the harvest and retention of krill in the EEZ
Designate essential fish habitat for krill
Deny the use of the exempted fishing permit process under the CPSFMP to allow krill fishing

This combined environmental assessment/FMP amendment has been prepared pursuant to the Magnuson-Stevens Fishery Conservation and Management Act, the National Environmental Policy Act, and other applicable law. The public was provided an opportunity to review and comment on drafts of this documentation to assess the impacts of the proposed action and of alternative means to conserve and manage krill resources off the West Coast. After receiving and considering public comments on this proposal, the Council (which includes NMFS) took final action at its meeting March 8, 2006.

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1.0 INTRODUCTION

1.1 Summary

The Coastal Pelagic Species (CPS) fishery in the Exclusive Economic Zone (EEZ) off the West Coast is managed under the Coastal Pelagic Species Fishery Management Plan (CPSFMP), which was developed by the Pacific Fishery Management Council (Council) pursuant to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). The CPSFMP was approved by the Secretary of Commerce and was implemented by regulations that can be found at 50 CFR Part 660, Subpart I.

The Council has expressed interest in and support for ecosystem-based fishery management programs that recognize the relationships between different components of the marine environment. Whether looking at management of multi-species fisheries or of fisheries for species that are both predators and prey, or at conservation of habitat that is essential for healthy fish stocks, the Council is attempting to incorporate ecosystem conservation principles into its management programs. In this context, the Council is interested in conserving and managing krill resources (see Section 3 for information on krill and their role in the environment) to maintain ecological relationships and ecosystem integrity and to minimize the risk of irreversible adverse impacts on managed fish stocks and other living marine resources from adverse impacts on the building blocks (such as krill) of the ecosystem in which those species exist. It is desirable to maintain krill stocks within the bounds of natural environmental variability to the extent practicable. Designation of essential fish habitat for krill will further this objective as well.

At its meeting October 31, 2005, the Council agreed to complete for public review and comment a draft CPSFMP amendment to conserve and manage krill resources. The Council subsequently took public comment and adopted the conservation and management measures for krill described in this combined FMP Amendment and environmental assessment, which is proposed to achieve the goal of the Council.

Summary of Environmental Impacts of the Proposed Action

The proposed action, if implemented, is expected to have the following impacts:

Krill stocks will remain at levels associated with prevailing environmental conditions and within the bounds of natural environmental variability.

Species of fish that are dependent on or sensitive to the abundance and availability of krill will be sustained to the extent that natural populations of krill support such species.

Species of other animals (marine mammals, seabirds) that are dependent on or sensitive to the abundance and availability of krill will be sustained to the extent that natural populations of krill support such species.

Fisheries for species that are dependent on or that are sensitive to the abundance and availability

of krill in the natural environment will be protected from any adverse effects that krill fishing might have on krill and associated and dependent species.

Because there is now no fishing for krill, there will not be adverse impacts on such fishers. However, the potential future benefits of krill fishing will be precluded as long as the prohibition of harvest remains in place.

Eco-tourism businesses (e.g., whale watching cruise providers) that serve non-consumptive users for a fee will be protected from any harm that krill harvest might have on the living marine resources which those users enjoy viewing.

Precluding the issuance of EFPs under the CPSFMP will ensure that exploratory or experimental fishing will not adversely affect krill stocks. Research fishing for krill would not be regulated by this proposed action.

1.2 History of the Action

In September 2004, managers of the Cordell Bank, Monterey Bay, and Gulf of the Farallones National Marine Sanctuaries (Sanctuaries) administered by the National Oceanic and Atmospheric Administration (NOAA) off central California requested that the Council consider prohibiting krill fishing in federal waters of the three sanctuaries. The Council was generally receptive to this request but recognized that it needed more substantive analysis of the krill resource and areas of predator dependence EEZ-wide and of the alternative ways to achieve the kinds of controls that might be imposed, before a final decision could be made. It is emphasized that waters in the Sanctuaries are not the only areas in which krill conservation and protection is critical. Krill occur in many parts of the EEZ and are likely important wherever they occur.

The Southwest Region (SWR), National Marine Fisheries Service, National Oceanic and Atmospheric Administration (NOAA Fisheries or NMFS), and NOAA General Counsel-Northwest subsequently presented the Council with advice on alternative approaches by which krill fishery controls could be implemented. In November 2004, the SWR and the Southwest Fisheries Science Center (SWC), NMFS, urged the Council to use the authority of the CPSFMP to effect this control. The Council agreed with this approach, with the commitment that the SWR would take the lead in overseeing documentation to provide a basis for a regulatory amendment to the CPSFMP to include krill as a species in the FMP management unit and to establish initial fishery controls as needed. Other alternatives were to be fully considered in this documentation. An Alternatives Analysis was prepared that presented information about the species of krill that occur off the West Coast, their productivity (as well as the uncertainty of the information available), and the relationship between krill and other fish and non-fish species; reviewed the potential mechanisms for achieving control over krill fishing in the EEZ; and evaluated different conservation and management measures which could be applied if krill fishing were to be permitted. The Council discussed the information in the Alternatives Analysis at its meeting October 31, 2005, and after receiving recommendations from its advisory groups and the public, directed that a draft CPSFMP amendment be prepared presenting a preliminary preferred alternative described above for public review and comment. That document was circulated for public review and comment. The Council reviewed and considered written comments and took

public testimony at its meeting on March 8, 2006. The Council then took final action to adopt the conservation and management program as a proposed amendment to the CPSFMP. The proposed amendment will now be submitted to the Secretary of Commerce to process under the MSFCMA. If approved, the amendment will be implemented by regulation. Draft regulations are included in this document.

2.0 PROPOSED ACTION

2.1 Purpose and Need

There are several species of krill in the EEZ off the U. S. West Coast (see Chapter 3 for a full discussion). Krill are a critical component of the ecosystem off the West Coast. They are a principal food source for many fish species that are subject to management under Council fishery management plans, including several overfished groundfish species. They are also a principal food source for many non-fish species, including baleen whales and some species of seabirds. Some of these species (e.g., whales) are listed as threatened or endangered and warrant special efforts for protection and recovery.

At this time, while there is no krill fishery, there also are no federal regulations that limit fishing for krill either within federal waters around the National Marine Sanctuaries or in the exclusive economic zone (EEZ) generally. The States of Washington, Oregon, and California prohibit their vessels from fishing for krill, and prohibit landings of krill into West Coast ports. However, these prohibitions would not prevent a vessel from another state from engaging in krill fishing and delivering the product to a port in another area. Under the current regulatory system, krill fishing has not occurred and is not occurring, and it is not likely by West Coast vessels due to the State laws noted. As is discussed in section 3.4 and 3.6, however, there are fisheries for krill and krill products in Japan, Canada and the Antarctic, and there is a potential for development of a fishery off the West Coast. Also, krill fisheries in certain areas such as the Antarctic have been conducted by large-scale harvester/processor vessels that process their catch at sea, and such vessels would not have to be dependent on West Coast ports to handle their products. International markets exist for krill and krill products, and while foreign fishing in the EEZ is a remote possibility, it may be that this market could or would be met by a West Coast krill fishery. Sources of information on the market for krill products are not definitive; the market for krill and krill products appears to be either slowly growing or on the verge of major growth.

The Council has considered the potential for development of a krill fishery and the potentially drastic effects a fishery could have on krill resources and on the fish and other species (especially species listed under the Endangered Species Act) that are dependent on or that are sensitive to the abundance and availability of krill (see section 3.2 and Appendix B). The Council has agreed it is critical to take preventive action at this time to ensure that a krill fishery will not develop that could harm krill stocks, and in turn harm other fish and non-fish stocks and adversely affect the consumptive and non-consumptive benefits that derive from these other resources. Therefore, the Council proposes to prohibit krill fishing in the EEZ off the West Coast. This is intended to ensure the long-term health and productivity of the ecosystem off the West Coast by protecting, to the extent practicable, one of the primary building blocks of that ecosystem.

2.2 Management Objectives

The Council has adopted the following objectives for this action:

- Ensure to the extent practicable that the stocks of krill are maintained at maximum levels within the bounds of natural environmental variability

This means that krill abundance and availability should be driven by natural fluctuations in environmental conditions and not be affected by human exploitation. At levels unaffected by human exploitation, krill would continue to fulfill their essential role as forage for important fish and other species to the extent possible within natural environmental variability. Krill also would, to the extent practicable, remain at levels at which they would support other essential ecological functions. It must be noted that distribution of krill is not restricted to waters within National Marine Sanctuaries.

- Provide protection for key krill habitat areas, that is, areas with topographic and oceanographic features that consistently serve to concentrate krill and support stock productivity (while incidentally supporting predator feeding)

Key krill habitat areas are areas in which krill repeatedly concentrate, most likely in response to environmental conditions conducive to feeding and reproduction. These areas also make krill most available to predators, so that krill concentrations will often result in predator concentrations. These areas need protection from potential adverse effects of human activities (which could include fishing) to ensure that the krill life functions enhanced by such environmental characteristics and conditions are not harmed or threatened by those activities. There would be ancillary benefits to the extent that predator species are thus given protection from potential adverse effects of interactions with fishing gear. The management program is intended to ensure that adverse effects on krill habitat areas from direct and indirect effects of human activities are avoided to the extent practicable.

- Provide a foundation for future research and data collection

This amendment and the information in it are meant to promote and support further research into the population dynamics of krill, the role of krill in the environment, and the potential biomass and productivity of krill in the natural environment. Section 3.1.3.5 of this amendment presents many recommendations for additional research and modeling and collaboration between scientists engaged in study of krill and other resources off the West Coast.

2.3 Krill Conservation and Management Alternatives

The Council considered three alternatives for this amendment as follows:

2.3.1 Alternative 1: No action

Every assessment of potential management strategies by the Council includes a No action^o baseline against which other alternatives are compared. Under this alternative, the Council would not have taken action at this time. This means that the States' prohibitions of landings of krill by their vessels would have remained in place (see section 3.5); but that a fishery by vessels from out of the region could have developed in the EEZ as long as landings were not made into a West Coast port. As there would have been no federal regulations controlling krill fishing, there would have been no need to consider issuance of EFPs to allow fishing that otherwise would be prohibited by such regulations. If a krill fishery developed, the Council would have an opportunity to develop conservation and management measures in the future.

2.3.2 Alternative 2: Manage Krill Fishing Through Amendment of the CPS FMP (Proposed Action)

Under this alternative, the Council proposes to add krill (all species) to the management unit species of the CPSFMP. The Council further proposes to establish a new category of management unit species - "prohibited harvest" - under the FMP and to place krill in that category. This means that optimum yield (OY) for krill would be zero, and the harvest of krill would be prohibited. The Council also proposes that no exempted fishing permits (EFPs) be issued under the EFP procedures of the CPSFMP to allow individuals to harvest krill as an exception to the prohibition of harvest. These actions would fully achieve the objectives of the amendment to the extent practicable, recognizing that environmental conditions and the responses of krill and other resources to changes in environmental conditions are beyond the control of the Council.

2.3.3 Alternative 3: Prohibit Krill Fishing but Establish Process for Allowing Future Fishing

This alternative would have added krill to the species under management through the CPS FMP and would initially have prohibited fishing for krill in the EEZ (i.e., Optimum Yield would have been zero), but a procedure would have been established by which krill fishing in the future could be permitted (subject to conditions). That procedure would have involved such steps as completing the modeling described in 3.1.3.5, establishing a firm MSY estimate(s), prohibiting the direct harvest of krill but possibly setting an initial low harvest allowance for EFPs with a complete monitoring and evaluation program (likely including observers) to determine if limited fishing were having any adverse effects, and setting future harvest limits at appropriate levels. EFPs could have been available under this alternative to help provide data needed to carry out the process allowing future fishing.

2.4 Alternatives Considered but not Analyzed Further

The Council considered several other alternative mechanisms for exercising control over krill fishing. One was to designate krill as forage for groundfish and possibly other species of fish under Council management. This approach had been taken in Alaska to provide protection to a number of species that filled that role. The Council decided that this approach was complex and could result in substantial delays in final implementation. It was noted that the legal environment in Alaska was more amenable to this approach than off the West Coast.

Another alternative was to designate krill as a component of essential fish habitat (EFH) for groundfish and perhaps other species under management by the Council's fishery management plans. This was explored in the Environmental Impact Statement for Establishment of Essential Fish Habitat (NOAA, 2005). The Council in June 2005 rejected this alternative when reviewing comments on and making selection of final proposed specifications of groundfish EFH. There was some concern that this approach would only limit persons in the groundfish fishery and would still leave open the possibility of krill fishing by persons in other fisheries or even by persons not subject to any FMPs. Further, the Council determined it wanted to be consistent with the decision relative to groundfish. The Council concluded it was not necessary to explore this alternative further as a means to conserve and manage krill resources as amendment of the CPS FMP would be more complete and direct.

The Council also considered whether to fully analyze alternatives that might allow limited krill fishing subject to possible controls on times and areas of fishing or amounts of catch. This could have included prohibition of krill fishing in EEZ waters around the National Marine Sanctuaries off the West Coast, consistent with the original request from the managers of the Sanctuaries off central California. Krill fishing in other portions of the EEZ might have been limited by other means (e.g., seasons, other area closures), but persons would have been able to engage in limited krill fishing in open waters. Consistent with the CPSFMP, there would have been requirements for permits, reports of catch and effort, and provisions for observer placements at the direction of NMFS. The Council ultimately concluded that consideration of such a wide range of detailed management options would detract from the principal objectives of the action and would be far more complex than necessary to achieve those objectives.

Therefore, these alternatives were not evaluated in more detail than shown in the Alternatives Analysis that was the basis for selection of the preliminary preferred alternative in the draft amendment that was circulated for public review and comment.

3.0 DESCRIPTION OF KRILL RESOURCE AND THE AFFECTED ENVIRONMENT

3.1 Krill Biology and Status

3.1.1 Species of Concern and Definition of Krill

The word "krill" comes from a Norwegian term meaning "young fish" but it is now the common term used for all euphausiids, a taxonomic group of shrimp-like marine crustaceans found throughout the oceans of the world. The term krill was probably first applied to euphausiids found in stomachs of whales caught in the North Atlantic, and later became a popular term for Antarctic krill (*Euphausia superba*). For the purpose of this document and analysis, the term 'krill' is synonymous with 'euphausiid'.

Eight species of euphausiid shrimp dominate the krill community in the Transition Zone of the California Current System (Brinton and Townsend 2003). However, only the two cold-water species, *Euphausia pacifica* and *Thysanoessa spinifera* (Fig. 1), form large, dense surface or near-surface aggregations and would have some potential to become fishery targets, as high catch densities (e.g., greater than 3 g wet weight m⁻³) are usually required to support commercial harvesting (Fulton and Le Brasseur 1984). These two species are also the most common euphausiids reported in the diets of a wide variety of California Current seabird, marine mammal and fish species (see Section 3.2.1 below).

The daytime near-surface aggregating behavior of *E. pacifica* and *T. spinifera* has been documented by Boden et al. (1955), Barham (1956), Percy and Hosie (1985), Smith and Adams (1988), and others. The sub-tropical and marginally tropical *Nyctiphanes simplex* also aggregates at the surface in large swarms, occurring predominantly to the south in Mexico waters (Gendron 1992; Brinton and Townsend 2003); it is only abundant in U.S. West Coast waters during strong El Niño years. Another euphausiid, *Nematocelis difficilis*, is very abundant in the California Current, but it is not a vertical migrator, preferring the deeper layers of the thermocline where it is less accessible to harvest than *E. pacifica* and *T. spinifera*. Based on current (limited) data, the remaining species (*T. gregaria*, *E. recurva*, *E. gibboides*, *E. eximia*) are less abundant and are even less likely candidates for exploitation.

All krill species are proposed to be included under the CPSFMP. However, most of the discussion of krill in this document refers to *E. pacifica* and *T. spinifera*. These are the only species for which there is substantial information with respect to abundance, distribution, and life history characteristics. Even for these species, there is insufficient information for a scientifically sound specification of maximum sustainable yield (MSY) (see 3.1.3.4). This is not indicative of the relative importance of the different species in the environment; it simply reflects what is known about them at this time. However, for any prospective fishing enterprise, it could be expected that any significant concentration of krill would be exploited if available, regardless of the species. It is not likely that a fisher would be able to distinguish between species until it was on a vessel or in a laboratory. It would not make sense to control the harvest of the principal species and allow uncontrolled harvest of other

species; this would simply invite difficulties of unintended incidental catches of principal species and likely result in enforcement problems and/or substantial discards. Therefore, all species would be in the “prohibited harvest” category proposed in this amendment.

3.1.2 Biology

3.1.2.1 Range

E. pacifica ranges throughout the subarctic Pacific, including the Gulf of Alaska as far south as 25° N latitude (Brinton 1962a, 1981) (Fig. 2). *T. spinifera* occurs from the southeastern Bering Sea south to northern Baja California, with regions of high density associated with centers of upwelling (Boden et al. 1955; Brinton 1962a) (Fig. 3). The ranges of other species are not known.

3.1.2.2. Horizontal Distribution in the EEZ

Distribution of the two principal species within the EEZ is thought to be closely related to bathymetric, topological and oceanographic features favorable for retaining adults, juveniles and larvae in optimum grazing areas. Periodically, distribution and occurrence can also be strongly affected by changes in local and large-scale physical and biological conditions such as anomalously strong upwelling events or extreme El Niño conditions. It is not known whether animals advected offshore are lost to the system, or whether transport of some individuals to the south and west via upwelling filaments or eddies may help to interconnect regional subpopulations and enhance gene flow among isolated stocks. The Scripps Institution of Oceanography (SIO) has recently assembled a 50-year time series of maps showing spatial densities of these and other euphausiid species in the CalCOFI sampling area (Point Reyes, California, south to the California-Mexico border, E. Brinton, SIO, unpub. data, personal commun. 6/8/05). Similar data on a real distribution have been and are continuing to be gathered off Oregon (Smiles and Pearcy 1971; Gómez-Gutiérrez et al. 2005; Peterson et al. NWFSC, pers. commun., Newport, OR 6/8/05). These recently available data and previously published distributional data, indicate that *E. pacifica* generally occurs within the West Coast EEZ over bottom depths greater than 100 fathoms (183 m). It can also occur (especially in the larval form) further shoreward over the deeper waters of the continental shelf. It is known to occur seaward to the outer boundary of the EEZ from the U.S.-Mexico border north to the U.S.-Canada border and beyond (Boden 1955), but highest densities appear to occur within the inner third of the EEZ (E. Brinton, SIO, unpub. data, pers. comm. 6/6/05). Within this area (< 60-100 nm from the coast), adults and juveniles reportedly can be found throughout both the inshore and offshore area, whereas larvae are often most abundant in upwelled areas much nearer the coast, generally inshore of the 1000 fm (Brinton 1976; Brinton 1967; Smiles and Pearcy 1971; Gómez-Gutiérrez et al. 2005). Off Oregon, the greatest concentration of adults appears to be located near the shelf break (~200 m isobath) (Gómez-Gutiérrez et al. 2005; W. Peterson, NWFSC, Newport Oregon, pers. comm. 6/6/05). Aspects of its life history may differ in the lower part of its range south of 40°N than to the north of that latitude, where environmental characteristics show stronger seasonality than to the south (Brinton 1976).

T. spinifera is more coastal, occurring mainly shoreward of the shelf break, usually over bottom

depths less than 200 m deep, although catches can occur further offshore beyond the shelf, especially off central California (Fig. 3). Daytime surface swarms have been observed off California in the San Diego, Santa Barbara Channel Islands, Monterey Bay, Gulf of the Farallones, Cordell Bank, and Tomales Bay areas, and off Oregon (Pearcy and Hosie 1985; Smith and Adams 1988; Brinton et al. 2000; Adams 2001; Howard 2001)

Gómez-Gutiérrez et al (2005) have described the cross-shelf life stage segregation of *E. pacifica* and *T. spinifera* off Central Oregon, which appear to be more tightly associated with the shelf break than in other areas, e.g., off southern California. *E. pacifica* tends to be more offshore extending from 3 to 60 nm miles (5.6-111 km) and beyond from the coast, whereas *T. spinifera* is more coastal, with highest concentrations over the continental shelf and slope. High densities of early life stages (nauplius to juveniles) of both species were primarily recorded in the inshore shelf zone (<18 km from the coast), but older stages were mainly recorded in the outer shelf, slope, and to some extent, beyond. Adult *E. pacifica* (and to some extent, older larval stages) were distributed over the shelf, slope and beyond, with reproductive swarms common along the shelf- break area. *T. spinifera* occurred primarily over shelf and shelf-break waters from 2-74 km (1- 40 nm) from the coast, especially between 5.6- 27.8 km (3 and 15 nm) from shore in water less than 100 m deep. Larvae and juveniles of *T. spinifera* were also generally restricted to relatively shallow inner shelf waters within < 18 km from the coast; while adults occurred generally in outer shelf, shelf break and slope waters beyond 18 km from the coast. They concluded that a strong cross-shelf gradient in euphausiids assemblages and age-segregated distributions for both *T. spinifera* and *E. pacifica* may represent maintenance of egg, nauplius, and metanauplius stages in the rich nearshore area; the offshore drift of older larval stages; and concentration of reproductive adults at the shelf break linking inshore and offshore segments of the populations. Off southern California, larvae of both species occur offshore beyond the shelf as well as inshore (Brinton 1967, 1973). Brinton and Townsend (2003) reported *T. spinifera* (mostly furcilia; rarely adults) disperses extensively offshore toward the main flow of the California Current. While it is possible that these individuals (especially *T. spinifera*) may be advected there by currents and represent individuals lost from the coastal population (Brinton and Townsend 2003), there may also be significant latitudinal differences in the inshore-offshore dispersion patterns and retention mechanisms off Oregon and California.

Gómez-Gutiérrez et al (2005) and others have suggested that the shelf-break is an important ecological region for both these species, with larger euphausiid patches often recorded there. Off Oregon, the main populations are thought to be concentrated within 10 to 20 nm either side of the shelf break (Peterson, W.T., pers. comm. NMFS, NWFSC, Newport Oregon, 6/6/05), though distribution may be further offshore to the south off central and southern California. Additionally, certain features have been associated with important “hot spots” of krill concentration. These are islands, banks, canyons, and promontories that enhance retentive water circulation patterns that tend to retain and concentrate krill and phytoplankton biomass in nutrient-rich upwelled water. Sometimes, these “hotspots” can also occur far offshore, contained in the meanders of upwelling jets that originate further inshore over the shelf or slope. Krill fishing is likely to be the most profitable in these high krill density areas, but also likely to be in direct competition with associated fish, seabird and cetacean predators concentrated there. Known high krill and krill predator areas include, but may not be limited to the Olympic Coast, Washington (Calambokidis et al. 2004); Heceta Bank and Cape Blanco areas, Oregon (Ainley et

al. 2005; Ressler 2005; Tynan et al 2005); Bodega Canyon, Cordell Bank, Gulf of the Farallones, Pescadero Canyon, Ascension Canyon, and Monterey Bay Canyon off northern California (Chess et al 1988; Smith and Adams 1988; Kieckhefer 1992; Schoenherr 1991; Adams 2001; Howard 2001); and around the southern California Channel islands (Armstrong and Smith 1997; Fieldler et al. 1998; Croll et al 1998).

3.1.2.3 Vertical Distribution in the EEZ

E. pacifica performs extensive vertical migrations, usually over depths greater than 200 m. The adults live at a daytime depth of 200-400 m (occasionally down to 1000 m) rising to near the surface at night (Brinton, 1976; Youngbluth 1976), often concentrating in the upper 20 to 50 m. It occasionally amasses near the surface during the day as well (Hanamura et al 1984; Endo et al. 1985; Brinton and Townsend 1991).

T. spinifera generally occurs from the surface to about 200 m deep but most frequently at vertical depths of less than 100 m (Ponomareva 1966; Brinton et al 2000; Alton and Blackburn 1972). It also undertakes diel vertical movements within its relatively shallow range (Alton and Blackburn 1972; Chess et al. 1988). It is the most predictable and extensive daytime surface swarmer along coastal California from Tomales Bay south to the Channel islands off southern California (Brinton 1962a; Smith and Adams 1988; Fielder et al 1998; Howard 2001; Adams 2001). Mass strandings of the species have also been reported along Oregon beaches (Pearcie and Hosie 1985) and as far south as La Jolla, California (Brinton 1962a).

3.1.2.4 Food Requirements and Trophic Transfer

Both species are grazers on microscopic plants and animals and provide an important link in the oceanic food web between phyto- and nanoplankton and upper trophic levels. Phytoplankton is thought to be a major component of the diet, but fish eggs and larvae are also thought to be consumed in large quantities. Theilacker et al (1993) suggests this predation may significantly affect fish recruitment. Field et al (2001), using a top-down Ecopath assessment model for the northern California Current ecosystem¹ (NCCE), estimated euphausiid average annual phytoplankton biomass consumption to be 650 g wet weight m⁻² during the early 1960s (a cool, productive regime), and 400 g wet weight m⁻² in the mid-1990s (a warm regime characterized by low productivity).

The phytophagous role of krill has a negative aspect. Bargu et al. (2002) found evidence that California krill (e.g., *E. pacifica*) may be a potential transfer agent of the phycotoxin domoic acid to higher trophic levels in the marine food web in Monterey Bay.

¹Defined as Cape Mendocino, CA north to the tip of Vancouver Island, Canada.

3.1.2.5 Growth, Sexual Maturity, Longevity, and Natural Mortality

Analysis of length at age is complicated by the fact that krill can shrink in size as an ecological adaptation to temporarily unfavorable environments (Marinovic and Mangel 1999). Both species are known to shrink in winter when food is scarce; *E. pacifica* is also known to shrink in summer during the reproductive season (W. Peterson and L. Feinberg, NMFS, SWFSC and OSU, pers. commun, 6/6/05). California Current krill can also regressively lose their sexual characteristics, skip developmental stages, or molt several times while remaining at the same stage (ibid). *E. pacifica* can also exhibit a large range of ages at any given size, and females at a given age can vary in size as much as 10 mm (ibid.). These characteristics can have a big impact on field calculations and complicate length frequency progression analyses.

Throughout its range, *E. pacifica* exhibits large variation in longevity and age at first sexual maturity (Table 3.1). According to Brinton (1976), the more abundant spring-summer cohort of *E. pacifica* off southern California generally reaches a maximum length of 22 mm in about 12 or 13 months, and has a one-year life span. Life expectancy for the lesser abundant winter cohort off southern California is shorter at 8 months. Individuals from 10 to 15 mm carapace length tend to predominate in the population. Growth rates of *E. pacifica* off southern California appear similar to those off Oregon (Smiles and Percy 1971). Under optimum conditions, sexual maturity could be attained at 11.6 mm length (Brinton 1976), and an adult cohort off southern California can reproduce about three times over a life span of about three years. Growth is thought to be slower and of longer duration to the north in the Subarctic North Pacific.

T. spinifera grows to a larger size—males to 20 mm, females to 38 mm. The difference in male and female growth is observed from the first year. Life span has been variously reported at from 10 months to two years or more (Boden et al. 1955; Nemoto 1957; Summer 1993; Tanasichuk 1998). In subarctic Alaskan waters, Nemoto (1957) reported a two-year life cycle (or at least 1+ yrs), with individuals growing to 10 mm in the first year and attaining sexual maturity at about 20-24 mm at one year of age, with a spawning season from June to September. He found large unfertilized specimens (26-30 mm) in mid July and was unsure whether these specimens represented ages 2+. Mauchline (1980) also estimated the maximum life span to be 2+ years with breeding maturity reached at 2 years of age. Summers (1993), using length frequency analyses of individuals collected in Barkley Sound, B.C., found that *T. spinifera* matures in one year, and some individuals survive to two years of age (most maximum-sized adults she found in the field were closer to 1 year of age). Tanasichuk (1998b) monitoring population structure in Barkley Sound, British Columbia, estimated a shorter life span of 10 months using length frequency progressions and certain initial assumptions about larval stage durations and furciliar growth. He also found more variable and protracted spawning. Annual and seasonal progression in size classes observed in *T. spinifera* collected in the Gulf of the Farallones and Channel Islands off southern California indicate that a 1 to 2 year life span may also be true for populations to the south, but more work is needed.

Few quantitative estimates of instantaneous natural mortality M are available for species of krill, although *E. pacifica* off California and Oregon has been better studied than most, and mortality found to be quite high. Brinton (1976) estimated that only 16% of *E. pacifica* larvae survive per month, then survival increases to 67% per month after the larval stage is complete, then mortality

increases once again in adulthood, with only about 60% surviving per month. Siegel and Nicol (2000) calculated M values based on data published in Brinton (1976) and Jarre-Teichmann (1996), and found $M = 3.0 \text{ y}^{-1}$ off California, and much higher ($M = 8.7 \text{ y}^{-1}$) off Oregon. Siegel and Nicol (2000) suggest the high mortality rates off Oregon may have been due to data collected under unusually severe El Niño conditions, and may not be representative of an ‘average’ year. No natural mortality estimates are available for *T. spinifera*.

Table 3-1. Estimates of maximum age, age at first maturity/spawning, spawning frequency and natural mortality rate (*M*) of the euphausiids *E. pacifica* and *T. spinifera*.

Species	Cohort	Area	MaxAge	1stMat	Spawning frequency ^{a/}	<i>M</i>	References
<i>E. pacifica</i>	Spring	S. Calif.	6-8 months	4 months	3 yr ⁻¹ ; ~ max. every 2 months ^{b/}	3.0 y-1	Brinton 1976 Siegel&Nicol 2000
<i>E. pacifica</i>	Autumn	S. Calif.	10-13 months	7 months	Max. every 2 months	3.0 y-1	Brinton 1976 Siegel&Nicol 2000
<i>E. pacifica</i>	---	Ore. & Wash.	1+yr	~1 yr	1 yr ⁻¹	---	Smiles&Pearcy 1971
<i>E. pacifica</i>	---	Ore	---	---	---	8.7y-1	Siegel&Nicol 2000 Jarre-Teichmann 1996
<i>E. pacifica</i>	---	Wash	---	---	2 yr ⁻¹ ; mostly spring, less in late summer.	---	Bollens et al 1992
<i>E. pacifica</i>	---	B.C.	---	---	4-6 yr ⁻¹ Mar-Oct	0.6-1.9 y ⁻¹	Tanasichuk 1998a; Siegel&Nicol 2000 Jarre-Teichmann 1996
<i>E. pacifica</i>	---	Aleutians; Kamchatka	2+ yr	~ 1 yr	1yr ⁻¹ for 2+ years	---	Siegel&Nicol 2000; Iguchi&Ikeda 1995
<i>E. pacifica</i>	---	NW Pacific; Kamchatka	2+ yr	~ 1+ yr	1 yr ⁻¹ for 2+ years	---	Ponamareva 1966; Nemoto 1957
<i>E. pacifica</i>	---	NE Japan	15 months	---	1 yr ⁻¹	---	Iguchi et al 1993
<i>E. pacifica</i>	---	SW Japan	21 months	---	---	---	Iguchi et al 1993
<i>E. pacifica</i>	---	N Japan	2+yr (female) 1+yr (male)	1+yr	---	---	Nicol&Endo 1997
<i>T. spinifera</i>	---	Barkley Sound, B.C.	1-2 yr	1 yr	2 pulses yr ⁻¹ Mar-July	---	Summers 1993
<i>T. spinifera</i>	---	Barkley Sound, B.C	10 months	---	3-4 pulses yr ⁻¹ Mar-Oct	---	Tanasichuk 1998b
<i>T. spinifera</i>	---	North Pacific	2+ yr	2 yr	---	---	Mauchline 1980
<i>T. spinifera</i>	---	Subarc-tic Alaska	1+ to 2+ yr	1 yr	1 y ⁻¹ June-Sept	---	Nemoto 1957

a/ distinct cohorts; egg release pulses
b/ depending on available food conditions

3.1.2.6 Reproduction and Recruitment

Both species are batch spawners; eggs are broadcast freely into the water, which sink in the water column. Males must transfer a spermatophore packet to the female for fertilization to take place. After hatching, larvae move toward the food-rich surface layers.

Recruitment of *E. pacifica* can occur year-round off Oregon and California, but distinct peaks are associated with upwelling periods (Brinton 1967; Brinton 1973; Barham 1957). *E. pacifica* appears to be more seasonal in the subarctic North Pacific and off Japan (Nemoto 1957; Ponomareva 1966). Recruitment typically crests off mid Baja California February-April; off southern California May-July; in Monterey Bay also spring and summer, and off Oregon, August-December (Brinton 1976). It may be that under optimal feeding conditions, a female, carrying 20-250 eggs which hatch into larvae could spawn every two months – first at about 11.5 -mm length; second at about 16 mm, and third at 20 mm – during which time it might produce a maximum of 650 eggs. The long duration of maturity (about half of the species' short life expectancy) is thought to contribute to population stability and continuity. Recruitment in California occurs after about 30 days when larvae enter the juvenile phase. There are at least 4 generations each year, at least off southern California. Due to the short life span and relatively few cohort pulses, the maximum stock size is reached immediately after successful recruitment of a single cohort (Brinton 1976; Siegel and Nicol 2000). In general, there is no spawning stock-recruitment relationship, in most years highest recruitment occurs from spring and summer cohorts, lesser recruitment occurs in autumn and winter. Off Washington, there is one large recruitment pulse in spring, and a lesser one in late summer (Bollens et al. 1992) and none in winter. This pattern is attributed to reduced phytoplankton levels in summer and low survival of adults into winter to spawn at that time.

Less is known of the population biology of *T. spinifera*. Brinton (1981) reported that the spawning season off California extended from May to July, coincident with the strongest upwelling. During this time, fully mature adults form extensive inshore surface swarms during the peak of the upwelling season off California (Brinton 1981, Smith and Adams 1988). These adults are thought to swarm, breed over a protracted spawning season, then presumably die at the end of their life cycle (Nemoto 1957). Off San Francisco, breeding appears to occur primarily from April through June-July. Spring reproductive swarms in this area contain mostly 18-30 mm fertilized adults in breeding condition, which presumably spawn (probably at intervals) and then die by late summer, when specimens of the size disappear from seabird and salmon diets, and from plankton collections. Swarms off central and southern California have also been sampled during late summer and fall (Aug-October) in association with blue and humpback whales, but these late summer and fall individuals are mostly immature or sexually developing individuals (14-20 mm). Maturing subadults are also known to swarm near the surface in late summer and fall (Schoenherr 1991; Kieckhefer 1992; Fiedler et al. 1998). Summers (1993) describes a distinct and extended spawning period off British Columbia from March through July with a late May peak. Unlike *E. pacifica*, the eggs of *T. spinifera* are quite adhesive, a possible mechanism to maintain recruits in the neritic zone and prevent offshore dispersal to less productive waters (Summers 1993).

To the north of the U.S. EEZ, Tanasichuk (1998b) has studied the population biology of *T.*

spinifera in Barkley Sound, Canada, including stock recruitment, biomass and productivity. He found neither the Ricker nor Beverton and Holt stock-recruitment models described the relationship between larval and parental abundances of this species he observed. Population production to biomass ratios (P:B) fluctuated between 14.4 and 44.7, with variations following the proportion of the biomass accounted for by larvae (e.g., the lowest P:B ratio was in 1994 when larvae accounted for only 0.05 of mean annual biomass).

3.1.3 Status of Principal Species

3.1.3.1 MSFCMA Requirements and Available Data

Under Section 303(a)(2) of the MSFCMA, an FMP is to specify the maximum sustainable yield (MSY) and optimum yield (OY) from the stock or stocks in a fishery, and under Section 303(a)(10) and summarize the information on which these determinations are made, an FMP, to the extent practicable shall identify objective and measurable status determination criteria for each stock or stock complex covered by that FMP and provide an analysis of how the status determination criteria were chosen and how they relate to reproductive potential.

In the case of krill, if the proposed action is implemented, the stocks will not be subject to fishing. Therefore, specifications of MSY and OY and of status determination criteria do not have any operational purpose. Notwithstanding, the following sections provide the best available information about krill abundance, distribution, and potential productivity, including discussion about potential MSY levels. This discussion is limited to the two principal species (*T. spinifera* and *E. pacifica*). There is no comparable information available on any of the other krill species, therefore, there also is no summary of the missing information. The information that is presented here is intended to further understanding of the rationale for the proposed action and its impacts; to promote scientific research and collaboration and additional stock assessment and modeling efforts; and to demonstrate the uncertainty about what is and is not known about krill. It also provides the basis for the determination that krill harvests are inappropriate (i.e., that OY is zero), both to prevent adverse effects of krill fishing and to prevent adverse effects on other living marine resources. It is emphasized that the scientific information available at this time does not provide a basis for setting harvest limits or other controls based on productivity measures such as MSY for the two principal species or other species of krill.

In the process of developing the Alternatives Analysis that was used by the Council as a basis for determination of its preliminary preferred alternative, NMFS invited California Current krill experts from federal and state government agencies, academia, and the private sector to a discussion in September 2005 about their research and their ideas as to the abundance, distribution and productivity of krill (see Appendix A). It was generally agreed that reliable input parameters for a suitable model to determine minimum stock size threshold and maximum fishing mortality threshold (the required status determination criteria for managed fish stocks), based on spawning biomass or other measure of productive capacity, still need to be developed and agreed upon for the two principal species of krill found off the West Coast. Benchmark status determination could not be made at that time. No catch histories or sufficient information on stock and recruitment (e.g., percent spawning potential ratio, or proxies based on spawning potential ratios) are available on which to make calculations of such measures as the level of

biomass B relative to its initial biomass level B_0 and relative to B_{MSY} , or to determine the potential level of mortality F relative to some target level like F_{MSY} . MSY levels of B or F could possibly be estimated as fractions of B_0 but no comprehensive EEZ-wide or stock-wide biomass estimates for any California krill species have been made for these species.

Even if reliable data were readily available, the MSY yield model based on traditional surplus production theory is inappropriate to set quantitative catch limits for krill, for the following reasons:

- Most current single-species modeling assumes the equilibrium condition from which a MSY can be derived and applied for managing harvest. This condition rarely if ever exists for these two species, which exhibit constantly fluctuating and extreme ranges of standing stock densities, depending on what environmental regime is prevailing that particular season, year, or group of years. It is not possible to predict in advance with any confidence what the krill abundance will be in time or space.
- The goal is not to maximize fishery yield from the krill stock(s) but is to ensure sufficient production and remove the risk of stock depletion so that krill can satisfy the forage requirements of predators, including not only commercially important fishes and invertebrates such as Pacific hake, salmonids, rockfishes and squid, but also recreationally important species, as well as seabirds and marine mammals under council and/or Federal management.
- Krill have unusual growth and molting patterns, and lengths at maturity vary (unlike other commercially important crustaceans). This makes it difficult to estimate vital rates and to derive an estimate of MSY for krill.
- No information exist on the extent to which population ‘seeding’ occurs from populations that lie to the north and west outside the U.S. EEZ and the year-to-year variability of the rate of immigration or emigration from the system.
- The lack of a harvest history precludes using average stock-wide catch levels as rough proxy MSY values.
- Data are available from diverse sources on average densities for certain EEZ areas and times, and even the historical range of densities of these species (especially off central and southern California and central Oregon), but there is no consensus on overall representative densities or range of densities, and habitat area utilized over which to expand these densities into EEZ-wide or range-wide B_0 estimates.

While a reliable point estimate of MSY cannot be specified at this time, there are considerable data available on natural variability of abundance, food web dynamics, and preliminary data on vital rates that can be used to obtain bounding values for initial modeling. These are based on rough estimates of average adult krill densities and presumed habitat occupied and are presented in section 3.1.3.4. Other measures of abundance and potential MSY, expressed as a range of average densities (all life phases) during El Niño versus La Niña years, are provided in section 3.1.3.3. These estimates are provided below consistent with the requirement of section 303(a)(3) of the M-SA to assess and specify the MSY for the fishery (if one were permitted). Again, these

estimates are only for the two principal species; there is no information to support similar estimates for other species of krill. The cumulative MSY for all krill species, which may be higher than the MSY for the principal species, is not known and cannot be estimated.

It also should be noted that available methods to determine abundance and units for measuring abundance are far from standardized, and estimates are based on many assumptions that may or may not be valid, including a lack of accounting for predator needs. More thorough analyses and standardization of density and biomass estimates are required to obtain more valid biomass estimates, as well as analyses to determine impacts on dependent predators and the ecosystem. Nonetheless, the information presented may be taken to represent the available range of estimates of MSY for the two principal species. In the case of krill, however, even for the two principal species, there are no specific MSY estimates on which scientists can agree at this time. As will be discussed later (see 3.1.3.5 Research Needs), there are some approaches by which agreed upon estimates might be developed, but these efforts have not yet been initiated. It is noted that NMFS uses such recommendations as a basis for seeking additional research funds and setting research priorities. The Council urges that this work receive a high priority in NMFS' research.

3.1.3.2 Annual and Decadal Variability in Abundance

Both species exhibit extremes in abundance and distribution patterns, depending on seasonal, annual, or multi-annual oceanographic conditions and regimes (e.g., Abraham et al 2004; Ainley et al 1966; Brinton 1981; 1996; Mullin and Conversi 1989; Brinton and Townsend 1991,2003; Marinovic et al. 2002). Brinton and Townsend (2003), using the CalCOFI data series, published a time series analysis of fluctuations in abundance of the major California Current euphausiid species relating to decadal oceanographic variability over the last 52 years. They studied fluctuations in densities ($\log_{10} +1$ number animals $10m^{-2}$) of dominant euphausiids in four sectors between about 26° and $38^{\circ}N$ (Central California, Southern California, Northern Baja California, and Central Baja California) between 1951 and 2002 (Fig. 4). In the southern and central California areas, cold-water *E. pacifica* and *T. spinifera* declined dramatically during extreme warm water events, although they appeared to be quite resilient in an ability to rebound from periods of unfavorable oceanographic conditions (Figs. 5-7). Abundances varied similarly over the five survey decades, both species having marked post-El Niño recoveries once cooler water periods returned. Periods of population depletion became increasingly frequent, though irregular, after a cool water regime shifted to a warm water regime in the 1970s. The more numerically abundant *E. pacifica* uniformly collapsed by as much as 90% during warm-water El Niño periods, but recovered to irregular but distinct bi-decadal peaks in abundance during six strong cold-water La Niña episodes, including the most recent cool-water episode from 1999 through at least spring 2002. Although both species reacted negatively to extreme El Niño conditions (slightly less so off central than southern California), abundance relationships with the Pacific Decadal Oscillation (PDO) varied, with *E. pacifica* showing a weak but significant ($P < 0.05$) negative association with the PDO, and *T. spinifera* showed no relationship. *T. spinifera* mean pre-and post-climate shift abundances off southern and Central California were similar, although this species' central and southern California numbers greatly decreased during the 1983 El Niño, and certain positive anomalies were associated with cooler years, especially during the most recent 1999-2002 cooling period. Over five decades, the more abundant *E. pacifica* approached or surpassed a high baseline density of $20,000 \times 10m^{-2}$ ($\log 4.30$) off southern

California in spring once per decade (except twice in the 1980s), at intervals varying from 4 to 11 years, and these high density years (1957, 1968-69, 1980, and 1996) were followed by declines to densities of $2,000 \times 10^6 \text{ m}^{-2}$ (log 3.30), and were associated with 3 of the strongest recorded El Niño events in 1957-58, 1982-83, 1997-1998, and a weaker one in 1969-70. CalCOFI net sampling off southern and central California suggests *E. pacifica* occurs at greater than 100 times *T. spinifera* amounts, although relative densities of the latter species which is larger and more efficient at avoiding nets, are likely underestimated.

3.1.3.3 Frequency Distributions of Krill Abundance off California

The above time series (Brinton and Townsend 2003) has recently been updated through spring 2004, and presented as a series of frequency distributions of abundances (Mark D. Ohman and Annie Townsend, unpub. analysis, 8/5/05, Pelagic Invertebrates Collection, Scripps Institution of Oceanography Long Term Ecological Research LTER Site).

Frequency distributions of abundances for both species for the two regions are illustrated in Figs. 8-11. Only spring nighttime collections are used, with all life history phases combined. The data are subdivided in two ways, first chronologically into three successive time periods: 1950-1976, 1977-1998, and 1999-2004, chosen because these have been hypothesized to reflect different ecosystem states in the Northeast Pacific. The second subdivision is by El Niño versus non-El Niño years. In the latter comparison, data from only the relatively strong El Niño's in mid-latitudes (1958, 1978, 1983, 1993, and 1998) are grouped together according to the springtime of the year when the Niño effect was the most pronounced. Samples were not available for Central California in 1993. All other years are grouped together as non-Niño years.

Statistical analysis by Analysis of Variance, following log (X+1) transformation of the euphausiid abundances has revealed the following:

- During El Niño springs, mean abundances of *E. pacifica* were significantly lower than in non-Niño springs in both Southern California ($P < 0.00001$) and Central California ($P < 0.01$).
- During El Niño springs, the mean abundance of *T. spinifera* was lower than in non-Niño springs in Southern California ($P < 0.0001$), but there was no significant El Niño effect in Central California ($P > 0.10$).
- For both euphausiid species and both regions of the California Current, there was significant heterogeneity of mean abundances among the 3 time periods hypothesized to represent different regimes of the California Current ($0.00001 < P < 0.05$). In all cases, mean abundances were significantly higher in the most recent time period (1999-2004) than in the two preceding time periods (1950-1976, 1977-1998).

Note that the sample sizes for some of these comparisons are small, especially in Central California in more recent years when only abundances from 2003 and 2004 are available. Therefore these comparisons should be treated with caution. Also note that data are not yet available for 2005, and there is some suggestion that oceanographic conditions were anomalous in this year.

The implications of these summaries are that both the presence of strong El Niños and the longer term “regime” state of the California Current influence expected abundances of these two species of euphausiids. Accordingly, any guidelines for euphausiid harvest should explicitly take into consideration the oceanographic conditions in the California Current.

Average numbers of *E. pacifica* (larvae, juveniles, adults) within southern and central California sectors during El Niño years were estimated to be 105 individuals 1000 m⁻³ and 566 individuals 1000 m⁻³, respectively; while during non-El Niño years, were 1,471 individuals 1000 m⁻³ and 1,565 individuals 1000 m⁻³, respectively. It must be noted that very large confidence limits are associated with these mean values. Approximately 7% (± 4%) of these individuals were estimated to be adults (Brinton and Townsend (2003, their Table 1). The average number of *T. spinifera* off southern and central California during El Niño years was 1.6 individuals 1000 m⁻³ and 6.7 individuals 1000 m⁻³, respectively, while during more productive non-El Niño years, was 4.8 individuals 1000 m⁻³ and 15.7 individuals 1000 m⁻³, respectively. *T. spinifera* densities are quite likely underestimated because adults and large juveniles of this larger species are thought to be very mobile and adept at avoiding towed nets, and thus likely to be underestimated when extrapolating abundance from net tows (Brinton 1965; and Brinton and Townsend 2003). These average densities, considered within the context of their respective distributions (Fig. 8-11) and averaged for the northern and southern California areas, provide an estimate of standing stock density and MSY expressed as a range of average densities (all life phases combined) observed during El Niño versus and non- El Niño years (1950-2004) (Table 3-2).

Table 3-2. Estimates of standing stock (D₀) and potential MSY (0.5D₀) expressed as overall average springtime densities, based on CalCOFI net sampling data (life phases combined) off central and southern California, El Niño versus non-El Niño years (1950-2004). Data based on Brinton and Townsend (2003) and M. Ohman and A. Townsend (8/2005, unpubl. data, Pelagic Invertebrates Collection, Scripps Institution of Oceanography LTER site). These average values do not reflect regional differences in abundances, which may be considerable, see text and Figures 6-11.

Species	Regime years	D ₀ (indiv. 1000m ⁻³)	0.5 D ₀ (indiv.1000 m ⁻³)
<i>E. pacifica</i>	El Niño (warm)	335	168
<i>E. pacifica</i>	Non-El Niño (cooler)	1,518	759
<i>T. spinifera</i>	El Niño (warm)	4.15	2
<i>T. spinifera</i>	Non-El Niño (cooler)	10.25	5

3.1.3.4 Point Estimates of Unfished Biomass (B_0) and Preliminary Estimates B_{MSY}

Because of the extreme annual, seasonal, and intra-decadal variability in abundances of these species, lack of standardized EEZ-wide surveys, and poorly known distributional differences coast wide, few attempts have been made to estimate unfished biomass of these two species, separately or collectively. The following summarizes various available estimates of krill biomass.

In 1983, a NMFS guide to underutilized fisheries resources (NMFS 1983) estimated the population of *E. pacifica* at "probably over 100 million tons in California," but no supporting data were provided. Furthermore, this number seems unusually high, considering the collective biomass of krill worldwide (~ 85 species) has been estimated at about 300 million tons (Pitcher 1995).

Field et al. (2004) estimated euphausiid mean annual standing biomass (all species, stages) in the northern California Current ecosystem (Cape Mendocino north to Cape Flattery, an area of 70,000 km²) to be 1,890,000 tons during the early 1960s (a cool, productive regime), compared with 1,450,000 tons in the early-1990s (a warm regime characterized by low productivity). The estimates were based on a top-down estimate of consumption requirements of upper-trophic level predators, calibrated to the extent possible by existing assessments of plankton and nektonic standing stocks and productivity for the two time periods in question. These estimates are dependent on accurate estimates of predator biomass (which are lacking or need updating), and would benefit from a starting estimate of krill standing stock to adjust the model.

Brinton (1976), in his study of the population biology of *E. pacifica* off southern California, described reproduction, growth and development of cohorts, and successions in population structure and biomass over a four year period (1953-56). He estimated *E. pacifica* general densities in the southern California Bight CalCOFI study area (covering approximately 1235 km²) to be 10-1,000 mg wet weight m⁻², which suggests a biomass of from 12,350 to 1.2 million kg (12-1235 mt) for the Bight study area. The minimum average density estimate of 10mg wet weight m⁻² extrapolated to the Pacific Coast EEZ (812,201 km²), would amount to over 8 million kg (8122 mt), but again, such extrapolations mean little without knowledge of relative densities within the extrapolated area. Even less is known of the population biology and status of *T. spinifera*.

W. T. Peterson (pers. commun. ongoing studies, 6/6/2005 and 9/9/05, NMFS, NWFSC, Newport, Oregon) recently made some preliminary first order calculations of adult krill biomass, based on average adult densities of both *E. pacifica* and *T. spinifera* observed at two stations off Newport, Oregon, each sampled monthly since 2001. One station is located just offshore of the shelf break (300m depth) and the other just inshore of the break over the shelf (140 m depth). Overall mean density of adult *E. pacifica* was 10.0 adults m⁻³ and 3.6 adults m⁻³ at the shelf break and shelf stations, respectively, averaging 6.8 adults m⁻³ for both. These stations are sampled at night, when the majority of krill are thought to reside in the sampled upper 20 m, suggesting an area density of 136 *E. pacifica* adults under each m² (Table 3). Peterson then estimated the area of maximum krill concentration along the U.S. West Coast to be centered around the shelf break, along the length of the EEZ (7.0176 x 10¹⁰ m²). Assuming this reflects the area occupied, and

converting average adult length to weight, the observed density extrapolates to a total EEZ $B_0 = 1,031,584$ mt after conversion from preserved to fresh weight (Table 4). Overall mean density of adult *T. spinifera* was $0.8 \text{ adults m}^{-3}$ at both shelf break and shelf stations, and extrapolates to $B_0 = 189,717$ mt of EEZ fresh-weight biomass. Alternately, one could assume a broader habitat is occupied, taking into account higher densities off California that can occur further offshore of the shelf break, as indicated by CalCOFI densities charted for these two species over the past 50 years (E. Brinton, Scripps Institution of Oceanography, La Jolla, CA, 6/6/05, ms. in prep.). Accounting for a broader distribution off central and southern California, the primary area occupied by these two species may be closer to one-quarter of the EEZ area. Based on these estimates and other assumptions, two alternative rough estimates of standing stock (B_0) and B_{MSY} ($0.5 B_0$) are presented in Tables 3-3 and 3-4. Again, these should not be taken to represent potential MSY levels for other species of krill; no estimates are available for those species.

Table 3-3. Preliminary estimates of standing stock (B_0) and B_{MSY} ($0.5 B_0$) based on assumption of average adult densities of 136 m^{-2} and 16 m^{-2} for *E. pacifica* and *T. spinifera*, respectively ^{a/}, for two habitat area assumptions ^{b/}. Uses length-biomass conversions of Miller (1966) and conversion of combined species totals to fresh wet weight from W.T. Peterson and L. Feinberg (NMFS, NWFSC, Newport Oregon).

Species	Est. avg. density ¹ , adults m^{-3}	Est. avg. density ¹ , adults m^{-2}	Est. avg. Adult weight ^{c/} (g)	Kg Km^{-2}	Est. B_0 (mt) Habitat Assumption A ²	Est. B_0 (mt) Habitat Assumption B ²	0.5 B_0 (MSY) Habitat Assump. A (mt)	0.5 B_0 (MSY) Habitat Assump. B (mt)
<i>E. pacifica</i>	6.8	136	0.064	8700	610,531	1,766,535	305,266	883,268
<i>T. spinifera</i>	0.8	16	0.100	1600	112,282	324,880	56,141	162,440
Total Metric Tons Preserved Weight (Miller 1966)					722,813	2,091,415	361,407	1,045,708
Total Metric Tons Fresh Weight (Peterson et al)^{d/}					1,221,301	3,533,759	610,651	1,766,880

- a/ *E. pacifica* and *T. spinifera* avg. overall mean adult density from W. T. Peterson, NMFS,NWFSC, Newport OR, pers. comm, 9/8/05 (see text).
- b/ Habitat assumption A assumes area main krill concentration 70, 176 km² (W. Peterson, ibid., see text); Assumption B assumes area of main krill concentration within inner quarter EEZ (~203,050 km²)
- c/ Avg. adult *E. pacifica* (11-25 mm TL) from A. Townsend (Scripps Inst. Oceanogr., Invertebrate Collections); avg. adult *T. spinifera* 22 mm TL from Summers (1993); all weights calculated in preserved weight (Miller 1966) and converted to fresh for combined total (see Table 4).
- d/ W.T. Peterson and L. Feinberg, NMFS,NWFSC, Newport OR. Carbon weight mg x 2.22=Dry Weight (DW) assuming carbon 45% of DW ; DW x 10 = WW (90% water). Fresh biomass est. approx. 1.7 x preserved biomass.

Table 3-4. Preliminary biomass estimates under two wet weight conversion assumptions presumed to reflect preserved (Miller 1966) and fresh (W.T. Peterson, NMFS, NWFSC, pers. commun., 9/9/05) weights. Provisional MSY estimates given in ‘fresh’ weight to approximate fresh-landed euphausiids.

Species	Est. B_0	Est. B_0	Est. B_0	Est. B_0	$0.5B_0$	$0.5B_0$
	Habitat Assumption A	Habitat Assumption A	Habitat Assumption B	Habitat Assumption B	(MSY) Habitat Assump. A	(MSY) Habitat Assump. B
	Miller 1966 Preserved (mt)	90% H ₂ O Fresh (mt)	Miller 1966 Preserved (mt)	90% H ₂ O Fresh (mt)	90% H ₂ O Fresh (mt)	90% H ₂ O Fresh (mt)
<i>E. pacifica</i>	610,531	1,031,584	1,766,535	2,984,826	515,792	1,492,413
<i>T. spinifera</i>	112,282	189,717	324,880	548,933	94,859	274,467
TOTALS	722,813	1,221,301	2,091,415	3,533,759	610,651	1,766,880

The above are not intended to be used as a basis for establishing quantitative limits on krill harvest. Among many tentative assumptions, the estimates of potential fishery yield do not account for ecosystem needs, habitat size differences between the two species, and possible geographic differences in the proportions and densities of adult, juvenile and larval phases. Oregon densities were sampled during 2001-2004, a favorable cool water period, when productivity was presumably high. Thus standing stock and MSY during a less favorable warm water period may be 22% and 40% of the above estimates, for *E. pacifica* and *T. spinifera* respectively, and reduced as much as 90%, judging from the range of densities observed for these species in warm versus cool water periods (Table 3; Brinton and Townsend 2003). Thus a maximum constant yield, the catch estimated to be sustainable with an acceptable level of risk at all possible future levels of biomass, might be as much as 0.9MSY. Stochastic population modeling is needed to better define these reference points once agreement is reached on the model parameters or parameter ranges.

Density-to-biomass conversions of the SIO CalCOFI time series are needed to compare with the Oregon data and adjust EEZ-wide krill biomass estimates accordingly, as appropriate. The SIO data represent an extremely valuable 50+ year record of krill population abundance and variability, data that are seldom available for most managed stocks, yet always so crucial to manage them effectively. Biomass conversions based on size distribution of krill found in the samples and applying allometric conversions of standard length to euphausiid weight still needs to be done. Presumably, working back from the size group composition of each spring collection,

proportion of adults could be extracted to approximate estimates of annual adult, or adult and juvenile biomass. Preserved weight to fresh wet weights conversions are also needed, as fresh weight is most appropriate for simulating potential landings. Conversion factors by size group are better known for *E. pacifica*; less known for *T. spinifera*, although limited raw data are available from Summers (1993) on *T. spinifera* sampled off British Columbia, Canada. Work is planned at the NMFS/NWFSC Newport Lab to refine standard length to fresh wet weight conversions for both species, but results are still pending as of this writing.

Most krill sampled by nets are larvae and early juveniles, with the proportion of adults (fishable stock) varying with sampling depth, time, season, year, and geographical area. Brinton and Townsend (2003) reported that off Southern California, decadal averages (1950-2002) of the proportion of adults to the rest of the sampled population (spring nighttime samples) ranged from 1.7-13 % (mean 7; s.d. =4). Off Oregon, Peterson and Feinberg⁴ report about 3 times the overall average volume densities of *E. pacifica* than off California. The Ohman and Townsend data (Table 2) show an average of 1,518 individuals 1000 m⁻³ off central and southern California in cool water years. Off Oregon, during generally cooler years 2001-2004, the Peterson and Feinberg average was 3,300 individuals 1000 m⁻³, of which 20-78% were adults. According to Brinton and Townsend (2003), area densities of *E. pacifica* along southern California CalCOFI station lines 77-93 averaged ~1,210 individuals under each square meter of sampled ocean during cool years. This would suggest an average density of roughly 85 adults m⁻², given a proportion of 7% adults, which compares with a density of 137 adults m⁻² off Oregon (Table 3- 3). Researchers to the north may be more consistently sampling aggregated adult individuals in shelf-break areas, whereas CalCOFI may be more consistently sampling dispersed individuals (including a greater proportion of calyptopes, furcilia and juveniles) over a wider sampling area. But to some extent, differences could be real, as net California Current surface flow is thought to transport many larvae predominately southward, and southern California Bight circulation patterns favor retainment or accumulation of larvae and juveniles there. Larger juveniles and adults, which undergo vertical migration, can take better advantage of subsurface, northerly-flowing currents during the day.

3.1.3.5 Research Needs

3.1.3.5.1 Need for Standardizing Biomass Assessment Methodology

No coordinated coast wide survey, especially one using the recommended combination of multi-beam acoustics technology and standardized net sampling, has ever been undertaken to assess U.S. Pacific Coast krill. The assessment and measurement of krill abundance presents challenges to both existing sonar and net collecting technology and to mathematical modeling (Brinton and Townsend 1981; Pitcher 1995, Macaulay 1995 and others). Estimating krill biomass cannot be done using standard fisheries acoustics techniques, most of which are designed for larger fin fish and higher target strengths. Krill bioacoustics involves careful selection of equipment, frequencies, target identification, calibration of gear, and consideration of measurement error. Even with scrupulous calibration and accurate information on the reflective properties of individual krill, the acoustic signal can change greatly with the orientation of the animals and condition (i.e., lipid content). Nonetheless, multibeam hydroacoustic surveys appear to offer the best solution for assessing abundance and distribution over large areas.

Net sampling, which has its own set of biases, is usually combined with acoustic sampling to obtain demographic, physiological, and relative density estimates. Obtaining a representative sample can be confounded by the varying net-avoidance abilities of different krill species and life phases, abilities that change with light level, water clarity, net speed and type, and hour of day. Daily day/night vertical migration of krill from the depths to the surface can further confound the interpretation of net sampling data. When simultaneous assessment methods are used, density estimates for a given krill aggregation using direct visual counts, net sampling and hydroacoustics often vary considerably. For accurate determinations to be made, various artificial variables need to be identified and krill estimates subsequently corrected, although a standard for this kind of correction has been difficult to establish. Even in recent times, the mechanisms that affect and determine distribution and density of krill are still under discussion in most cases (Siegel 2000). While estimating density or abundance using nets is prone to bias, standardized net sampling is still very important for obtaining information on species, life phase, and their relative densities which can seldom if ever be obtained from acoustics alone.

Standardization of collecting and processing methods used in surveying California Current krill is needed so that net collection and acoustic data are comparable and can be combined for different geographic areas. This would include:

- A meeting among a team of krill bioacoustic experts to decide on and develop standardized methodology for calibrating, measuring, surveying and interpreting zooplankton acoustic backscatter for the primary purpose of estimating distribution and biomass of both species in the West Coast EEZ, and integrating with net collection data.
- Standardization of krill body length to weight/carbon conversion to wet fresh weight factors by krill species and size group is needed for better and more consistent biomass conversions.
- Expert agreement as to the spatial bounds of primary krill habitat from which density and subsequent biomass conversions can be expanded to obtain initial estimates of biomass of *E. pacifica* and *T. spinifera* standing stocks.
- Analyses (and scientific agreement) to determine which krill life phase of what species might best serve as a proxy of adult abundance in future sampling.
- Lab physiological experiments to refine estimates of productivity, growth and turn-over rates.

Modeling krill population dynamics is also subject to considerable uncertainty, especially with regard to recruitment, individual and population rates of growth, mortality, and the effects of swarming behavior. Krill recruitment and distribution within the California Current system is thought to be strongly influenced by environmental factors - the position of frontal systems, changes in intensity and direction of major currents and ocean forcing - as well as behavioral adaptations by krill themselves, including a strong tendency to aggregate in layers and in schools, swarms and patches. Vertical migration may be a mechanism by which krill effectively shuttle between multidirectional surface and subsurface currents in order to maintain their populations in highly productive core areas (and to separate developmental stages). Offshore Ekman transport

via upwelling plumes, jets, and filaments is thought to contribute to large losses from the system (especially larvae), but this transport may also serve as a mechanism to genetically link a substock with another downstream, allowing for greater genetic diversity. Also, in addition to changes in the physical environment, inter-annual variability in abundance may also be affected by changes in predation pressure.

3.1.3.5.2 Need for Probabilistic and Ecosystem Modeling

Because of the large range of uncertainty concerning input parameters, one option would be to take a probabilistic modeling approach for determining the likelihood of safe harvest occurring. The model would estimate the probability of a highly productive krill year occurring, when a harvest of either or both species might be made with acceptably low risk of harm. Certain very cool, biologically rich oceanographic years might produce adequate surplus production (beyond predator and system needs) to support limited amounts of removals, but presumably these events (with probabilities greater than zero), would be relatively rare. The likelihood of this fishable surplus occurring could be estimated by using probability density functions for biomass, productivity, and predator demand in the following or similar model equation

$$Y = K * (r - M) - P$$

where Y is krill yield, K is krill biomass, r is the instantaneous krill growth rate, P is predation from predators, and M is natural mortality other than predator removals (R. Hewitt, NMFS, SWFSC La Jolla, CA; A. Leising, NMFS, SWFSC Pacific Grove, CA, pers. commun. 6/10/05). For each parameter, instead of a single value being specified (for the most part these values are poorly known), probability distributions would be specified that would allow for uncertainty. At the time of this writing, starting values or suggested bounds for these parameters to initiate computer runs were not yet available. Further work to run Monte Carlo simulations and obtain the probability distributions is still pending assignment of resources. Potential data sources for bounding estimates for this model include: M for *E. pacifica* (Brinton 1976); Siegel and Nicol (2000) citing Jarre-Teichmann and data from Brinton (1976); K - M. Ohman, E. Brinton, A. Townsend, SIO, La Jolla, CA; W.T. Peterson NMFS, NWFSC and Leah Feinberg, Oregon State University, Newport, OR; r - *E. pacifica* (Brinton 1976); Ross 1982; P - John Field, NMFS, Santa Cruz, Ca; krill consumption rates, Don Croll, UC Santa Cruz.

Ecosystem modeling provides another potential management tool for looking at possible harvest impacts on krill and predator stocks. Field et al (2001) constructed a mass balance snapshot of ecosystem consumption and production rates in the Northeast Pacific Ecosystem; krill being an important component of the model. Additional work has been provided by J. Field (NMFS, SWFSC Santa Cruz, CA unpub. pers. commun. 6/2005) in collaboration with Robert Francis, Kerim Aydin, and Sarah Gaichas (doing similar work in the Gulf of Alaska and Bering Sea). The modeling framework uses Ecopath with Ecosim and a static, mass-balance snapshot of energy flow through the system where the production of a prey species is more or less equal to the consumption of that species by predation. Ecosim is a dynamic model that turns these properties into a series of rates that are consumption-based, and the main factors that change abundance are food availability and predation. Top-down estimates of consumption requirements for upper trophic level predators are derived and calibrated to the extent possible using existing

assessments of plankton and nektonic standing stocks and productivity.

Field² recently described an approach using ecosystem modeling as a tool for evaluating harvest impacts. Preliminary simulations were run of a krill harvest of 300,000 mt/yr (roughly equivalent to the scale of the Pacific hake fishery) and the potential impacts on krill stocks and krill predators. The response was an average decline of 5% in krill stocks (with a range of roughly 3 to 14%), and an average decline of 2 to 4% (range 1 to 8%) in most commercially important predators of krill (coastal pelagics, hake and rockfish). However, certain adjustments are needed, including a better range of estimates for both predator and krill standing stocks, as well as expansion of the Eastern North Pacific Ecosystem Ecopath/Ecosim Model to include the entire West Coast EEZ. To apply a derivation of this model to estimate effects of various harvest levels off the West Coast, the following items are needed:

- More reliable data on predator abundance (a problem with existing “top-down” models is that the high demand estimated for krill predators often does not agree well with available estimates of krill biomass, and this may be due to overestimates of predator standing stocks);
- ‘Bottom-up’ runs (based on rough estimates of adult krill biomass from observed krill densities) are to compare with ‘top down’ runs; and
- Council/NMFS resources (funding, staff time of 6 mo-1 yr) to assemble additional data, run the models, and document the results.

Resulting sustainable yield estimates suitable for use in establishing quotas or total allowable catches through such modeling also would need to be used in conjunction with other management approaches, such as area closures, to ensure adequate protection of species that are dependent on or sensitive to the abundance of krill or which could be directly affected through fishery interactions.

3.2 Role of Krill in the Ecosystem off the West Coast

3.2.1 Importance as Forage

Krill provide a critical link in oceanic food webs between phytoplankton food and upper level predators, many of which are commercially important fish species and ecologically important protected marine mammals and birds (see Appendix B for a complete description of species listed as endangered and threatened that occur in areas in which krill also occur and that may be dependent on krill to some degree). As major California Current herbivores, krill act as particularly efficient conduits of nutrients and primary production from the upwelling zone off the coast to the higher trophic levels of the broader marine ecosystem at large, as well as a buffer against the possible development of a degraded ocean system that might result from a buildup of excessive algal blooms in our coastal waters (Bakun and Weeks 2004). Some contend that the

² Presentation, California Current Krill Meeting, June 6, 2005, NOAA, NMFS, Southwest Fisheries Science Center, La Jolla, CA 92037. J. Field, K. Aydin, R. Francis and S. Gaichas. “Modeling Northeast Pacific Ecosystems.”

removal of apex predators such as large whales in the previous century of whaling is thought to have increased the availability of krill to other consumers in the North Pacific, but whatever ‘surplus’ that resulted has already been absorbed into the system. Furthermore, the dynamics of this shift are difficult to understand even in hindsight, especially against a backdrop of a host of other changes (environmental and man-induced) that have taken place in the North Pacific over the last 60 years which may have affected the energy flow dynamics within the system. Intensive, direct harvesting of such a pivotal component in the food web would undoubtedly have ecological impacts on the stability of our current trophic system, especially regional systems. Thus the possible extent of these impacts needs to be critically evaluated if large-scale fisheries are contemplated (Pitcher and Chuenpagdee 1995). Possible impacts could include:

- Negative impacts on krill-dependent predators
- Subsequent lower abundance of commercial fish and squid stocks
- Reduced food levels for federally protected marine mammals and birds
- Algal blooms of unharvested phytoplankton, whose growth in nutrient-rich upwelling systems like the California Current may be held in check largely by grazers.
- Degraded ocean conditions caused by unutilized phytoplankton biomass sinking to the sea floor, resulting in thick accumulations of deposited unoxidized organic matter with low or non-existent dissolved oxygen concentrations (Bakun and Weeks 2004) fed by nutrient rich eastern boundary current waters
- Loss of associated goods and services that depend on our regional ecosystem resources and quality.

As with other CPS, California Current krill are eaten by a number of predators, but their importance as forage may vary from predator to predator. Individual consumption rates for even the most krill-dependent species have been difficult to obtain, and almost nothing is known about the extent to which krill predators can switch to other prey.

Within the U.S. Pacific Coast EEZ, *E. pacifica* and/or *T. spinifera* are preyed upon by market squid, *Loligo opalescens*; octopus, *Octopus rubescens*; Pacific hake, *Merluccius productus*; Pacific herring, *Clupea harengus*; spiny dogfish, *Squalus acanthias*; blue shark, *Prionace glauca*; sablefish, *Anoplopoma fimbria*; myctophids (family: Myctophidae); jack mackerel, *Trachurus symmetricus*; various juvenile and adult rockfishes, *Sebastes spp.*, which prey on eggs, larvae and adult krill; various flatfishes (e.g., Pacific sanddab, *Citharichthys sordidus*, slender sole, *Lyopsetta exilis*; Pacific halibut, *Hypoglossus stenolepis*; Pacific salmon *Oncorhynchus spp.*; albacore, *Thunnus alalunga*; humpback whale, *Megaptera novaeangliae*; blue whale, *Balaenoptera musculus*; Grey whale, *Eschrichtius robustus*; and various seabirds, especially Cassin’s auklets, *Ptychoramphus aleuticus*; sooty shearwater, *Puffinus griseus*; and common murre, *Uria aalge* (Phillips 1964; Alversen and Larkins 1969; Gotshall 1969; Alton and Nelson 1970; Pinkas et al. 1971; Cailliet 1972; Manuwal 1974; Tyler and Percy 1975; Baltz and Morejohn 1977; Jones and Geen 1977; Karpov and Cailliet 1978; Vermeer 1981; Chu 1982; Peterson et al. 1982; Livingston 1983; Lorz et al. 1983; Brodeur and Percy 1984; Briggs et al. 1988; Chess et al. 1988; Smith and Adams 1988; Ainley and Boekelheide 1990; Ainley et al.

1990, 1996, 2005; Tanasichuk et al. 1991, 1999; Kieckhefer 1992; Reilly et al. 1992; Laidig et al. 1995; Tanasichuk 1995a,b, 1999; Ware and McFarlane 1995; Robinson 2000; Benson et al. 2002; Hewitt and Lipsky 2002).

Hake and Cassin's auklet appear so dependent on these species for food that the distributions of euphausiids determine those for hake and auklets (Vermeer 1981; Tanasichuk 1995a,b; Ainley et al. 1996; Briggs et al. 1988). Results of diet analyses conducted by Tanasichuk et al (1991) along the southwest coast of Vancouver Island, Canada, showed that euphausiids *E. pacifica* and *T. spinifera* account for 93 and 64% of the daily ration for the dominant pelagic fish species, Pacific hake and spiny dogfish, respectively. Adult Pacific herring are known to feed exclusively on euphausiids. Additionally, *T. spinifera* has persisted as the preferred euphausiid prey of Pacific hake even though numbers of this species declined from representing 60% to 16% of the available population of adult euphausiids (Tanasichuk 1998). Krill of both species are known to comprise >50% of the diet of yellowtail rockfish, 21-50% of the diet of bocaccio and widow rockfish, 98% of the diet of hake in fall, and almost 97% of the diet of market squid (Reilly et al. 1992; Dark et al 1983; Pereyra et al 1969; Livingston 1983). Krill are also important food of salmon, preparatory to their ascending tributaries to spawn. When the rust-colored swarms appear off central California, commercial sport fishing boats, guided by flocks of feeding seabirds, seek krill swarms out in search of salmon, which feed heavily on krill from April to July, especially *T. spinifera* (Smith and Adams 1988; Adams 2001). Blue and humpback whales also converge on krill-rich upwelling centers such as off the Olympic Peninsula, Heceta Bank, around the Farallon Islands, Monterey Bay, and the Point Conception/Channel Islands area to feed on *T. spinifera* and *E. pacifica* during summer and fall, since at least the mid-1980s and early 1990s (Smith and Adams 1988; Schoenherr 1991; Fiedler et al. 1998, Croll et al. 1998).

Ecopath-Ecosim Modeling --- A model of the basic trophic components of the northern California Current ecosystem food web (Fig. 12) has been constructed by Field et al. (2001), with subsequent work by Field et al. 2005³, using top-down biomass balance estimates of euphausiid production and consumption. Two time periods, representing different oceanographic regimes, were compared. Krill consumption by predators (and production) was estimated to be higher during the early 1960s (a cool, productive regime) when krill total annual production amounted to 207.3 g wet weight m⁻². It was lower during the mid-1990s (a warm regime characterized by low productivity) when krill total production amounted to 123.5 g wet weight m⁻².

The important role of these two species in the food web was also revealed in Jarre-Teichmann's (1995) trophic flow model of the British Columbia, Canada, shelf area. She found that krill appeared to constitute about 50% of the diet of herring (the dominant predator in that area), followed by hake, with other species being of minor importance (Table 3-5).

3 J. Field, K. Aydin, R. Francis, and S. Gaichas. (in prep) "Modeling Northeast Pacific Ecosystems." (Presentation). California Current Krill Meeting, 6 June 2005, NOAA NMFS Southwest Fisheries Science Center, La Jolla, CA 92037

Table 3-5. Preliminary assessment of role of krill, *Thysanoessa spinifera* and *Euphausia pacifica* in the food web on the shelf off southern British Columbia, Canada (from Jarre-Teichmann 1995).

Fraction krill total diet (%)		Fraction total predation on krill (%) a/
51-100	Pacific hake	11
26-50	Herring	88
	Ocean perch	<0.1
0-25	Sablefish	0.2
	Sharks	0.2
	Marine birds	<0.1
	Baleen whales	<0.1
a/ initial estimates as of original publication, 1995.		

In a more recent modeling exercise, Field et al. ⁴ estimated krill compose >10% of the diet by volume for 24 species groups and >50% of the diet for 9 species groups in the area between Cape Mendocino and Cape Flattery. Pacific hake and certain groundfishes (e.g., Pacific Ocean perch, canary rockfish, etc.) are particularly krill-dependent in this area. Baleen whales accounted for relatively small portion of total krill consumption in the presented model, but since runs were based on 1960s data, may not reflect current consumption of baleen whales, which are now much more abundant in EEZ and may account for up to 4% of total annual krill consumption (J. Field, NMFS, SWFSC, Santa Cruz, CA, pers. comm. 6/6/05). Model results for total annual consumption in the northern California Current by different forage assemblages are provided in Figure 13. Because the southern California Current area between Cape Mendocino and the Mexican border differs considerably to the northern area, this model or models need to be expanded for the entire EEZ, or constructed similarly for the area south of Cape Mendocino to the Mexico border.

One problem with existing top-down models is that the high demand estimated for krill predators often does not agree well with available estimates of krill biomass, and it is unclear as to whether this is due to an overestimate of predator biomass or underestimate of krill biomass or both. Better predator biomass estimates are needed.

3.2.2. Assessing Predator Requirements

In addition to Field et al's (2001, 2005) top-down estimates of consumption of major krill consumers mentioned above, Croll and Kudela (In press) recently compiled allometric estimates of daily metabolic have recently assessed current and pre-exploitation prey biomass requirements (kg individual⁻¹ day⁻¹) for North Pacific large whale populations, obtaining a mean of estimates from five different prey requirement models. The mean estimates for the two major krill

⁴ Field, J., K. Aydin, R. Francis, and S. Gaichas. Modeling Northeast Pacific Ecosystems. Presentation California Current Krill Meeting, June 6, 2005, La Jolla, CA)

consumers, the blue and humpback whale, were 1120 (S.D.= 359, CV=0.32) and 532 kg (S.D.= 123, CV=0.23) individual⁻¹ day⁻¹, respectively.

3.2.3. Krill Predator Harvest and Effects

Selective fishing pressure on krill predators may also have a dramatic but not easily predictable effect on the ecosystem. The Bering Sea ecosystem was thought to have been drastically changed by whaling, sealing and fishing efforts over the last 40 years (D. Bowen cited in Head (1997)). Between the 1950s and 1970s, some 300,000 sperm and baleen whales were taken by whalers, together with large numbers of fur seals. Subsequently Pacific Ocean perch were fished to negligible levels, followed by herring and saith. When the “natural” fish species had gone, the area was taken over by pollock, and its levels increased from 2 million metric tons in the 70s to 16 million metric tons in the 80s, when it was 80% of the fish biomass. During this period the Stellar sea lion and harbor seal populations declined, perhaps in response to decreases in the abundance of capelin and sand lance, the latter being forage for the pollock. The suggestion is that the removal of the baleen whales may have led to an increase in zooplankton (and krill) levels, which in turn may have led to the proliferation of species that competed for forage with the sea lions and harbor seals.

3.2.4 Other Ecosystem Roles

In addition to the considerable importance as prey, largely unknown are the ecosystem needs for the huge detritus and effluvia contributed by krill populations. Krill casts, which contain nitrogen, carbon, Vitamin A and other materials, as well as associated chitinoclastic bacteria, form an important food source for other organisms (Ackman et al. 1970). Molting once every five days, krill can produce weight equal to seven times the dry weight produced in one year. Krill are also important contributors to the Vitamin A cycle in the sea, and can synthesize and store Vitamin A in high concentrations in their bodies, especially in the eyes. As major consumers of phytoplankton and other microplankton, krill also remove and recycle vast quantities of primary production from coastal waters. To what extent this grazing helps to hold algal and dinoflagellate blooms in check and aid in maintaining stability and health of the system is not known. This function may become increasingly important as harmful blooms increase along our coast with the increased fertilization from urban run-off. Euphausiids are also thought to influence carbon flux and food availability to pelagic and benthic organisms in the sea by physically fragmenting sinking organic particles called “marine snow,” with the collective rapid beating of their appendages. Marine snow can comprise as much as 60% of water column particulate organic carbon, which would otherwise sink out of reach of the upper ocean where light is available for photosynthesis, and before bacteria could break down the organic matter into dissolved nutrients to sustain phytoplankton. The krill in their massive swarm numbers, especially in upwelling zones such as off the U.S. West Coast, are thus able to fragment much larger organic particles into smaller particles (which sink more slowly), a process thought to increase the residence time of carbon in the upper water column, enhancing attached bacterial production and helping to enrich the upper ocean zone (Goldthwait et al 2004).

3.3 Essential Fish Habitat

3.3.1 MSFCMA Requirements

Section 303(a)(7) of the MSFCMA requires that FMPs describe and identify essential fish habitat, minimize to the extent practicable adverse effects on such habitat caused by fishing and identify other actions to encourage the conservation and enhancement of such habitat. The MSFCMA provides the following definition:

“The term ‘essential fish habitat’ means those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity.” (16 U.S.C. § 1802 (10)).

NMFS has published regulations for implementation of the EFH requirements. These regulations (at 50 C.F.R. 600 Subpart J) provide additional interpretation of the definition of essential fish habitat:

“‘Waters’ include aquatic areas and their associated physical, chemical, and biological properties that are used by fish, and may include aquatic areas historically used by fish where appropriate; ‘substrate’ includes sediment, hard bottom, structures underlying the waters, and associated biological communities; ‘necessary’ means the habitat required to support a sustainable fishery and the managed species’ contribution to a healthy ecosystem; and ‘spawning, breeding, feeding, or growth to maturity’ covers a species’ full life cycle.”

The NMFS guidelines intended to assist councils in implementing the EFH provision of the M-SA set forth the following four broad tasks:

- Identify and describe EFH for all species managed under an FMP;
- Describe adverse impacts to EFH from fishing activities;
- Describe adverse impacts to EFH from non-fishing activities; and
- Recommend conservation and enhancement measures to minimize and mitigate the adverse impacts to EFH resulting from fishing and non-fishing related activities.

In sum, the EFH regulations require that EFH be described and identified within the U.S. EEZ for all life stages of each species in a fishery management unit if they occur within that zone. FMPs must describe EFH in text and/or tables and figures which provide information on the biological requirements for each life history stage of the species. An initial inventory of available environmental and fisheries data sources should be taken to compile information necessary to describe and identify EFH and to identify major species-specific habitat data gaps. The EFH regulations also suggest that where possible, FMPs should identify Habitat Areas of Particular Concern (HAPCs) within EFH for habitats which satisfy the criteria of being 1) sensitive or vulnerable to environmental stress, 2) are rare, or are 3) particularly important ecologically.

The Council proposes that EFH be established consistent with option 2 below. The following discussion is provided to summarize the alternatives considered and presented to the public to solicit public comment.

3.3.2 Data Sources and Methods

Data and information to describe krill EFH were obtained primarily from the scientific literature, as well as through consultation with krill researchers (Appendix A) and examination of data on geographic catch densities off California for the years 1950-2002 provided by E. Brinton and A. Townsend, Scripps Institution of Oceanography (SIO), Pelagic Invertebrates Collection (pers. commun., La Jolla, CA 6/6/2005). The majority of these data are level 1 data, where all that is known is where a species occurs based on distribution data for all or part of the geographic range of the species (presence/absence). Some preliminary data are also available on areal densities of relative abundance (Level 2, see SIO reference above). Little is known of growth, reproduction or survival rates within habitats (Level 3); or habitat-dependent production rates quantified by habitat quantities, qualities and specific locations (Level 4).

3.3.3 Description and Analysis of EFH Alternatives: Proposed Action and Options Considered

Option 1. Status Quo. Do not designate EFH.

The Council proposes that krill be incorporated as a MUS in the CPSFMP; therefore, the option of not identifying EFH is not acceptable. The MSFCMA requires designation of essential fish habitat for all MUS in FMPs.

Option 2. Adopt EFH as described below (Proposed Action)

The designation of essential habitat for krill is based on information about essential fish habitat for the two principal species. It was not possible at the time that this amendment was being developed to discern consistent differences in distribution of the various life stages, other than coastwide, the larvae of both species tend to occur closer to shore, often over the shelf. It is recommended that these designations be updated on final analysis and publication of the SIO 50-year time series of maps showing spatial densities of these and other euphausiid species in the CalCOFI sampling area (E. Brinton, SIO, unpub. data, personal commun. 6/8/05).

Isobaths (depth contours) are used below as outer boundaries of EFH, but only because they roughly approximate the outer bounds of reported densest concentrations of the populations, and because static boundaries are preferred for the legal definition of EFH. These contours also roughly form the outer boundaries of some of the major upwelling areas (though perhaps not some of the larger offshore jets), within which consistently high concentrations of phytoplankton occur (Fig. 15). The boundaries are not meant to imply the strict association of these highly dynamic macropktonic species with fixed bottom topography.

A review of the literature and available data on krill aggregating areas and reproductive swarms, with high densities of predators such as salmon, seabirds and large baleen whales, revealed

certain krill-rich upwelling areas to be especially important. Dense krill swarms and predator aggregations are reported most consistently within the ocean boundaries of the following NOAA Marine Sanctuaries: Olympic Coast NMS off Washington (Calambokidis 2004) and Cordell Bank NMS, Gulf of the Farallones NMS (Chess et al 1988; Smith and Adams 1988; Kieckhefer 1992; Schoenherr 1991; Adams 2001; Howard 2001) and Channel Islands NMS in California (Armsrong and Smith 1997; Fiedler et al. 1998; Croll et al 1998). (Fig. 14). Additionally, the following other high-density krill and krill predator areas have been reported: Heceta Bank and Cape Blanco areas, Oregon (Ainley et al. 2005; Ressler 2005; Tynan et al 2005) and Bodega Canyon (Howard 2001). A confluence within these areas of rich, upwelled unstratified water and topological features such as submarine canyons, banks, and island shelves may not only provide rich feeding areas for krill, but may also contain features necessary for krill patches to be exploited by baleen whales, fish and seabirds, by concentrating and trapping krill over the shelf as they attempt to descend to the depths during the day (Chess et al. 1988; Fieldler et al. 1998; Ressler et al. 2005)

After considering this information, the Council agreed to propose the following designations of EFH for krill.

Euphausia pacifica EFH (Fig. 16)

Larvae, juveniles and adults: From the baseline from which the shoreline is measured seaward to the 1000 fm (1,829 m) isobath, from the U.S.- Mexico north to the U.S.-Canada border, from the surface to 400 m deep, from the U.S.- Mexico north to the U.S.-Canada border (Fig. 16). Highest concentrations occur within the inner third of the EEZ, but can be advected into offshore waters in phytoplankton-rich upwelling jets (Fig. 15) that are known to occur seaward to the outer boundary of the EEZ and beyond.

Thysanoessa spinifera EFH (Fig. 17)

Larvae, juveniles and adults: From the baseline from which the shoreline is measured to the 500 fm (914 m) isobath, from the U.S.- Mexico north to the U.S.-Canada border, from the surface to 100 m deep. Largest concentrations in waters less than 200 m deep, although individuals, especially larvae and juveniles, can be found far seaward of the shelf, probably advected there by upwelling jets (Figs. 15, 17).

Other krill species

Larvae, juveniles and adults: From the baseline from which the shoreline is measured seaward to the 1000 fm (1,829 m) isobath, from the U.S.- Mexico north to the U.S.-Canada border, from the surface to 400 m deep, from the U.S.- Mexico north to the U.S.-Canada border. No biological, social or economic impacts are expected beyond administrative costs of reviewing federally regulated projects for potential impacts on this habitat, where krill and krill predators concentrate.

Option 3: Designate the full EEZ as EFH

There is little statistical basis for designating EFH beyond the areas identified above. However, it is conceivable that krill exist throughout the EEZ even if not in concentrations that support a forage role or that support reproduction or other life stages.

3.3.4 Habitat Areas of Particular Concern (HAPCs)

The Council considered the following HAPC options:

HAPC Option 1. Status Quo—Do not designate HAPCs

HAPC Option 2. Designate HAPC to consist of the ocean area within the boundaries of Cordell Bank, Gulf of the Farallones, Monterey Bay, Channel Islands, and Olympic Coast NOAA Marine Sanctuaries. These sanctuaries encompass the most important consistently krill-rich areas around California islands as well as important submarine canyons, bank, shelf and slope areas (e.g., Gulf of the Farallones, Pescadero Canyon, Ascension Canyon, Monterey Bay Canyon area, Channel Islands).

HAPC Option 3. Designate HAPC for krill to consist of the ocean area within the boundaries of Cordell Bank, Gulf of the Farallones, Monterey Bay, Channel Islands and Olympic Coast NOAA Marine Sanctuaries, and Heceta Bank area (east of longitude 125° 30' W Long, between 43° 50' and 44° 50' Lat), off Cape Blanco (east of longitude 125° 30' between 42° 20' and 43° 000' Lat), and the Bodega Canyon area as HAPCs. This is similar to Option 3, but also includes three additional known important krill areas outside of Sanctuary boundaries.

HAPC Option 4. Designate HAPC for krill to consist of the ocean area within the boundaries of Cordell Bank, Gulf of the Farallones, Monterey Bay, Channel Islands and Olympic Coast NOAA Marine Sanctuaries as HAPCs and all other waters of the EEZ federal coastal and island waters off Washington, Oregon and California out to 60 nautical miles from shore. This would cover all the areas Option 1, the highest krill density areas in Option 2, and add other inshore island, shelf, bank and slope areas along the coast suspected of supporting high densities of krill and krill predators within the EEZ.

In the process of reviewing the literature and available data on habitat use and preferences of krill, an effort was made to determine specific areas within U.S. West Coast EEZ EFH that satisfied the criteria of being 1) sensitive or vulnerable to environmental stress, 2) rare, or 3) particularly important ecologically. As noted above, this included a review of the literature and available data on krill aggregating areas and reproductive swarms, with high densities of predators such as salmon, seabirds and large baleen whales, revealed certain krill-rich upwelling areas to be especially important.

The Council concluded that it is not necessary at this time to propose designation of any specific HAPC. All the prospective high quality areas identified in the literature review and meetings with scientists would be included in the proposed designations of EFH.

3.3.5 Affected Environment

The California Current marine ecosystem offshore Washington, Oregon and California is home to vast variety of fishery, seabird, marine mammal, and sea turtle resources, many of which depend on krill directly or indirectly to sustain their populations. These include groundfish species (shelf and slope rockfishes, Pacific whiting, flatfishes, sablefish, lingcod, greenlings, sturgeon; sharks; skates, rays); four species of Pacific salmon; steelhead; highly migratory pelagic species (tunas, marlin, swordfish, pelagic sharks, dorado); other relatively large pelagic fishes (louvar, oarfish, lancet fishes, escolar, oilfish, opah, saury, common mola, spearfish, sailfish, blue marlin, wahoo, bonito, black skipjack and others); small coastal pelagic species (sardines, herring, anchovy, mackerels, smelts, and squid); marine mammals (California sea otter and various whales, porpoises and dolphins, sea lions, and seals); pelagic seabirds (including northern fulmar, brown pelican, albatrosses, shearwaters, loons, murre, auklets, storm petrels and others) (Leet et al. 2001).

The California Current system is particularly rich in microscopic organisms (diatoms, tintinnids and dinoflagellates) which form the base of the food chain, especially in areas where consistent ocean upwelling occurs, enhancing primary production. The California Current area is an eastern boundary current ecosystem, one of the most productive regions of the world. As with other eastern boundary current systems, primary production is not nutrient-limited except in extreme El Niño years because of a relatively constant supply of nutrients upwelled from the depths and supplemented by nutrients from estuarine and urban runoff. This rich supply of diatoms and other small plankters provides food for euphausiids and many other zooplanktonic organisms such as shrimps, copepods, ctenophores, chaetognaths, oceanic squids, salps, siphonophores, amphipods, heteropods, and various larval stages of invertebrates and fishes. Grazers like small coastal pelagic fishes and squid depend on this planktonic food supply, which in turn provide forage for larger species nearer the apex of the food chain. Certain seabirds and turtles and also baleen whales also depend on the euphausiid food supply, and many fishes, seabirds and toothed cetaceans feed on fishes that are plankton feeders.

Episodic oceanographic events such as El Niño (warm water incursion) and La Niña (cooler water incursion) may affect the occurrence and distribution of organisms and productivity of the system. Longer periods of certain ocean temperature regimes that persist for decades can also affect reproduction and recruitment of marine species (e.g., sardine, rockfish) for several generations and result in substantial changes in abundance over time (Leet et al. 2001). During episodic or persistent warm periods when cold water euphausiids decline or shift north, the more tropical species may become more abundant within the EEZ, along with some of the more tropical prey species upon which they feed. For example, pelagic red crab and the neritic warm-water euphausiid, *Nyctiphanes simplex*, may shift northward from Mexico waters, displacing *T. spinifera* from its usual habitat over the continental shelf off California and Oregon to the more northerly parts of its range.

3.3.6 Possible Adverse Impacts to EFH from Fishing Activities

As the proposed action would prohibit krill fishing, there will be no adverse effects on EFH from krill fishing. It is not known if other types of fishing gear and techniques used in other federally

managed fisheries (e.g. HMS, CPS, Groundfish, and Salmon) off the West Coast might adversely affect EFH. Midwater gear and techniques would not be expected to cause harm. Bottom gear could conceivably result in turbidity or other water quality disturbance, but this would likely be minimal and temporary. In any event, the consultation process for looking at the effects of fishing on EFH under the regulations governing EFH administration should provide a mechanism for ensuring that any such impacts would be fully considered and mitigation would be sought for any adverse effects

3.3.7 Possible Adverse Impacts to EFH from Non-fishing Activities

Little is known of the effects of non-fishing activities on krill habitat. The only known study was conducted in 1996 and 1997, when NOAA/NMFS investigated for the U.S. Army Corps of Engineers the effects of disposal of dredged materials at the San Francisco Deep Ocean Disposal Site on midwater organisms (Roberts et al 1997; Roberts et al 1998) at a site off the San Francisco peninsula. In year one of the study, the effects of dumping were studied by comparing the abundance of selected zooplankton and micronekton taxa (including euphausiids as a group) at the dump site, with collections taken at a reference area (Pioneer Canyon) and in the area bordering the dump site (buffer zone). Tests comparing the buffer zone abundances with the dump site abundances did not show significant differences between the disposal and buffer areas, and in 13 of these cases there were actually more organisms found in the disposal area than in the buffer area. Thus the findings did not show an adverse dump effect, and suggested that some other factors may have influenced differences in the observed locations. In year two, dump site abundances, with euphausiids broken down to species, were compared with abundances at seven peripheral stations 11 miles to the north and 10-14 miles to the south. Results and analyses failed to show any striking impacts at the dump site that could be attributed to the disposal of dredged materials. Nonetheless, sampling took place during a highly variable small window of time and during a period of low euphausiid productivity, whereas effects during more productive, non-El Niño years may differ.

3.4 Krill Fisheries

3.4.1 Existing Krill Fisheries: Global Perspective

There are at least six commercial fisheries that now harvest (or have harvested in the recent past) six different species of euphausiid. These are the fisheries for Antarctic krill (*E. superba*) fished in the Antarctic; for North Pacific krill (*E. pacifica*) fished off Japan and off western Canada; for *E. nana*, fished off the coast of Japan; for *Thysanoessa inermis* fished off the coast of Japan and off eastern Canada; and for *T. raschii* and *Meganyctiphanes norvegica*, which have been experimentally harvested off eastern Canada (Nicol and Endo 1999). The largest quantities of krill are harvested off Antarctica and Japan. The current world catch of all species of krill is over 150, 000 tons per annum, although few fisheries are being exploited to their maximum theoretical potential. The size of the world krill harvest is currently limited by lack of demand, although some fisheries are being deliberately managed at low levels because of ecological concerns or to control prices (Nicol and Endo 1999).

3.4.2 Krill Product Uses and Markets

The products of the krill industry have been variously reviewed by Budzinski et al (1985), Eddie (1977), Everson (1977), Grantham (1977), Suzuki (1981), Suzuki and Shibata (1990), Nicol and Endo (1997, 1999), and most recently by Nicol et al. (2000) and Nicol and Foster (2003). Krill products are mostly used for the aquaculture and sport fishing bait market but considerable effort has also been put into developing products for human consumption, particularly from Antarctic krill. Krill products are also currently being promoted for pharmaceutical, industrial and the so-called 'nutraceutical' industry as a nutritional/health supplement.

The Japanese Antarctic krill fishery, which takes most of the current catch, produces four types of product: Fresh frozen (34%), boiled frozen (11%), peeled krill meat (23%) and meal (32%). Yields in the manufacture of these products are 80-90% for fresh frozen and boiled frozen, 8-17% for peeled krill and 10-15% for meal in 1995 (T. Ichi, cited by Nicol and Endo 1997).

3.4.2.1 Human Consumption

The use of krill for human consumption has been reviewed and the nutritional value of krill has been assessed (Suzuki and Shibata 1990; Nicol and Endo 1997). The Japanese Antarctic fishery produced boiled, frozen krill and peeled tail meat for human consumption and 43% of the catch is used for this market. All of the peeled tail meat is now frozen in blocks on board. Information on other nations' Antarctic krill fisheries is not generally available. A small amount of *E. pacifica* caught off Japan is also used for human consumption. Although much effort in the past has gone into producing krill products for human consumption, there have been few recent developments in this area. (Nicol and Endo 1997).

3.4.2.2 Bait for Recreational Fisheries.

Approximately 70 % of the fresh frozen portion of the Japanese Antarctic krill catch is sold whole as bait, and 10% of this is used as chum for sport fishing. Nicol and Endo (1997) citing Kuroda and Kotani, report there is little competition between Antarctic krill, *E. superba*, and *E. pacifica* used for sport fishing, because the smaller *E. pacifica* is used as chum (about 50% of the total catch), whereas the larger *E. superba* is mostly used as bait.

3.4.2.3 Aquarium food.

A small quantity of Antarctic krill is freeze dried for the home aquarium market. An estimated 50% of the catch of *E. pacifica* from the British Columbia fishery is used as aquarium food (Nicol and Endo 1997).

3.4.2.4 Aquaculture

Currently most krill caught in all commercial fisheries is used for aquaculture feed. For Antarctic krill, 34% of the Japanese catch is fresh frozen, of which 20% is used for aquaculture and 32% is used to produce meal which is used in fish culture; 50% of the Japanese *E. pacifica* catch and much of the Canadian catch of this species is used as an ingredient in feed for fish culture (Nicol

and Endo 1997). Krill provide a nutritious diet and can be used successfully as a source of protein, energy and flesh pigmenting carotenoids. Carotenoids are found in krill at around 30 ug g⁻¹ and can deteriorate rapidly during storage if not refrigerated below 0° C . The Japanese *E. pacifica* catch destined for aquaculture is used in feed to add reddish color to the skin and meat of fishes such as bream, salmon, trout, yellowtail and others, since *E. pacifica* contains large amounts of carotenoid pigments, especially astaxanthin. Extracts from Antarctic krill have also been used as pigmenting agents for yellowtail (*Seriola quinqueradiata*) and coho salmon (*Oncorhynchus kisutch*). Japanese people perceive the color red as an indication of good luck, and they often choose red fish and shellfish for celebrations and holidays. Krill amino acids are thought to have growth-promoting properties (Storbakken 1988) and krill are known to stimulate both feeding and growth in some fish (Shimizu et al 1990) . Diets supplemented with krill meal stimulated feeding behavior in sea bream (*Pagurus major*), an effect probably due to the presence of the amino acids proline, glycine and glucosamine. The growth promoting factors seem to be steroids located in the cephalothorax region, thus are available in non-muscle meal. The use of *E. pacifica* as a food source has also contributed to increased disease resistance in hatchery reared salmon smolts (Haig-Brown 1994). This has been attributed to the early development of the immune system when using krill as a food source. Krill-fed salmon were also found to have a superior taste and did not significantly accumulate fluoride from the krill exoskeletons in their flesh. Krill products are also thought to be a good source of minerals for aquatic animals. Rainbow trout feeds contain krill as the principal protein source has significantly less dorsal fin erosion than did those fed the fish meal based control food (Nicol et al 2000).

3.4.2.5 Autoproteolytic precipitates

Krill precipitate is produced using autoproteolysis, making use of krill's high level of proteolytic enzymes to produce a high yield (80% protein recovery) krill concentrate or precipitate. The final product has a very low fluoride content (< 29 mg F kg⁻¹), a protein content of 18-22%, fat less than 7% and a high level of carotenoid pigments. This product is used mainly as a colorant and flavourant additive to fish feeds and other products for human consumption.

3.4.2.6 Biochemical use/ food additive/ health supplement

A freeze-dried krill concentrate is prepared from peeled tail meat and marketed as a food additive and health food supplement. It is promoted as having a major revitalizing effect on the body, with a high n-3 fatty acid content, moderate caloric content, high nutritional value, and easy to digest. It is advertised by the manufacturers to be an important source of antioxidants and minerals required to prevent dental cavities and osteoporosis and have anti-aging properties. It is promoted as being 100% natural and free of any side effects, even when taken at higher doses, and low in contaminants such as PCBs. Krill oil, sold in gel caps, is also sold and marketed as a clean, pure source of special antioxidants not found in other products and having a higher content of Omega-3 fatty acids than other fish oils. It purportedly maintains healthy heart, joints and even regulates symptoms of premenstrual syndrome (Aquasource Products 2005). It is anticipated that this market, while probably expanding, requires relatively low volumes of high quality krill product compared to the aquaculture feed and supplement market (S. Nicol, Australian Antarctic Division, Tasmania, Australia, pers. commun, 21 Mar 2005, La Jolla, CA.) In addition, a Chilean company recently announced (Aquafeed.com, 5/17/05) that it has launched a patent for assisting

in calcium intake and deposition on bones for helping osteoporosis prevention and cure through a combination of krill and salmon byproducts with other specific ingredients. It is not known if this product has in fact cleared all regulatory hurdles for sale. The claim is that this new dietary nutraceutical organic supplement is a rich source of calcium and fluorine. It would be available in a pate form for direct human consumption. As with other additives, it is unlikely that this product would establish a very large market for krill or krill products in the near term.

3.4.3 Potential for Market Expansion

Nicol and Foster (2003) reviewed recent trends in the fishery for Antarctic krill, and also speculated on possible expansion of krill fisheries worldwide, examining records of krill patents lodged by year and country of origin. Fisheries for krill have shown much potential for expansion, yet have not reached anticipated levels. The slow development of fishing for krill over the years has allowed environmental considerations to be taken into account when developing management strategies. The fishery for Antarctic krill has been relatively stable for a decade at 100,000 tons per year; the Japanese coastal krill fisheries are probably near capacity at ~ 70,000 tonnes/ year (Endo 2000); and the British Columbia fishery has been essentially capped at 500 tons. Nonetheless, commercial focus on products derived from krill has continued to develop, with interest in aquaculture, pharmaceutical and medical products apparently overtaking those for human consumption. Following a recent trend, most new growth in terms of volume is likely to come from the aquaculture industry, which has been increasingly pursuing natural food additive sources to enhance flesh color as well as promote rapid and healthy growth of cultured fish and invertebrates (Nicol 1989). Secondarily, krill oils are likely to be the subject of expanding markets in the nutraceutical, cosmetic and pharmaceutical industries, which focus on a high quality, high value, and relatively low volume product. Nicol and Foster (2003) propose that only in the Antarctic does there appear to be great scope for expansion of a krill fishery, considering that environmental and political considerations in recent years have prevented development or expansion of most Northern Hemisphere krill stocks (off Alaska, U.S. Pacific coast state waters, the east Coast of Canada). Even so, with the growth of aquaculture and increasing demand for new and improved aquaculture feeds and supplements, it is reasonable to assume that demand for krill sources closer to aquaculture operations within the tri-state area may continue to persist.

3.5 Existing Management of Krill Fisheries off the West Coast

3.5.1 California

There has never been a krill fishery in California. California imposed a ban on landing and krill fishing in state waters in 2000.

3.5.2 Oregon

There has never been a krill fishery in Oregon. In 2003, Oregon imposed a ban on landing of krill by State-registered vessels, and banned krill fishing in state waters as well.

3.5.3 Washington

There has never been a krill fishery in Washington. Under Washington law, it is unlawful to deliver krill taken for commercial purposes from state or offshore waters into Washington and it is unlawful to possess krill taken for commercial purposes. It also is unlawful to traffic in krill.

3.5.4 Federal Regulations

There are currently no federal regulations constraining krill fisheries off the West Coast. As directed by Section 305(a) of the MSA, NMFS has published a national list of fisheries at 50 CFR 600.725. The list of fisheries identifies fisheries that existed at the time of the rule. Under this rule, a person is prohibited from fishing in an unlisted fishery. An individual who wanted to engage in "unlisted" fishing activities could notify the appropriate regional fishery management council (regional council) of the intent to use a gear or participate in a fishery not on the list. Ninety days after such notification, the individual could use the gear or participate in that fishery as proposed unless the regional council has proposed regulatory action to prohibit or otherwise control the use of the gear or participation in the fishery (e.g., through emergency or interim regulations). This provides regional councils with an opportunity to take action in the event a new fishery is proposed that might pose new fishery management problems. A general category of "fishing with trawl gear" for unspecified species was among the fisheries listed by NMFS for waters under the jurisdiction of the Council. Thus, someone wanting to engage in fishing for krill with trawl gear (the principal gear used in other krill fisheries) off the West Coast would not need any permits from NMFS and would be subject only to state controls in states where the catch would be landed. Someone wanting to engage in krill fishing with other gear (e.g., purse seine gear) would have to notify the Council 90 days in advance. The Council would then have opportunity to advise NMFS whether to control the activity or allow it as proposed. No such proposals have yet been directed to the Council. Thus, it appears that this rule would not constrain or prevent a trawl fishery for krill at this time.

3.6 Krill Fisheries and Management in Other Areas – Lessons Learned

Krill was little known until the middle of the nineteenth century, and then mainly as a food item found in the stomachs of whales. The first krill fishing was likely done by Mediterranean fishermen who harvested daytime surface swarms of krill for use as bait in the mid to late 1800s. Krill was promoted as a food alternative during World War II by the British (Haig-Brown 1994), and in the late 1960s and early 1970s, commercial fishing began in Antarctic waters and in the North Pacific off Japan and British Columbia, Canada. Exploratory and scientific permit fishing also began in the early 1970s off eastern Canada in the Gulf of St. Lawrence.

The following is a brief description of each species:

Euphausia superba (Antarctic krill) is one of the bigger species, growing to a maximum size of 6.5cm and weighing up to 2g. Antarctic krill grow to their maximum size over a period of approximately 3-5 years. The fishery concentrates on the larger adults in the 40-65mm size range. Antarctic krill occurs throughout most of the waters south of the Antarctic Convergence but is most abundant closer to the Antarctic continent and around some of the Antarctic and sub

Antarctic islands. It has been commercially harvested all around the Antarctic although the current fishery concentrates in the South Atlantic with summer fisheries along the Antarctic Peninsula and winter fisheries around South Georgia Island (Miller 1991).

E. pacifica is commercially harvested off the coast of Japan (Odate 1979; Odate 1991) and off the coast of British Columbia, Canada (Haig-Brown 1994).

Euphausia nana, closely related to *E. pacifica*, is only found in the waters off southern Japan and in the East China Sea. *E. nana* reaches a total length of 12mm and is harvested commercially off the Japanese coast (Hirota and Kohno 1992).

Thysanoessa inermis is found in the North Pacific and in the North Atlantic, particularly in the colder waters but does not breed north of 65°N-70°N. It reaches a length of 30mm. It has been commercially harvested in the Japanese coastal zone (Kotori 1994) and in the Gulf of St. Lawrence, Canada (Runge and Joly 1995).

Thysanoessa raschii is found in the North Pacific and in the North Atlantic, particularly in the colder waters and in Arctic regions. It was commercially harvested on an experimental basis in the Gulf of St. Lawrence, Canada (Runge and Joly 1995). It reaches a length of 25mm.

Meganyctiphanes norvegica is found over a large climatic range, from the subarctic in the waters surrounding Greenland, Iceland and Norway to the warmer waters of Cape Hatteras in the West and the Mediterranean in the East (Mauchline 1969). It has been commercially harvested in the Gulf of St. Lawrence and there was a proposal to fish for this species on the Scotian Shelf, Eastern Canada in 1995 (Runge and Joly 1995). Small scale harvesting of *M. norvegica* has also occurred in the Mediterranean (Fisher et al. 1953). *M. norvegica* is a medium-sized krill reaching a total length of over 40mm.

3.6.1 Antarctic Krill (*Euphausia superba*) and the CCAMLR Management Approach

Nicol (1995), Nicol and Endo (1997), Kock (2000) and others have summarized the development of the Antarctic krill fishing industry. Krill fishing on a commercial scale started in the 1972/73 season. Results of scientific exploration revealed the size of the krill resource, and interest grew in exploiting the so-called “surplus” krill left remaining after removal of their chief predators—baleen whales—by commercial exploitation. Another important factor in the development of the fishery was the declaration of 200 mile Exclusive Economic Zones in the late 1970s, which prompted distant water fishing nations to turn to international waters for new fishing grounds. The fishery soon concentrated in localized areas in the Atlantic Ocean, with the main fishing grounds to the east of South Georgia, around the South Orkney Islands and off the north coast of the South Shetland Islands. After peaking at more than 500,000 mt in 1981/82, catches dropped substantially because of problems in processing krill and more effort being diverted to finfishing. From 1986/87 to 1990/91, annual catches stabilized at between 350 000 and 400 000 mt, which was about 13% of the world catch of crustaceans. When economic factors forced the Russian fleet to stop fishing, catches declined dramatically after 1991/92 to about 80 000 mt per annum. Since then, Chile has also stopped fishing for krill. The current krill catch is in the range of 90,000–100,000 mt per year. The South Orkney Islands and the Antarctic Peninsula region are

usually fished in summer, while the South Georgia fishing grounds are mainly fished in winter, when the more southerly grounds are covered by ice. The amount of krill harvested to date totals slightly more than 5.74 million mt, of which the former Soviet Union and two of its succeeding states (Russia and Ukraine) took almost 84% and Japan 14.5%. More than 90% of the catch was from the western part of the Atlantic Ocean area.

In the first 10 years of krill fishing, catches, in particular those made by vessels from countries of the former Soviet Union, were largely used for animal feed. In the mid-1980s, difficulties in processing krill were overcome. Today, most krill is processed for aquaculture feed, bait and human consumption. Its use in aquaculture and its potential in biochemical products is increasing interest in krill fisheries.

CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) manages the Antarctic krill fishery; the system is considered the most sophisticated and comprehensive of krill management schemes. It addresses CCAMLR's Article II objectives to 1) manage fisheries so harvested stocks maintain stable recruitment, 2) maintain ecological links between harvested and dependent species, and 3) prevent changes that cannot be reversed within 20-30 years.

In managing krill, it was concluded that an MSY model was inappropriate to set adequate catch levels of krill, since it assumes stability in natural systems, considers the exploited stock as coming from a single species, and relies on a predictable relationship between stock size/growth and fishing effort. Furthermore, MSY does not account for interactions between exploited stocks and other species, which is crucial to address the CCAMLR objectives.

In 1990, CCAMLR's Scientific Committee identified general operational management principles for setting catch limits for krill that were subsequently endorsed by the Commission. These were to 1) aim at keeping krill biomass at a level higher than would be the case for single-species harvesting considerations, and, in so doing, to ensure sufficient escapement of krill to meet the reasonable requirements of predators; 2) focus on the lowest biomass that might occur over a future period, rather on the average biomass at the end of the period, as might be the case with a single-species context; and 3) ensure that any reduction of food to predators which may result from krill harvesting does not disproportionately affect land-breeding predators with restricted foraging ranges as compared to predators in pelagic habitats (CCAMLR 2004).

CCAMLR has approached krill management using a model that enables calculation of a precautionary catch limit, and a program to monitor the health of dependent species. The approach uses three primary elements described below:

The Krill Yield Model--A single species model is used to assess the potential yield available for the krill stock that has the lowest risk to the stock itself (Agnew 1997). Based on the approach of Beddington and Cooke (1983), the model projects the dynamics of a krill population over a period of time with random recruitment to establish the probability distribution of risk of population decline for a number of fixed harvesting strategies. The approach calculates the proportional value of γ in the formula

$$\text{Yield} = \gamma B_0 - 1$$

where B_0 is the estimated pre-exploitation biomass of the krill population. The modeling exercise can proceed in the absence of an estimate of B_0 , since this is taken to be 1.0, and will yield a value of γ . To be applied in management so that a precautionary total allowable catch (TAC) can be set, an estimate of B_0 is required; this has been estimated from acoustic surveys, the most recent being carried out in 2000. Subsequent biomass assessments are not needed on a regular basis, because the model uses the pre-exploitation biomass estimate, plus various parameters (variation in population age structure, recruitment, mortality, etc), which can be refined over time. The higher level of uncertainty in any parameter, the more conservative the estimate of TAC.

Decision rule requirements--These involve straightforward decision rules for defining acceptable long-term catch from the yield model calculations.

- Rule 1: Choose γ_1 where probability of spawning stock biomass dropping below 20% of its median level in the absence of fishing, over a 20 year simulation, is <10%.

- Rule 2: Choose γ_2 where the median spawning stock biomass after 20 years is 75% of its median level in the absence of fishing.

- Rule 3: Select the lower of γ_1 and γ_2 for the calculation of krill yield.

Ecosystem monitoring--CCAMLR's Ecosystem Monitoring Program (CEMP) monitors predator species, and uses the information to differentiate between changes due to krill harvest, and due to environmental change. This monitoring provides ongoing feedback on trends in the ecosystem, so that management adjustments can be made in light of changes and needs of dependent species.

The yield model and its decision rules offer a method of setting precautionary catch limits which consider both the harvested species and its predators, when there is some uncertainty in the assessment of the stock. The system was developed in consultation with Convention members and arrived at by consensus. In general, the higher the level of uncertainty in any parameter, the more conservative will be the estimate of Total Allowable Catch (TAC). One of its advantages is that it sets a fixed catch for a 20-year period. Agnew (1997) reports that the choice of limits, especially the limit of 75% of unexploited biomass of Rule 2, is somewhat arbitrary, but Rule 1 limits are becoming accepted internationally as appropriate for a precautionary approach. And Rule 2 limits, along with the continued ecosystem monitoring, are considered by CCAMLR to be a pragmatic interim solution to the problem of estimating the escapement from the fishery required to maintain predator populations where data are lacking.

In addition to the model and decision rules, catch "triggers" have been established to enable managers to respond quickly to any rapid increases in the fishery, especially in areas that support dependent species. Currently, Antarctic krill catch limits amount to about 9% of the estimated biomass in two major statistical areas. These two areas, which together cover just over 51% of the CCAMLR Area, consist of the Atlantic sector of the Southern Ocean (Area 48 and its

subareas,) and in the South East Indian Ocean sector (area 58.4.1). In Atlantic Area 48, the overall precautionary catch limit has been set at 4 million tons; subdivided into regional limits of 0.832 million, 1.104 million, 1.056 million and 1.08 million tons for South Sandwich Islands (48.4), South Georgia (48.3), South Orkneys (48.2), and Antarctic Peninsula (48.1) subareas, respectively. These subareas, especially the Antarctic Peninsula and South Georgia, include large colonies and breeding sites of land-based krill predators, so that catch limits are also augmented by the provision that if the total catch in Area 48 in any fishing season exceeds a “trigger” level of 620,000mt (catches over the past decade have been relatively stable at around 100, 000 t^{-yr}), the precautionary limits could be subdivided into even smaller management units following the advice from the Scientific Committee. This would allow the Commission to partition the overall limit into even smaller areas, for more effective management and protection of predator populations, in the event a rapid expansion of the fishery should occur. In the South Indian Ocean statistical area, the overall limit is set at 440,000 mt subdivided into 277,000 mt west of 115°E, and 163 000 mt east of 115°E, respectively.

3.6.2 Japan

The Japanese commercial fishery, which began in the mid 1940s, concentrates on highly visible daytime surface swarms in coastal waters. It operates without quotas to fulfill the needs of local aquaculture operations, and amounts to some 100,000 mt (Nicol 1997). There is external regulation by the number of licenses, the size of boats, and the duration of fishing effort and self-regulation, to keep the prices up. Of the three species commercially exploited in Japanese waters (*E. pacifica*, *E. nana*, and *T. inermis*), the catch of “Isada,” or *E. pacifica*, is much larger than the other two and more important. The average annual catch of *E. pacifica* was 60,427 mt in the late 1980s and 1990s with a value of 1.5 to 3.6 billion yen. It is especially abundant in Sanriku waters, the sea area off northeastern Japan, where many endemic and migrant predators including pelagic and demersal fishes, marine mammals, seabirds and benthic organisms also depend on this species for food (Nicol and Endo 1997). Early in the fishery, a sand lance dip net fishing method (using a bow-mounted trawl with a small mesh size) was used when fishing conditions for sand lance were poor. In the late 1960s, increasing demand for food for sea bream culture and sportfishing bait caused the fishery to expand to the northern and southern coasts of Miyagi Prefecture, and in 1972 expanded to Ibaraki Prefecture and to the south. Thus the fishery which began in Miyagi Prefecture developed into an important fishery in the Sanriku and Joban coastal waters.

The fishery requires a license from a prefectural governor. Small boats (less than 20 t) are predominantly engaged in the fishery. One or two-boat seines are used in all prefectures except Miyagi, where both one-boat seines and bow-mounted trawls have been used. A bow-mounted trawl can only catch swarms with 8m of the surface, while the seines can catch subsurface swarms as deep as 150 m by using echo sounders to detect swarms. The fishing grounds are over the continental shelf (< 200m) within 10-20 m from shore.

The total annual catch of *E. pacifica* has increased steadily over the last 20 years, exceeding 40,000 mt in 1978, 80,000 mt in 1987, and 100, 000 mt in 1992. This increase followed the introduction of plastic containers in about 1975 and by the use of fish pumps in the 1980s. In 1993 the total catch decreased to 60,881 t, when catch regulations were imposed in certain

prefectures to obviate price declines (Nicol and Endo 1997).

For fishermen, the most important factor related to the fishery is the ability to predict the length of the fishing season and the area of occurrence of the fishery. The fishing ground is formed near the front between the coastal branch of the Oyashio Current and the coastal waters with optimal surface water temperatures of 7-9° C. Various researchers have classified various types of oceanographic conditions that influence optimum catches in the fishery.

E. pacifica fishery regulations are set separately for each prefecture. The license of the prefecture governor decides the fishing period, the time limit to come back to port, operation time, fishing area, boat size and other factors. Other regulations include total catch limit per season, and maximum number of plastic storage containers per boat per day. Fishermen regulate catches in order to keep the price high, collaborating with their counterparts in adjacent prefectures.

Thysanoessa inermis and *Euphausia nana* are two other species harvested in Japanese waters. *T. inermis* has been fished since the early 1970s along the western coasts of Hokkaido. Reproductive surface swarms of this species are fished during the day, usually from early March to early April.

A spoon net, with a 1-m diameter and 3-4 m handle is used to catch the swarms. The price varies from 75 to more than 3,000 yen per kg. The yearly catch varies from several mt to 200 mt. The neritic species *E. nana* has been commercially fished also since the 1970s in Uwajima Bay, Ehime Prefecture, Shikoku. The yearly catch varies from 2,000 to 5,000 mt from 1981-1991, and two fishing methods are used. One is nighttime purse seining from March through July using a netting boat, a transport boat, and up to three light boats equipped with attracting lamps. The other method is a daytime seining operation during spring through early summer that uses two netting vessels, a boat with hydroacoustics to locate swarms, and a transport vessel. Landed *E. nana* are used as feed for red sea bream and the price is about 50 yen per kg (Nicol and Endo 1997).

3.6.3 British Columbia, Canada

The only krill fishery along the U.S.-Canada Pacific Coast exists in the Strait of Georgia, British Columbia (Fulton and Le Brasseur 1984; Nicol and Endo 1997). *E. pacifica* is typically one of the dominant species, accounting for over 70% of the euphausiid biomass where the commercial fishery occurs (Nicol and Endo 1997). Fishers deploy fine mesh plankton trawl nets that are towed several meters below the surface after dusk. The catch is either frozen at sea on board the catcher vessel, or placed in totes and iced for transport to a land-based facility for further processing and freezing. Most of the product is used as a feed supplement in fish food for the fin fish aquaculture industry and for aquarium needs. There are also limited and developing markets for uses of euphausiids as a human food product in Canada and abroad. The Department of Fisheries and Oceans Canada conducts biomass surveys annually in the Strait of Georgia in the area of greatest harvest to monitor abundance and to ensure that the impact of the commercial harvest is negligible.

Two types of vessels participate: smaller freezer vessels whose catches are limited due to freezing capacity (5-6 t of krill a day) and larger vessels that land large quantities of krill for onshore

processing and freezing (Nicol and Endo 1997). The catch must be frozen within 24 hrs to avoid a significant deterioration of product quality. The fishing season can be as short as 20 days (actual fishing days) and individual vessels may land as little as 32 mt in a season. Nets used have mouth areas of around 80 m², the trawl mouth is kept open by means of a beam and is buoyed to keep it from flipping when the ship turns. There are weights on the footline to maintain the net's shape. Fishing is carried out close to the surface - often less than 20 m deep and on moonless nights when the krill rise to the surface forming layers less than 10 m in vertical extent. The krill are located by echosounders. The larger vessels use a seine net and are usually out-of-season salmon fishing boats with no onboard freezing capacity. The presence of these vessels in the fishery is usually dependent on the success of the salmon fishery. If there has been a bad salmon catch, then krill are fished to increase revenues.

Information on the history of the British Columbia fishery has been summarized by Nicol and Endo (1997). It began on an experimental basis in 1972, confined to the Strait of Georgia and the east coast of Vancouver Island. Quotas were established in 1976 in response to concerns about harvesting an important forage species upon which salmon and other commercially important finfish depend. The annual catch was set at 500 mt with an open season from November to March to minimize the incidental catch of larval and juvenile fish and shrimp. This quota was reportedly derived from an estimate of the annual consumption of euphausiids by all predator species in the Strait of Georgia, and is 3% of this estimate. In 1983, participation in this fishery was restricted to those individuals who had applied for, and held, a certain category license, which was not subject to limited entry. Until 1985, annual landings were less than 200 t, with fishing concentrated initially in Saanich Inlet, then Howe Sound and most recently in Jervis Inlet. Due to continued concentration of fishing effort in Jervis Inlet rather than the adjacent waters in the Strait of Georgia, separate inlet quotas were introduced in 1989. The annual TAC increased to 785 mt; 500 mt for the Strait of Georgia and 20 to 75 mt for each of the major mainland inlets.

In 1990, due to concerns of local stock overfishing, the overall annual quota was reduced again to 500 t; 285 mt for the mainland inlets and 215 mt for the Strait of Georgia. That year, 56 licenses were issued, of which 17 reported landings of 530 mt for a landed value of Can \$415,000. This was the first year since the beginning of this fishery that the annual quota had been reached. Only 53 mt of euphausiids were reported landed in 1993 with a total landed value of Can \$41,000. This decline in landings from 381 mt reported in 1992 was a function of market conditions rather than any decline in krill stocks. Preliminary landings of euphausiids reported for 1994 were in excess of 300 mt, with a value of Can\$ 259,000, as markets stabilized somewhat from the previous year. The number of licenses issued for this fishery increased annually from 7 in 1983 to 56 in 1990, then declined to 45 in 1991. In 1993, licenses were limited to 25 vessels upon the advice of industry and because the annual quota was being taken by the current fleet. Only one vessel during 1993 and three vessels during 1994 reported euphausiid landings. Bycatch consists of larval and juvenile fish and myctophids (Lee 1995).

In late 1995, a workshop was held at the University of British Columbia on "Harvesting Krill: Ecological Impact, Assessment, Products and Markets " (Pitcher and Chuenpagdee 1995). The workshop dealt in some detail with the British Columbia euphausiid fishery, the importance of euphausiids to the coastal marine ecosystem, and improvements in assessments methods of the potential yield of British Columbia krill stocks. The Regional Executive Committee of the

Canadian Department of Fisheries and Oceans has stated that as a matter of policy the region is not prepared to support additional developmental fisheries on forage species such as krill, and the 500 mt quota for the Strait of Georgia and mainland inlets is expected to remain fixed for the foreseeable future (Morrison 1995).

3.6.4 Atlantic Coast of Canada (Gulf of St. Lawrence Fishery and Scotian Shelf Permit Request)

Exploratory scientific fishing was started on the Atlantic coast of Canada in 1972 to locate large harvestable concentrations of krill (*Meganyctiphanes norvegica*, *Thysanoessa raschii* and *T. inermis*) in the Gulf of St. Lawrence (Nicol and Endo 1997). The estimated biomass of krill in two areas of the Gulf where the krill were most concentrated was 75,000 t and an estimated catch rate for trawlers fishing a 100 m² mouth opening trawl was estimated to be 379 kg h⁻¹ based on a biomass estimate of 1 g m⁻³. The estimated potential for exploitation of all three krill species in the Gulf, based on an exploitation rate of 50% of the biomass, was 37 500 mt estimated in 1975 to be worth Can\$3.75 million (Sameoto 1975).

The first experimental, pre-commercial fishery to harvest krill was permitted in the Gulf of St. Lawrence in 1991. New acoustic studies determine the abundance of krill in the Gulf ranged from 400 000 mt to 1 million mt (Nicol and Endo 1997). It was determined that the allowable catch level of 300t would have a negligible effect on the krill populations and on the populations of natural predators on krill, but there was concern about the possible impacts of taking the whole of the catch from a restricted area, the effect on the populations of whales that feed in that area, and concern over the incidental bycatch, particularly of juvenile fishes. The Gulf fishery produced frozen krill and freeze dried krill for ornamental fishes and for public aquaria and freeze dried krill as an ingredient in salmon feed and as a flavourant for food for human consumption. But interest in this fishery declined and catches were quite low, and the fishery became inactive after 1998.

Another permit request was received in 1995 to fish 1,000 mt of krill (primarily *M. norvegica*) on the Scotian Shelf and Gulf of Maine, off Nova Scotia, Canada. The krill was to be used to produce a product to coat fish pellets to be fed to young salmon in fish farming. Concerns were voiced about effects on krill-dependent fish species of the region that have a major portion of krill in their diet. There was also concern over the significant by-catch of larval and juvenile forms of other commercial species that could be taken with the krill catch and possible interactions with populations of the endangered right whale. In 1998, Canada's Minister of Fisheries and Oceans announced that he would not consider authorizing a fishery for krill (or any other untapped forage species) on the Atlantic Coast of Canada until more information was known about the effects on the food chain for harvesting forage species, and before an ecosystem approach and plan was developed.

4.0 PROPOSED ACTION AND ALTERNATIVES AND THEIR IMPACTS

4.1 Management Issues

4.1.1 Krill Conservation

The first and foremost issue is conservation of krill to ensure that their stocks are not reduced to levels that might place at risk future krill sustainability or the other living marine resources that depend on krill. As Chapter 3 indicates, the abundance and distribution of krill stocks vary greatly both from year to year and within years. Abundance and distribution cannot be predicted with any certainty except in general terms, and there is no sound scientific basis for a point estimate of MSY or other measures of potential sustainable fishery yields. Further, the factors that promote greater or lesser reproductive success are not well understood, and a stock-recruitment relationship cannot be quantified. Thus any fishing is likely to result in risk to the stock, and while this risk cannot be specified in precise terms, it is reasonable to hypothesize that the higher the level of fishing allowed, the greater the risk. Given the uncertainties, a very conservative management policy would be appropriate.

4.1.2 Fishery Sustainability

The second issue is to ensure that fishing for krill would not adversely affect (directly or indirectly) other fisheries by reducing krill abundance or availability to levels that would not support survival, growth or sustainability of dependent or associated fish species. Chapter 3 discusses the many fish species that are dependent on or sensitive to the abundance and availability of krill. Most West Coast fisheries pursue stocks in this category, and many of the stocks are in Council-managed fisheries. Some of the fish species are overfished and are the subject of rebuilding plans. Given the value of the fisheries involved and the difficulties suffered when fishery restrictions have to be imposed (the West Coast Groundfish Fishery is an example) to deal with stock declines, it is reasonable to take such action as can be taken to ensure that necessary components of the ecosystem such as forage are protected and maintained to support the fish stocks that provide such important economic and social benefits. At the least, allowing a new fishery for such forage stocks should not be permitted at levels that would threaten the stocks that are targeted by existing fisheries.

4.1.3 Protection of Sensitive Species

The third issue is to ensure that fishing for krill would not adversely affect (directly or indirectly) the maintenance and health of other living marine resources that depend on or are sensitive to the abundance and availability of krill. Chapter 3 presents information on the number of non-fish species that are dependent on or sensitive to the abundance and availability of krill. Society, as expressed in a variety of laws, has recognized many of these species as having great importance, and programs and regulations are in effect to try to ensure that these species will survive and even increase in the wild. The food supplies that these animals depend on need to be protected and conserved. Given the variability of krill populations, it would seem even more important to take such actions as possible to minimize the risk of human-induced perturbations that could

exacerbate natural variability of the stocks. It would seem more prudent to take a very conservative approach to achieve high abundance of forage for these animals to the extent practicable.

4.1.4 Economic Values

There is no fishery for krill at this time on the U.S. West Coast, and there is no known interest in krill fishing. There are markets for krill and krill products, but it is not known if krill off the West Coast constitute a fishable resource. Prices of krill products vary widely, depending on the market and types of products involved. There is no basis for projecting potential values of a krill fishery off the West Coast. At this point, they would not seem to be substantial.

On the other hand, there are known values associated with existing fisheries, many of which are identified for species that are dependent on krill or are sensitive to the abundance and availability of krill. These could be adversely affected by a krill fishery. Further, there are eco-tourism businesses that provide services to non-consumptive resource users such as whale watching cruise companies. Some species of whales are dependent on krill abundance and availability and are more likely to be the subject of whale watching when in areas of krill concentrations, it is very possible that krill fishing could result in lower whale abundance and in turn lower demand for or value of whale watching cruises.

4.2 Proposed Action

As summarized in Section 1, the proposed action is to amend the CPSFMP as follows:

4.2.1 Add krill (all species) to the management unit species under the CPSFMP

The Council has initially determined that the CPS FMP is the appropriate mechanism for controlling fishing for krill. The CPS FMP embodies the principle of protecting key forage stocks; for stocks with harvest limits, harvest is only permitted after the spawning biomass is above a minimal level necessary to ensure stock sustainability and meet forage needs of associated species. The CPS FMP is a coastwide fishery management program and will have effect throughout the EEZ for all fishery interests.

4.2.2 Establish a “prohibited harvest” species category for management unit species, place krill in that category, and thus prohibit the harvest of krill

The CPS FMP currently has two categories of management unit species: managed and monitored. Managed stocks are subject to annual harvest guidelines, with the level of harvest tied to the size of the spawning biomass. Monitored stocks are stocks for which harvests are not bound by harvest guidelines. Fisheries for these stocks are very small, not at levels which threaten the stocks or any species that rely on those stocks in a significant way. The Council proposes to add a third category: “prohibited harvest” species, and to place krill in that category.

This means that the harvest of krill would be prohibited in the EEZ. This will ensure that, to the extent practicable, fisheries will not develop that could put at risk krill stocks and the other living

marine resources that depend on krill. Krill abundance and availability will be driven by natural environmental conditions, which will undoubtedly fluctuate considerably over time. It should be noted that by creating the “prohibited harvest” species category, the Council would leave open the possibility of adding other species in the future.

This new category is different from the existing “prohibited species” designation which is given to species (salmon, trout, halibut) which may not be taken and retained incidentally by CPS fishery participants, but which are subject to fishery controls under other federal regulations.

4.2.3 Designate essential fish habitat

Section 3.3 presents the proposed designations and the rationale for them.

4.2.4 Deny the availability of the exempted fishing permit process in the regulations implementing the CPS FMP for consideration and issuance of exempted fishing permits (EFPs) for krill fishing.

EFPs are generally available in fisheries to provide authority to fish in a manner that would otherwise be prohibited by federal fishery management regulations. The Council has considerable experience in reviewing and recommending action on EFPs in its managed fisheries. Indeed, the Council has in some cases established formal protocols to both solicit and consider EFP applications. The CPS FMP currently contains procedures under which the Council would review and recommend approval (with such conditions that the Council would conclude are necessary) or disapproval of EFP applications. Under this FMP amendment, that procedure would not be available to persons who want to engage in some fishing for krill. The intent of this proposal is to discourage prospective applicants by clearly indicating that the Council has no interest (at least at this time) in considering applications for EFPs. In the Council’s experience, EFPs have been used to develop and test new fishery procedures or gear that might result in lower bycatch or lower rates/numbers of interactions with protected species. Inasmuch as the Council does not propose to allow a directed fishery for krill, the Council sees no merit in allowing for the potential to test fish for krill. This would not affect legitimate fishery research by government or academia to better understand the characteristics and population dynamics of krill and the relationship of krill to other ecosystem resources.

4.2.4 Optimum Yield

After considering all the above information, including the major and critical uncertainties associated with the productivity of krill, its sensitivity to environmental conditions, and its importance to the ecosystem off the West Coast, the Council proposes that optimum yield (OY) for krill be zero (0). The greatest benefit to the Nation is achieved by protecting krill and ensuring their availability as an unexploited part of the environment. The potential benefits from development of a krill fishery are outweighed by the value of krill in the natural environment. The risk of adverse effects from a krill fishery is unacceptable. No fishing for krill should be permitted given the importance of krill in the environment, the value of krill as forage for fish and other living marine resources, and the importance of those other living marine resources to the people of the United States and of the West Coast. If at some time in the future there is new

information that demonstrates that a krill fishery can be prosecuted at some level with an acceptable level of risk, the Council will consider amending its position.

4.2.5 Status Determination Criteria

The maximum fishing mortality rate threshold is proposed to be zero (0).

The minimum stock size threshold is indeterminate and irrelevant. The Council proposes that no fishing be allowed, so the stock size will vary with environmental conditions. There is no threshold stock size at which the species will be considered overfished as no fishing would occur.

4.3 Impacts of the Proposed Action

4.3.1 Effects on Status of Krill

This would provide maximum protection for krill in the EEZ. The future productivity of krill would be affected only by variability in natural environmental conditions and events other than fishing. Essential fish habitat designations should support the protection from harvest.

4.3.2 Effects on Other Fish Species

This would likely provide benefits to, or at least prevent adverse effects on, other fish species by ensuring that krill fishing would not cause a decline in the availability of krill to other fish species at historic levels.

4.3.3 Effects on Other Living Marine Resources

This alternative would likely provide benefits to, or at least prevent adverse effects on, other living marine resources by ensuring that fishing would not cause a decline in the availability of krill to these resources as well as preventing any direct interaction between krill fishing and these other living marine resources.

4.3.4 Effects on Other Fisheries

This alternative would likely provide benefits to other fisheries to the extent that the prohibition of fishing for krill protects other fish stocks from any adverse effects of krill stock reduction due to fishing.

4.3.5 Economic Effects

This alternative would provide benefits to existing fisheries and to eco-tourism businesses and entities involved in such activities as whale watching. It would preclude development of a fishery for krill and thus any potential economic benefits (not calculable) from such fishing.

4.3.6 Effects on Data Collection

This alternative would have no benefits in terms of added data collection. However, the documentation for this action includes recommendations that may result in enhanced collaboration between researchers and in additional research directed at a better understanding of krill resources and their role in the environment.

4.3.7 Effects on Bycatch

This alternative would preclude any potential for bycatch in krill fishing in the EEZ.

4.3.8 Effects on Habitat

This alternative would prevent any adverse impacts on habitat from fishing in the EEZ. Further, to the extent krill provide an ecosystem support function (see 3.2.4), the prohibition of krill fishing ensures that this function will be carried out to the maximum extent practicable in the natural environment.

4.3.9 Effects on Protected Species

This alternative would provide benefits to, or at least prevent adverse effects of krill fishing on, protected species. Krill abundance and availability would not be affected by fishing, and krill would be available to protected species to the maximum extent practicable in the natural environment.

4.3.10 Administrative Considerations

This alternative would be relatively simple to carry out under existing procedures for implementing fishery management plans and amendments under the Magnuson-Stevens Act. It is consistent with existing West Coast states' laws and therefore should raise no fishery management or coastal zone management conflict. It is highly "precautionary" as it would prevent rise of a fishery when there is little or no information about the likely risk of krill stock depletion from fishing and about the consequences of such a condition. It would go beyond the original request of the National Marine Sanctuaries Program. While a complete prohibition of fishing might result in some objections, it is noted that there is now no krill fishing and thus no party would be removed from a fishery already underway. This should reduce the likelihood of objections on economic grounds. There is no krill fishing now that would be eliminated so there would not be adverse social impacts that would raise concerns. Total prohibition of krill fishing is also easily enforced.

4.3.11 Consistency with Management Objectives

This alternative would meet all the management objectives (see section 2.2).

It would ensure that, to the extent practicable, the stocks of krill off the West Coast are maintained within the bounds of natural variability and at maximum levels supported by

environmental conditions. There would be no risk of fishing resulting in disruption of krill populations or their distribution and availability in the environment.

It would provide protection for key krill predator foraging areas (i.e., topographic and oceanographic features that consistently serve to concentrate krill and facilitate predator feeding). There would be no risk of fishing that would directly or indirectly affect the availability of krill to predators or would interact with the predators and disrupt their feeding patterns in key foraging areas.

It would provide a foundation for future research and data collection. Sections 3.1.3.1 and 3.1.3.5 contain a number of recommendations for further research and for collaboration among researchers to better understand the size and dynamics of krill populations off the West Coast and the relationship between krill and other resources off the West Coast. NMFS uses such recommendations to support funding of research proposals and to set priorities for research. Given the interest in krill, academic scientists also appear willing to collaborate with NMFS on krill research. The Council urges NMFS to give high priority to such work.

4.4 Alternatives and Their Impacts

4.4.1 No Action (Alternative 1)

4.4.1.1 Effects on Status of Krill

This would provide no protection for krill in the EEZ and would have the highest risk of adverse effects on the stock. There would be no limit on the amount of krill that could be harvested, nor on the times and areas in which harvest could occur, including in national marine sanctuary waters.

4.4.1.2 Effects on Other Fish Species

This would result in increased risk to other fish species by allowing fishing that could result in reduced abundance and availability of krill to fish resources dependent on or sensitive to such conditions. As there would be no limit on the amount of krill that could be harvested or on times and areas of harvest, the potential for adverse impacts would be substantial, especially in years in which environmental conditions might be less suitable for krill.

4.4.1.3 Effects on Other Living Marine Resources

This alternative would result in increased risk to other living marine resources that are dependent on or sensitive to the abundance and availability of krill. Fishing could cause a decline in the availability of krill to these resources. Also, there could be a potential for direct interactions between krill fishing vessels and protected species if fishing were to occur in proximity to such species.

4.4.1.4 Effects on Other Fisheries

The effects on other fisheries would depend on the extent of krill fishing and the impact on other fish stocks that are harvested in these other fisheries. To the extent krill harvest resulted in lower abundance (numbers and/or size) of other target species, there would be adverse effects on the other fisheries. It should also be noted that, to the extent the reduced krill abundance affected overfished stocks and their ability to rebuild as predicted, krill fishing could result in more extended fishery restrictions for stocks taken in association with the rebuilding stocks.

4.4.1.5 Economic Effects

This alternative would result in increased risk to existing fisheries as well as to businesses that may supply fishing enterprises. Also, eco-tourism businesses that provide services to non-consumptive users of other living marine resources (e.g., companies providing whale watching cruises) could be harmed if krill fishing resulted in changes in the abundance and distribution of such resources. For example, if krill fishing resulted in less frequent use of West Coast waters close to ports from which whale watching cruises depart, there would likely be less demand for whale watching cruise services. The extent to which this would occur would depend on the amount, timing and location of krill harvest. As there would be no krill harvest restrictions, this alternative would pose the greatest probability of economic harm in this area. On the other hand, this alternative could result in krill harvest and associated economic benefits. Whether anyone would engage in krill fishing is not known.

4.4.1.6 Effects on Data Collection

This alternative would have no effect on data collection and research. There would be no requirement for any krill fishing businesses to report or make their fishing available for observers.

4.4.1.7 Effects on Bycatch

This alternative would have the highest risk of bycatch. As no krill fishing in the EEZ has occurred in the past, there is no basis for determining the extent to which there would be a bycatch problem off the West Coast. However, krill concentrations that would attract fishing also are likely to attract other species (fish, mammals, possibly seabirds); therefore, there is reason to expect that there would be bycatch at some level, especially of early life stages of fish. In the Antarctic situation, there has been bycatch of fur seals. There also could be interactions with baleen whales and possibly other animals.

4.4.1.8 Effects on Habitat

This alternative would have the potential for adverse habitat impacts. While the fishing gear would not likely adversely affect habitat, the removal of krill may result in disrupting or even precluding krill from carrying out their ecosystem or habitat enhancement role (see 3.2.4).

4.4.1.9 Effects on Protected Species

This alternative has the potential to have significant adverse impacts on protected species of whales and seabirds. If fishing occurred in proximity to cetaceans or in areas in which cetaceans and seabirds would normally feed, then feeding patterns could be seriously disrupted. In the case of seabirds, this could be especially harmful given the need for forage supplies in close proximity to nesting areas during reproductive periods.

4.4.1.10 Administrative Considerations

This alternative has no administrative impacts or costs.

4.4.1.11 Consistency with Management Objectives (see section 2.2)

This alternative would not meet all the management objectives.

Krill abundance and availability could be at risk due to new fishing enterprises.

Key foraging areas for predators could be impacted by fishing.

As with the proposed action, this action (as it would be based on this document and others that identify research needs) would support improved research into the abundance and dynamics of krill and associated resources.

4.4.2 Prohibit Krill Fishing Initially but Include Procedure for Future Fishing (Alternative 3)

This alternative would add krill to the management unit species under the CPSFMP. The amendment would have to meet MSFCMA requirements to specify MSY and OY and to establish status determination criteria for krill (i.e., minimum spawning stock threshold and maximum fishing mortality threshold). The initial OY would be zero (0); no directed fishery would be permitted. Essential fish habitat would have to be established. The FMP would set up a procedure (process and criteria) by which the Council could consider additional information (including possibly information from EFP fishing) and determine whether to allow fishing in the future, and if so at what level and under what conditions. Initial harvest limits would presumably be low, and fishing would be closely monitored (likely including observers). Harvest limits could be adjusted up or down depending on the results of fishing, other research results, and observers' records of any bycatch or protected species interactions. Harvest limits also might be adjusted up or down depending on the anticipation of unusual oceanographic/climatologic events (e.g., El Niño years would likely support higher harvests). EFPs could be considered under the procedures of the CPSFMP. There would be permit and reporting requirements for any fishing consistent with existing provisions of the CPSFMP.

4.4.2.1 Effects on Status of Krill

This would provide reasonable protection for krill in the EEZ and would have little risk of adverse effects on the stocks. There would be no harvest permitted at this time, and to the extent harvest were permitted in the future, it would presumably be based on additional information that demonstrated that there would be very little risk to krill stocks from the fishing permitted. To the extent EFPs were considered and issued, there could be very useful information for making decisions about future fishing risks to krill and for reducing uncertainty about the abundance, distribution and potential productivity of krill. However, there would still be substantial gaps in knowledge about such things as how critical different areas of occurrence of krill may be or the linkage between areas inside and outside sanctuaries, it is likely that the broad distribution of krill reflects the overall importance of all areas. Therefore, this alternative would possibly result in some higher risk of adverse effects on krill than the proposed action. The risk cannot be quantified because of the limited knowledge about krill and the inability to predict if a fishery would actually develop and, if so, at what level or in what times and areas fishing would occur.

4.4.2.2 Effects on Other Fish Species

This would result in limited risk to other fish species by allowing some fishing that could result in reduced abundance and availability of krill to fish resources dependent on or sensitive to such conditions. As there would initially be no allowance for krill fishing, there would be no initial risk to other fish species. However, to the extent krill fishing were allowed in the future, there could be some risk of adverse effects. The level of impact would depend on the level of fishing allowed and the times and areas in which fishing was permitted. There would be a potential for fishing (especially if closely monitored under an EFP or with observers) to result in some improvement of the understanding of the linkage between krill and other fish species. However, it would take much time and fishing for a substantial reduction of uncertainty about the abundance, distribution and potential yield of krill and the relationship with other fish species. Therefore, this alternative would result in a higher risk of adverse effects on other fish species than the proposed action. The risk cannot be quantified because of the limited knowledge about krill and their dependence on different waters, the relative dependence of these other fish species on krill in the open waters, and the inability to predict if a fishery would actually develop and, if so, at what level or in what times and areas fishing would occur.

4.4.2.3 Effects on Other Living Marine Resources

This alternative would result in low initial risk to other living marine resources that are dependent on or sensitive to the abundance and availability of krill. Fishing would initially be prohibited and thus could not cause a decline in the availability of krill to these animals. Also, there could not be a potential for direct interactions between krill fishing vessels and protected species if fishing were to occur in proximity to such species. In the future, however, there could be some krill fishing with a risk of adverse effects on other living marine resources. This risk cannot be quantified because of the limited knowledge about krill and their dependence on and productivity in different waters, the dependence of other living marine resources on krill in these waters, and the inability to predict if a fishery would actually develop and, if so, at what level or in what times and areas fishing would occur.

4.4.2.4 Effects on Other Fisheries

The effects on other fisheries would depend on the extent of krill fishing ultimately permitted by the Council. Initially, however, this alternative would have no impact on other fisheries. To the extent future krill harvest resulted in lower abundance (numbers and/or size) of other target species, there would be adverse effects on the other fisheries. It should also be noted that, to the extent there were a reduction in krill abundance and this were to affect overfished stocks and their ability to rebuild as predicted, krill fishing could result in more extended fishery restrictions for stocks taken in association with the rebuilding stocks. Therefore, this alternative would result in a higher risk of adverse effects on other fisheries than the proposed action. The risk cannot be quantified because of the limited knowledge about krill and their dependence on different waters, the relative dependence of these other fish species on krill in the open waters, and the inability to predict if a fishery would actually develop and, if so, at what level or in what times and areas fishing would occur.

4.4.2.5 Economic Effects

This alternative would not have any direct economic impacts initially. As no krill fishing would be permitted initially, there would be neither economic benefits from a fishery nor adverse effects on any businesses engaged in other fisheries. To the extent this alternative helps maintain krill stocks that sustain species of interest to non-consumptive users (e.g., whale watchers), this alternative would help maintain the revenues and profits to eco-tourism businesses. Future fishing could have economic impacts, beneficial and harmful. If a fishery were to develop, it could generate revenues and profits to participating fishers and to support businesses. A fishery could also result in higher risk of adverse effect than the proposed action on existing fishing enterprises as well as on businesses that supply fishing enterprises. Also, eco-tourism businesses that provide services to non-consumptive users of other living marine resources (e.g., companies providing whale watching cruises) could be harmed if krill fishing resulted in changes in the abundance and distribution of such resources. Therefore, this alternative would result in a higher risk of adverse effects on existing businesses than the proposed action. The risk cannot be quantified because of the limited knowledge about krill and their dependence on different waters, the response that will be shown by the businesses that are ultimately dependent on the fish and other resources associated with krill as the populations of those animals change, and the inability to predict if a fishery would actually develop and, if so, at what level or in what times and areas fishing would occur.

4.4.2.6 Effects on Data Collection

This alternative would initially not generate additional data, but in the future could result in additional data collection if a fishery were to develop. This would especially be true if there were efforts to obtain EFPs to engage in trial fishing for krill subject to stringent controls on times and areas of fishing, observer coverage, and reports of catch, effort, and possibly other information. Observers also would document fishing gear and techniques and monitor any effects on habitat, bycatch, or protected species interactions.

4.4.2.7 Effects on Bycatch

This alternative would initially ensure that there would be no bycatch, but could in the future result in increased risk of bycatch. As no krill fishing in the EEZ has occurred in the past, there is no basis for determining the extent to which there would be a bycatch problem. To the extent observers were placed on krill fishing vessels, especially under EFPs, there would be an improved basis for estimating bycatch and assessing its seriousness.

4.4.2.8 Effects on Habitat

This alternative would have little potential for adverse habitat impacts. Even if fishing were to occur, the fishing gear would not likely adversely affect habitat. However, the removal of krill, depending on the size of any harvest allowed, could result in the ecosystem role of krill (see 3.2.4) being disrupted or precluded altogether. The risk of adverse effects cannot be quantified at this time.

4.4.2.9 Effects on Protected Species

This alternative would initially have no impacts on protected species of whales and seabirds. If fishing were to be permitted in the future, there could be adverse effects if fishing occurred in proximity to cetaceans or in areas in which cetaceans and seabirds would normally feed, such that feeding patterns could be disrupted. In the case of seabirds, this could be especially harmful given the need for forage supplies in close proximity to nesting areas during reproductive periods. The Council would likely seek to control this risk (which cannot be quantified) by restricting areas known to have concentrations of whales or known to be primary feeding areas for whales and/or seabirds.

4.4.2.10 Administrative Considerations

This alternative has substantially higher administrative impacts or costs than the proposed action. Like the proposed action alternative, this alternative would require amendment of the CPS FMP; however, there are some significant differences. This alternative would add only the two principal species of krill identified in Chapter 3 to the management unit species of the CPS FMP; other krill would not be added. Under this alternative, these species of krill would be designated as managed or monitored, consistent with the current classifications in the CPS FMP. Initially, while there would be no harvest of krill, a procedure would have to be developed for ultimately allowing harvest. This would have to specify information requirements as well as a process and criteria for determining when or under what conditions fishing would be permitted. This could include establishment of harvest guidelines or perhaps quotas based on formulas. The Council would have to specify the MSY and OY (quantitative or by formula) more narrowly for the principal krill stocks, and establish specific status determination criteria for determining if overfishing of any stock was occurring or if a stock was overfished. As indicated in Section 3, this would be very difficult and possibly not even practicable (at the least, it would be subject to substantial criticism on scientific grounds) given the great uncertainties about krill and their life history characteristics and yield potentials. The Council would have to deliberate on specific fishery controls such as time/area closures or harvest limits. The amendment also would have to

specify essential fish habitat, a difficult proposition. Also, while NMFS and the Council have ample experience applying the administrative procedures for processing fishery management actions under the Magnuson-Stevens Act, it is acknowledged that allowing any krill fishing would be more controversial than the proposed action and could result in greater need for documentation or deliberation. This might give rise to a conclusion that a full Environmental Impact Statement would be required. While this alternative would be consistent with the request from the National Marine Sanctuaries Program, it would be inconsistent with states' laws and possibly thus not consistent with the states' approved coastal zone management plans. This could pose a difficulty. A full Section 7 consultation under the ESA would likely be required before fishing could be authorized; this could delay the process. Further, if a fishery were to develop, NMFS and Coast Guard would be required to enforce any fishery regulations. Finally, if a fishery were to develop, there would be data collection and processing costs, administrative costs for annual reviews by the Council and its advisory bodies, and permit and observer costs to NMFS (though some of this could perhaps be passed along to the fishing vessels). In sum, these administrative burdens would be quite substantial.

4.4.2.11 Consistency with Management Objectives (see section 2.2)

This alternative would not meet all the objectives of the proposed action. This document would, however, still contribute to achieving the objective of furthering scientific research and collaboration and ultimately might generate additional information about krill resources.

4.5 Relationship to the Magnuson-Stevens Act and other Applicable Laws

Final determinations of consistency of the proposed action and associated documentation with requirements of the Magnuson-Stevens Act and other applicable law have not been made. However, this section assesses the likely determinations based on current information.

4.5.1 Magnuson-Stevens Act

The CPSFMP as originally prepared was determined to be consistent with the Magnuson Fishery Conservation and Management Act, and all amendments have been similarly consistent with that act as amended. Available information suggests that this amendment would also be found consistent for the following reasons.

4.5.2 National Standards for Fishery Conservation and Management

Section 301 of the MSFCMA establishes ten National Standards for fishery conservation and management. FMPs and their associated regulations must be consistent with the National Standards. The Council's assessment of the degree of consistency of the proposed actions relative with the national standards is discussed below.

Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry.

The proposed action would prohibit fishing for krill and thus prevent overfishing. At this time, in the Council's view, the optimum management strategy is to prevent fishing for krill to promote optimum natural conditions for krill and species that depend on or are sensitive to the abundance and availability of krill, and thus promote the sustainability of other fish stocks to the extent practicable. Thus, the proposed action would support achievement of optimum yield for other fisheries.

Conservation and management measures shall be based upon the best scientific information available.

The information in this document and appendices constitutes the best scientific information available about krill and the associated resources.

To the extent practicable, an individual stock of fish shall be managed as a unit throughout its range, and interrelated stocks of fish shall be managed as a unit or in close coordination.

The proposed action would prohibit fishing for all species off krill off the West Coast and thus would address all interrelated stocks of krill.

Conservation and management measures shall not discriminate between residents of different States. If it becomes necessary to allocate or assign fishing privileges among various United States fishermen, such allocation shall be (A) fair and equitable to all such fishermen; (B) reasonably calculated to promote conservation; and (C) carried out in such manner that no particular individual, corporation, or other entity acquires an excessive share of such privileges.

The proposed action would not discriminate between residents of different States as the prohibition of krill fishing in the EEZ would apply to any and all U.S. vessels.

Conservation and management measures shall, where practicable, consider efficiency in the utilization of fishery resources; except that no such measure shall have economic allocation as its sole purpose.

The proposed action would discourage the development of a krill fishery and thus promote the maintenance of healthy fisheries for stocks that are dependent on or sensitive to the abundance and availability of krill.

Conservation and management measures shall take into account and allow for variations among, and contingencies in, fisheries, fishery resources, and catches.

The proposed action would recognize the important uncertainties about the abundance and productivity of krill resources off the West Coast and about the potential responses of other fish stocks and other living marine resources to potential declines in krill abundance. The action would be aimed primarily at preventing adverse effects of krill fishing on associated resources such as other fish stocks and other living marine resources. The largely preemptive measure would be taken because of the apparent importance of krill and the inability to predict the effects

of krill fishing on krill stocks and on associated and dependent species, including other targeted fish stocks.

Conservation and management measures shall, where practicable, minimize costs and avoid unnecessary duplication.

The proposed action would not impose any costs on any existing fisheries. It would be consistent with but would not duplicate any existing State regulations and requirements.

Conservation and management measures shall, consistent with the conservation requirements of this Act (including the prevention of overfishing and rebuilding of overfished stocks), take into account the importance of fishery resources to fishing communities in order to (A) provide for the sustained participation of such communities, and (B) to the extent practicable, minimize adverse economic impacts on such communities.

To the extent the proposed action would help maintain the stocks of harvested fish species, it would contribute to maintenance of fishing communities and prevent future adverse impacts on such communities.

Conservation and management measures shall, to the extent practicable, (A) minimize bycatch and (B) to the extent bycatch cannot be avoided, minimize the mortality of such bycatch.

The proposed action would prevent the development of a krill fishery off the West Coast and thus would ensure that no bycatch occurs in any such fishery

Conservation and management measures shall, to the extent practicable, promote the safety of human life at sea.

The proposed action would prohibit krill fishing and would have no effect of the safety of human life at sea.

4.5.3 Treaty Indian Fishing Rights

There is currently no Treaty Indian fishing for krill in the EEZ, and there is no known interest in krill fishing. Amendment 9 to the CPSFMP established a regulatory process to deal with any future expressions of interest in fishing for CPS species and that process is codified in 50CFR660.518. That process would apply in the event any tribal interest in krill fishing is expressed.

4.5.4 Bycatch Reduction and Reporting

The proposed action would prohibit fishing for krill. Therefore, there would be no bycatch in krill fisheries and the requirement for a standardized bycatch reporting methodology is moot.

4.6 Coastal Zone Management Act

The Coastal Zone Management Act (CZMA) requires a determination that a proposed management measure has no effect on the land, water uses, or natural resources of the coast zone, or is consistent to the maximum extent practicable with an affected state's approved coastal zone management program. A copy of this document will be submitted to the State coastal zone management agencies in Washington, Oregon and California with a request for consistency determinations. It is noted that the proposed action is to prohibit krill fishing, which is consistent with the States' prohibitions of harvest and landing of krill by state vessels. Therefore, it is expected that the States will confirm consistency with their coastal zone management plans

4.7 Endangered Species Act

The Endangered Species Act of 1973 (ESA), as amended (Public Law 93-205; 87 Stat. 884) prohibits the taking of endangered species except under limited circumstances. In 1986, 1991, and 2002, formal Section 7 consultations were completed by NMFS for the FMP (addressing sea turtles and marine mammals, but not seabirds). The results of the consultations are Biological Opinions as to whether the action B in this case, fishing under the FMP B is likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of critical habitat of such species. As no krill fishing would be permitted, the proposed action would ensure that krill will be available to ESA listed species off the West Coast to the maximum extent possible subject to natural environmental conditions. Therefore, it is believed that informal consultations will be sufficient to conclude that this action is not likely to adversely affect any ESA listed species or any designated critical habitat for listed species

Appendix B lists the species listed as endangered or threatened under the ESA that have been observed in the EEZ off the West Coast.

4.8 Marine Mammal Protection Act

The proposed action would prohibit fishing for krill off the West Coast. This would preclude both direct impacts of a fishery on marine mammals (thus obviating any need for a take authorization permit) and indirect impacts (e.g., by removing forage) on marine mammals.

4.9 Regulatory Flexibility Act

The RFA requires government agencies to assess the effects that various regulatory alternatives would have on small entities, including small businesses, and to determine ways to minimize those effects. A fish-harvesting business is considered a "small" business by the Small Business Administration (SBA) if it has annual receipts not in excess of \$3.5 million. For related fish-processing businesses, a small business is one that employs 500 or fewer persons. For marinas and charter/party boats, a small business is one with annual receipts not in excess of \$5.0 million. Harvesters and processors of Pacific sardine and mackerel would be expected to be the only types of small entities directly impacted by the proposed action, and that is only in the sense that they

would not be able to engage in a new krill fishery. There appears to be a good basis to certify that the proposed action would not have a significant economic impact on a substantial number of small entities. Information required for the certification follows:

Basis and Purpose of the Rule

The proposed action would be taken under the authority of the Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. 1801 et seq.). The purpose and need for the proposed action are discussed in Section 2.0. The objectives of the proposed action are to ensure that krill populations are maintained within the bounds of natural environmental variability, provide protection for key krill predator foraging areas (i.e., topographic and oceanographic features that consistently serve to concentrate krill and facilitate predator feeding), and provide a foundation for improved research and data collection. Krill are an important component of the marine environment of the U.S. West Coast, supporting many species of fish and other living marine resources (see Section 3). There is no fishing now for krill, but there is a potential for a krill fishery to develop in the absence of action to prevent it. A krill fishery could severely impact many other resources and the persons and businesses that benefit from use and/or protection of those resources. The context of the proposed action is the need to protect fish and non-fish resources and the users (consumptive and non-consumptive) of those resources from the adverse effects that could result from declines in krill populations that might occur if krill fishing were permitted. There is currently no fishing for krill but there are krill fisheries in other parts of the world and there is currently no limitation on krill fishing in the EEZ. The proposed action would be preemptive and precautionary.

Estimated Number of Small Entities to Which the Rule Would Apply

No small entities would be directly affected if this action were taken. There are currently no entities engaged in fishing for krill off the West Coast. It is possible that, in the absence of this action, a krill fishery could develop, but it is not possible to estimate the number of entities (large or small) that might engage in such fishing in the future.

Estimated Economic Impacts on Small Entities by Entity Size and Industry

The proposed action would not have any direct economic impacts on any small entity. There is no fishing now for krill, and thus no entities (large or small) would be displaced from or otherwise affected by the proposed action.

Criteria Used to Evaluate Whether the Action Would Impose “Significant Economic Impact”

No criteria for such an evaluation were used as no entities (large or small) will be directly affected by the proposed action. No entities now fish for krill so no entities would be disproportionately affected or suffer reductions in profits.

Criteria Used to Evaluate Whether the Action Would Impose Impacts on a “Substantial Number” of Small Entities

No criteria were used for such an evaluation as no entities (large or small) would be directly affected by the proposed action. No entities now fish for krill so a “substantial number” of small entities would not be affected.

Assumptions Used in the Analysis

No assumptions were used in the analysis. No fishing for krill currently occurs and there have been no indications of active interest in development of a krill fishery off the West Coast. It is not necessary to make assumptions about future behavior to determine that the proposed action will not directly affect any entities given that no entities currently engage in krill fishing.

4.10 Executive Order 12866 - Regulatory Impact Review (RIR)

The purpose of an RIR is to determine whether any of the proposed actions could be considered "significant regulatory actions" according to E.O. 12866. This action will not have direct effect on any individuals or businesses. The proposed action could have beneficial impacts on fishers who target stocks dependent on or sensitive to the abundance and availability of krill by preventing adverse effects on krill stocks. It also could have beneficial impacts on providers of whale watching services and other tour providers who benefit indirectly from the ability of krill to meet forage needs of other living marine resources. However, any such impacts cannot now be measured. To the extent there would be economic effects, they would be expected to be positive relative to the No Action Alternative.

The proposed action, if implemented, would not have an annual effect on the economy of \$100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs or the environment, public health or safety, or state, local, or tribal governments or communities. It would not create a serious inconsistency or otherwise interfere with an action taken or planned by another agency. It would not materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of recipients thereof. It would not raise novel legal or policy issues arising out of legal mandates, the Administration’s priorities, or the principles set forth in E.O. 12866.

4.11 National Environmental Policy Act (NEPA)

This document has been prepared as a combined amendment to a fishery management plan and environmental assessment. As required by NEPA, this document identifies management problems and issues, sets forth alternatives to address those problems and meet objectives of management, and evaluates and compares the effects and effectiveness of the alternatives. Other specific analytical requirements of NEPA are set out in guidelines or administrative directives by NOAA and the Council on Environmental Quality and are addressed in the following sections.

4.11.1 Significance of Impacts of the Proposed Action

The Council believes that, if adopted, the proposed action will not have a significant impact on the human environment. This conclusion is based on consideration of NOAA and Council on

Environmental Quality Significant Impact Criteria (as outlined in NOAA Administrative Order 216-6) as follows:

- 1) Can the proposed action reasonably be expected to jeopardize the sustainability of any target species that may be affected by the action?

The proposed action is not expected to jeopardize the sustainability of any target or non-target fish stock. It would prevent the development of a fishery for krill off the West Coast. This would ensure that (to the extent practicable) the krill stocks will remain as healthy and productive as possible under prevailing (and changing) environmental conditions. In turn, the ability of krill stocks to fulfill their role in the environment will be maintained and fishing for krill will not adversely affect other species that are dependent on, or sensitive to the abundance of, krill. These other species include a number of species (some of which are overfished) under Pacific Council FMPs as well as species listed under the Marine Mammal Protection Act and Endangered Species Act.

- 2) Can the proposed action reasonably be expected to jeopardize the sustainability of any non-target species?

The proposed action is not expected to jeopardize the sustainability of any non-target species. As indicated above, species that are dependent on, or sensitive to the abundance of, krill will not be affected by any change in krill abundance or distribution due to a krill fishery. Krill fishing will be prohibited.

- 3) Can the proposed action reasonably be expected to cause substantial damage to the ocean and coastal habitats and/or essential habitat as defined under the Magnuson-Stevens Act and identified in FMPs?

The proposed action is not expected to cause substantial damage to the ocean and coastal habitats or essential fish habitat as defined under the Magnuson-Stevens Act and identified in FMPs, as it is not likely to lead to substantial physical, chemical, or biological alterations of these habitats (Section 4.1.2).

- 4) Can the proposed action reasonably be expected to have a substantial adverse impact on public health or safety?

The proposed action is not expected to have a substantial adverse effect on public health or safety. It would prevent a krill fishery and, to the extent practicable, ensure that krill will support populations of other marine resources that are dependent on, or sensitive to the abundance of, krill resources.

- 5) Can the proposed action reasonably be expected to adversely affect endangered or threatened species, marine mammals, or critical habitat of these species?

The proposed action is expected to contribute to the health of populations of marine mammal species protected under the ESA and their critical habitat and of species protected under the

MMPA. It would not be possible for a krill fishery to develop, and therefore krill stocks would remain as healthy and productive as possible under prevailing (and changing) environmental conditions. This should ensure the availability of krill as forage for any species protected under the ESA and MMPA that are dependent on or affected by the availability and abundance of krill.

- 6) Can the proposed action be expected to have a substantial impact on biodiversity and/or ecosystem function within the affected area (e.g., benthic productivity, predator-prey relationships, etc.)?

The proposed action is expected to contribute to maintenance of biodiversity and ecosystem function off the West Coast. Krill are forage for a wide variety of species (fish, marine mammals, seabirds), and reduction of krill stocks could have a substantial adverse impact on biodiversity or ecosystem function within the affected area. However, the proposed action would prevent development of a krill fishery and thus ensure that krill stocks remain as healthy and productive as possible under prevailing environmental conditions.

- 7) Are significant social or economic impacts interrelated with natural or physical environmental effects?

The proposed action is not expected to have significant economic effects associated with physical environmental effects. There is currently no fishery for krill, so no business entities or other economic activities would be directly affected by the proposed action. It is noted that the prohibition of krill fishing would preclude a fishery that could have direct economic benefits in the future. The level of such benefits cannot be estimated with available information. However, to the extent prohibition of krill fishing helps in maintenance or rebuilding of fish stocks that are harvested (and that might not be as productive without krill for forage), the proposed action would contribute to the economic health and productivity of West Coast fisheries. There also are businesses that provide services for non-consumptive beneficiaries of healthy marine mammal stocks. To the extent that the protection of krill from fishing contributes to the productivity or abundance of krill and in turn support the presence of such marine mammal stocks, the proposed action would contribute to the value of such businesses.

- 8) Are the effects on the quality of the human environment likely to be highly controversial?

The effects of the proposed action are not likely to be highly controversial. There is broad support within the Pacific Council and the fishing community as well as the conservation community for action to protect krill stocks due to their importance for other living marine resources. The action was developed in response to a request for consideration of a less protective regime (i.e., prohibition of krill fishing in EEZ waters in selected National Marine Sanctuaries). The Council ultimately concluded that prohibition of krill fishing throughout the EEZ was appropriate and necessary, and this action has been supported by virtually all who have commented.

- 9) Can the proposed action reasonably be expected to result in substantial impacts to unique areas, such as historic or cultural resources, park land, prime farmlands, wetlands, wild and scenic rivers or ecologically critical areas?

The proposed action would result in substantial protection of krill and associated marine resources in National Marine Sanctuaries off the West Coast and thus will contribute to the quality of those unique resources. There are no other known historic and cultural resources, park land, prime farmlands, wetlands, wild and scenic rivers, or ecologically critical areas that will be affected by the implementation of the proposed action.

- 10) Are the effects on the human environment likely to be highly uncertain or involve unique or unknown risks?

The effects on the human environment are uncertain due to the inherent variability of the marine environment. As documented, krill resources are extremely sensitive to changes in environmental conditions, and the prohibition of fishing will not guarantee that krill resources will be productive in the future. However, the proposed action would reduce the risk that a combination of fishing and unfavorable environmental conditions will result in long-term (and possibly irreversible) reduction in krill stocks with ensuing adverse effects on other living marine resources. The approval and implementation of the proposed action involves unique or unknown risks associated with the effects of fishing on the abundance and distribution of krill stocks. The proposed action is intended to preclude risks to the sustainability of target and non-target fish stocks by preventing fishing on krill, a principal food source of those fish stocks.

- 11) Is the proposed action related to other actions with individually insignificant, but cumulatively significant impacts?

The proposed action is not expected to result in any significant cumulative adverse effects (Section 4.3). Because the proposed action would not result in direct or indirect adverse effects, there likewise would be no incremental effects to any resource of concern.

- 12) Is the proposed action likely to adversely affect districts, sites, highways, structures, or objects listed in or eligible for listing in the National Register of Historic Places or may cause loss or destruction of significant scientific, cultural or historical resources?

There are no districts, sites, highways, structures, or objects within the EEZ, or significant scientific, cultural or historical resources that would be adversely affected by the proposed action. The proposed action would result in substantial protection of krill and associated marine resources in National Marine Sanctuaries off the West Coast.

- 13) Can the proposed action reasonably be expected to result in the introduction or spread of a nonindigenous species?

There are no reasons to expect that the proposed action would result in the introduction or spread of nonindigenous species.

- 14) Is the proposed action likely to establish a precedent for future actions with significant effects or represents a decision in principle about a future consideration?

The proposed action is precedent setting in establishing a “prohibited harvest” species category in a Pacific Council FMP. It is possible that other species may ultimately be placed in this category in the CPSFMP or that this category could be established in other Pacific Council FMPs. It is also possible that this approach (which can be considered an “ecosystem-based approach” to resource management) is just the first instance of explicit incorporation of ecosystem management principles in fishery management by the Pacific Council. However, a fundamental concept of the action (i.e., recognition of the forage importance of species in an FMP) has already been adopted in the CPSFMP and is applied in the harvest management strategy for CPS, which considers the forage importance of such species as Pacific sardine and Pacific mackerel in the harvest guideline formulas for those species. The incorporation of ecosystem management principles into fisheries management is being promoted within NOAA and NMFS as well as by Congress, and this action may further advance that effort.

15) Can the proposed action reasonably be expected to threaten a violation of Federal, State, or local law or requirements imposed for the protection of the environment?

This action is not likely to impose or cause a violation of Federal, State, or local law or requirements imposed for the protection of the environment. West Coast states already prohibit krill fishing by their residents. The proposed action will reinforce the states’ prohibitions.

16) Can the proposed action reasonably be expected to result in cumulative adverse effects that could have a substantial effect on the target or non-target species?

As indicated in the following section, the proposed action would ensure that there would be no adverse effects on the new management unit species, and would not be expected to result in cumulative adverse effects that could have a substantial effect on non-target species.

4.11.2 Cumulative Impacts

Cumulative effects would occur when direct and indirect effects of the alternatives combine with effects of factors exogenous to the West Coast marine environment to produce a net effect different than the separate effects or the exogenous factors. These net effects can be beneficial or adverse. Principles of cumulative effects analysis identified by the Council on Environmental Quality have been applied in completing the cumulative effects analysis for this EA.

As discussed in the following section, this action will not result in cumulatively significant impacts on the environment. The proposed action is not expected to result in cumulative adverse effects that could have a substantial effect on the target species or non-target species, based on historical and predicted fishing effort and the condition of these stocks.

4.11.2.1 Target Fish Resources

4.11.2.1.1 Exogenous Factors

Two major exogenous factors were identified as having the potential to contribute to cumulative effects on krill resources in the EEZ off the West Coast:

Fluctuations in the ocean environment and possible effects on krill stocks (reproduction, recruitment, abundance, and availability); and

Changes in abundance and distribution of major predators of krill.

4.11.2.1.2 Fluctuations in the Ocean Environment and Possible Effects on Krill Stocks

The future condition of krill stocks depends largely on environmental conditions. Future ocean climate shifts may alter surface currents and water temperature in ways that could significantly affect the level of krill abundance and availability to major predators.

4.11.2.1.3 Changes in abundance and distribution of major krill predators

Several predator species are protected under existing laws and regulations. Cetaceans are protected by the MMPA. Certain seabirds are protected under the Migratory Bird Treaty Act, and while that statute does not apply in the EEZ, some of those bird species could be affected by an overall decrease in krill abundance. Several species of fish are classified as endangered or threatened under the ESA or as overfished under the MSFCMA. To the extent these protected species recover and rebuild, there could be added natural mortality of krill stocks, at least on a localized level. An indirect effect of the alternatives could be to support recovery of species that would then compete for krill in certain times and places.

4.11.2.1.4 Cumulative Effects

The cumulative effects of each alternative are analyzed by combining (a) the direct effects of each alternative and (b) the indirect effects of each alternative with c) the effects of exogenous factors, as modified by (b).

The proposed action is more likely than other alternatives to protect krill resources over the long-term. Alternative 3 could provide full protection in the short-term but there would be some future risk if a krill fishery were allowed under the selected procedure. To the extent that the Federal List of Fisheries and existing states' controls prevent development of a krill fishery, Alternative 1 could provide some protection, at least in the short-term.

The proposed action is more likely than the other alternatives to provide indirect benefits to other living marine resources by ensuring that the krill stocks are as productive as natural conditions allow. Alternative 3 could provide similar benefits, at least in the short-term as fishing would be prohibited until conditions were determined suitable by the Council. Alternative 3 could also provide similar benefits in the short-term as the Federal List of Fisheries and existing states' controls would prevent a fishery from developing.

A significant change in environmental conditions could render the Council's approach to conserve krill and associated resources ineffective. Krill demonstrate extreme sensitivity to environmental conditions, with high production in good conditions and low production (and almost absence from the marine environment) in unfavorable conditions. Under the latter, there

could be substantial adverse effects on krill predators. This is a fundamental rationale for the Council's proposal to prohibit a krill fishery; it will reduce the risk of significant adverse effects on fish, marine mammals, and other animals in (unpredictable) periods of low krill productivity.

At the same time, if stocks of major krill predators increase, this is not likely to result in or cause long-term damage to the krill stocks. The environment will rarely be "stable;" there will always be shifts in productivity and abundance of different species in the marine environment, even in the absence of fishing or other resource perturbations from human sources. Any shift in abundance of predators would not likely be rapid or intense enough or focused on specific locations or krill species so as to cause significant long-term damage to the stocks involved. A fishery would be much more likely to pose risk to krill stocks, both short-term and long-term, especially if exacerbated by a period of low krill productivity. The proposed action is the least likely to result in a combination of increased natural mortality and the effects of fishing, and therefore would likely raise a lower risk of adverse effects on krill. Alternatives 1 and 3 would have a higher risk of adverse cumulative effects of higher predation and fishing mortality in the future.

4.11.2.2 Essential Fish Habitat and the Marine Environment

4.11.2.2.1 Exogenous Factors

Three major exogenous factors were identified as having the potential to contribute to cumulative effects on essential fish habitat and the marine environment:

Fluctuations in the ocean environment;

Vessel anchoring, groundings, marine debris and waste disposal; and

Introduction of marine species.

4.11.2.2.2 Fluctuations in the Ocean Environment

Environmental fluctuations are characteristic of marine benthic ecosystems in shallow waters. Significant sources of inter-annual physical and biological variation are *El Niño* and *La Niña* events (Lehodey et al. 1997). Physical and biological oceanographic changes have also been observed on decadal time scales. These low-frequency changes, termed regime shifts, can affect productivity over extensive areas and may account for large fluctuations in population abundance. This factor, therefore, could contribute significantly to cumulative effects on essential fish habitat and the marine environment.

4.11.2.2.3 Vessel Waste Disposal, Marine Debris, and Sinkings

If a fishery were to develop, there could be disturbance to krill habitat from waste disposal and marine debris. Waste disposal by U.S. vessels is controlled by U.S. laws and regulations, and there should not be a high risk of severe damage to krill from such activity. Similarly, while marine debris may be a risk to some species in the marine environment (e.g., marine mammals), it

would not seem to pose significant risk to krill, which are relatively small animals and not generally subject to entanglement in or other harm from marine debris at levels that would be harmful to the krill stocks.

The accidental grounding or sinking of a non-fishing vessel (e.g., there is a large amount of shipping of petroleum resources into West Coast ports) could pose a much more substantial risk of harm to krill and associated species. However, even this kind of event is more likely to have substantial effect on non-krill species (e.g., marine mammals) and nearshore or shoreline habitat than on krill and open ocean habitat.

4.11.2.2.4 Introduction of Marine Species

Transport of introduced marine species among world ports has occurred with increasing frequency in the last 25 years and introductions have sometimes produced devastating changes in the marine ecosystems of receptor areas. Worldwide shipping is believed to be the primary vector responsible for such invasions. Ships may transport viable organisms within their ballast water or on their hulls as fouling organisms. If precautions are not taken, these potential invaders may be discharged in ports where, with no natural predators or controls, they may proliferate rapidly. The West Coast is one of the major commercial shipping arenas in the eastern Pacific and potentially represents a regional center where marine species introductions may occur and spread. This exogenous factor has greater potential to add to cumulative effects on essential fish habitat and the marine environment in nearshore and inshore ecosystems than in the open ocean waters inhabited by krill.

4.11.2.2.5 Cumulative Effects

The cumulative effects of each alternative are analyzed by combining (a) the direct effects of each alternative and (b) the indirect effects of each alternative with (c) the effects of exogenous factors, as modified by (b).

The exogenous factor relating to fluctuating environmental conditions is less likely to have long-term adverse effects under the proposed action and Alternative 3 as both actions would identify EFH for krill and identify prospective actions to protect EFH. Alternative 1 would have less effect as there would not be identification of EFH or of actions to protect EFH. The exogenous factor relating to vessel grounding could be modified by Alternative 1 (no action) that is more likely than other alternatives to result in some fishing for krill by vessels without a legal connection to the West Coast (West Coast registered vessels may not fish for krill under states' laws). This is in turn more likely than the proposed action to result in inadvertent introduction of marine species that could be detrimental to naturally occurring stocks or animals. Alternative 3 would have slightly less likelihood of introduction of marine species. The exogenous factor related to introduction of non-indigenous species could be modified by Alternative 3 which would prohibit krill fishing by out-of-region (as well as in-region) vessels. Except for Alternative 1, when the estimated direct and indirect effects are combined with the potential effects of exogenous factors, none of the alternatives are likely to have effects that could be detectable against the background of cyclical oceanographic processes.

4.11.2.3 Sea Turtles

4.11.2.3.1 Exogenous Factors

Exogenous factors affecting the survival and recovery of sea turtle populations include numerous natural and human-induced hazards.

Natural hazards include nest washover, beach erosion, egg predation (by animals and humans) in addition to the basic sex- and stage-specific survival probabilities.

Anthropogenic hazards include beach egg harvest, juvenile/adult harvest, boat strikes, debris ingestion and incidental capture in driftnet, longline and coastal net fisheries. Egg harvest and coastal net fisheries are deemed the most significant of the man-induced hazards.

4.11.2.3.2 Cumulative Effects

The cumulative effects of each alternative are analyzed by combining (a) the direct effects of each alternative and (b) the indirect effects of each alternative with (c) the effects of exogenous factors, as modified by (b).

There has been no krill fishery, and thus there has been no reported or observed incidental captures of sea turtles in krill fishing. However, it is known that sea turtles (especially leatherback, an endangered species) occur off the West Coast in waters in which krill fishing would be likely if the fishery were allowed.

The proposed action is least likely to compound the adverse effects of other risks to sea turtle populations. There would be no krill fishing and therefore there would be no incidental take of sea turtles in a krill fishery. Alternative 3 would prevent sea turtle takes in the short-term, while Alternative 1 would provide the least protection against the possible take of sea turtles. However, when the estimated direct and indirect effects (likely minimal) are combined with the potential effects of exogenous factors, none of the alternatives would be likely to add to the already significant cumulative effects on sea turtle populations in the Pacific.

4.11.2.3.3 Significant Cumulative Effects Requiring Mitigation

Because of multiple natural and anthropogenic threats to sea turtle populations, and regardless of the krill fishery alternatives under consideration, mitigation of significant cumulative effects would and will require international cooperation, including consideration of which populations and life stages are the highest priority for conservation efforts.

4.11.2.4 Seabirds

4.11.2.4.1 Exogenous Factors

The principal exogenous factor is fluctuations in the ocean environment that have the potential to cause changes in seabird reproductive success through changes in abundance and availability of prey during nesting seasons. This factor could contribute significantly to cumulative effects on seabirds.

4.11.2.4.2 Cumulative Effects

The cumulative effects of each alternative are analyzed by combining (a) the direct effects of each alternative and (b) the indirect effects of each alternative with (c) the effects of exogenous factors, as modified by (b).

The proposed action is least likely to result in cumulative effects on seabird species whose range includes the West Coast. This alternative would prohibit krill fishing and therefore have no effect on the abundance and availability of krill off the West Coast. Alternative 3 would have some potential in the future to have a cumulative effect through adding fishery mortality to natural krill stock size changes in response to changing environmental conditions. Alternative 1 would have the highest likelihood of some impact on krill stocks which, when added to natural fluctuations in response to environmental changes, could affect abundance and availability of krill to seabirds at important nesting areas or important nesting seasons.

4.11.2.5 Marine Mammals

4.11.2.5.1 Exogenous Factors

Most stocks of large whales were severely depleted by modern whaling. Moratoriums on hunting by the International Whaling Commission have restricted this activity, but poaching of whales and other marine mammals still occurs. Four other major exogenous factors were identified as having the potential to contribute to cumulative effects on marine mammals:

- Fluctuations in the ocean environment;
- Incidental take in fisheries;
- Ship traffic and anthropogenic noise; and
- Marine debris and waste disposal.

4.11.2.5.2 Fluctuations in the Ocean Environment

Ocean climate fluctuations that change the habitat quality or the prey availability of marine mammals have the potential to affect their short-term or long-term distribution and abundance. Changes in oceanographic conditions may also alter rates of incidental takes of marine mammals in commercial fisheries. The magnitude of potential effects is uncertain but this factor could contribute significantly to cumulative effects on marine mammals.

4.11.2.5.3 Incidental Take in West Coast Fisheries

West Coast fisheries may adversely affect marine mammals through gear hooking, entanglement or ingestion or by removal of prey species. This factor may contribute significantly to cumulative effects on marine mammals.

4.11.2.5.4 Ship Traffic and Anthropogenic Noise

Collisions with vessels and disturbance from low frequency noise are potential threats to the recovery of large cetaceans. Because many of the ship strikes occur far offshore and, thus, are unreported, this impact on large whales is most likely underestimated (NMFS 2000). The increasing levels of anthropogenic noise in the world's oceans may have an adverse effect on whales, particularly deep-diving whales that feed in the oceans' "sound channel" (Forney et al. 2000). These effects are difficult to assess but they may be significant as part of cumulative effects on marine mammals.

4.11.2.5.5 Marine Debris, Waste Disposal, and Vessel Groundings and Sinkings

Activities that may have adverse effects on marine mammal habitat include the dispersal of marine debris, large oil spills and other types of marine pollution. Petroleum has the potential to be toxic to marine mammals if it is inhaled, ingested or absorbed through the skin, mucous membranes or eyes, or if it inhibits feeding by fouling the baleen plates of whales. Hydrocarbons can also bio-accumulate in zooplankton and fish eaten by marine mammals and other wildlife. Any detrimental effects of marine pollution on their prey species would also affect marine mammals. Aside from large, catastrophic spills, the long-term effects of low levels of petroleum exposure are unknown.

Marine debris can be toxic to marine mammals if ingested or it can entangle them, leading to decreased ability to breathe, feed, breed, swim or haul out. The animals affected may be more vulnerable to predators or disease, reducing their survival or ability to reproduce.

4.11.2.5.6 Cumulative Effects

The cumulative effects of each alternative are analyzed by combining (a) the direct effects of each alternative and (b) the indirect effects of each alternative with (c) the effects of exogenous factors, as modified by (b).

There has been no krill fishery and thus no reported or observed incidental captures of whales in

krill fishing. However, there are numerous marine mammal populations that occur off the West Coast, and there is a history of takings in many fisheries. Further, some cetaceans are most likely to be present in the same time/space strata in which krill concentrations would occur. Therefore, it would not be unreasonable to hypothesize that marine mammal interactions with fishing would occur if a fishery were permitted. Also, there would be a greater probability (albeit perhaps very low) of vessel groundings, waste disposal and debris problems with a fishery than without.

The proposed action would prevent any cumulative effects of fishing with other exogenous factors on marine mammals. No krill fishing would occur, and therefore there would be no incidental takes nor would there be problems from waste disposal, pollution or vessel groundings. Alternative 3 would have identical effects in the short-term at least, while Alternative 1 would have a slightly higher probability of resulting in a fishery with risk of cumulative effects on marine mammals.

4.11.2.6 Economic Impacts

4.11.2.6.1 Exogenous Factors

Exogenous factors that might contribute to cumulative effects are:

Increased world demand for krill resources and products

Lack of krill to meet world demand due to collapse of other krill stocks

Fuel costs that promote greater fishing in domestic waters

To date, there has not been sufficient demand for krill and krill products to warrant development of a West Coast krill fishery. Even though states' laws on the West Coast might prohibit krill fishing by West Coast vessels, there would not have been federal laws prohibiting such fishing. If prices of krill or krill products were to increase due to higher demand or lack of krill resources in other areas (e.g., Antarctic), there would be greater incentive for development of a krill fishery off the West Coast. Also, fuel costs have risen dramatically in the past few years, making distant water fishing (such as off Antarctica) much more costly. As a result, it is possible that there is greater incentive than ever to fish for krill off the West Coast. Development of such a fishery could generate new income for participants (which might offset recent declines in other fisheries to some extent), but also could result in declines in fisheries for other resources (if krill fishing led to krill declines which led to declines in other harvested stocks) and in non-consumptive but economically valued resource uses linked to krill (e.g., whale watching in places where whales might seek out or feed on krill).

4.11.2.6.2 Cumulative Effects

The cumulative effects of each alternative are analyzed by combining (a) the direct effects of each alternative and (b) the indirect effects of each alternative with (c) the effects of exogenous factors, as modified by (b).

The proposed action would ensure that increased demand for krill would not result in adverse effects on West Coast krill or associated resources. Alternative 3 would have the same effect in the short-term but maybe not the long-term. Alternative 1 would allow a fishery to develop if world demand were sufficiently strong to warrant investment in the fishery. This could result in harm to established fisheries and non-consumptive users.

The proposed action would ensure that high fuel prices would not result in a shift of vessels from distant water fishing to krill fishing off the West Coast. However, it also would ensure that fishermen who have been displaced from distant water fishing by high fuel costs would not be able to turn to krill as an alternative. Alternative 3 would have the same effects in the short-term but maybe not in the long-term. Alternative 1 would provide greater potential for distant water fishing vessels to shift to krill fishing closer to the West Coast. This in turn could result in harm to established fisheries and non-consumptive marine resource users.

4.11.2.7 Social Impacts

4.11.2.7.1 Exogenous Factors

Two major exogenous factors were identified as having the potential to contribute to cumulative social impacts:

Fishermen's options for switching fisheries or relocating effort, and

Economic climate.

4.11.2.7.2 Options for Switching or Relocation

The possibilities for switching fisheries or relocating fishing effort could contribute significantly to cumulative social effects.

4.11.2.7.3 Economic Climate

Unemployment in West Coast ports has been high in recent years due in large part to fishery cutbacks (especially groundfish) as well as declines in timber and other natural resource using industries. Many fishers have been eager to explore new fishing opportunities, but such opportunities have been rare. Limited entry at both the federal and state levels has greatly reduced the ability of fishers to shift from one fishery to another. This has in many communities caused significant social stress. The economic climate could have major significance for cumulative social impacts.

4.11.2.7.4 Cumulative Effects

The cumulative effects of each alternative are analyzed by combining (a) the direct effects of each alternative and (b) the indirect effects of each alternative with (c) the effects of exogenous factors, as modified by (b).

None of the alternatives is expected to act in concert with exogenous factors to contribute to social impacts. While a new krill fishery could improve the economic climate for a small group of vessels/operators, the majority of fishers and businesses on the West Coast would either not be affected or could be adversely affected if krill fishing resulted in problems for other fish stocks or for non-fish resources of economic importance. The condition of the West Coast's economy could improve or worsen the effects of all of the alternatives. If employment opportunities expand, displaced fishermen could possibly find new jobs. If employment opportunities decrease, they will have more difficulty in finding new livelihoods. Therefore, the cumulative social effects associated with these economic variables may or may not be significant in a positive or negative direction. The social costs are likely to be more severe for the small-boat operators who have limited resources and/or education, while large-vessel participants may have more capital and opportunity to shift fisheries (e.g., by buying into limited entry fisheries). The proposed action has less potential for exacerbating problems as it would protect krill, which serves as a building block for many fishery and non-fishery resources. Alternative 3 could have the same effect, at least in the short-term. Alternative 1 would be the most likely to have adverse effects in combination with other factors.

4.11.3 Controversy Regarding Environmental Effects

There is no known controversy with respect to environmental effects of the proposed action. There is broad public support for the action, which is consistent with existing states' controls on the West Coast. Public comments have also promoted action as soon as practicable. No public comments have been received to date opposing the proposed action. On the contrary, comments in favor of the proposed action have indicated that allowing a krill fishery would be controversial and have argued that an Environmental Impact Statement would be necessary before opening a new fishery for such an important resource. Although there is a high degree of uncertainty regarding the nature and productivity of krill and its role in the natural environment, there does not appear to be substantial controversy about the likely benefits of the proposed action among the public, the scientific community, or other parties.

4.12 Paperwork Reduction Act (PRA)

The proposed action would not impose any new collection-of-information requirements that would be subject to approval by the Office of Management and Budget (OMB), pursuant to the PRA.

4.13 Migratory Bird Treaty Act (MBTA)

The Migratory Bird Treaty Act does not apply in the EEZ. However, the proposed action if implemented would reinforce states' prohibitions of krill harvest and ensure maximum protection of krill resources to the extent practicable off the West Coast. To the extent any species covered by the MBTA that occur off the West Coast are dependent on or sensitive to the abundance and availability of krill, and could be adversely affected by reductions in krill stocks due to krill fishing, those potential effects would be precluded by the proposed action.

4.14 Environmental Justice

The proposed action will have no impacts or implications in terms of environmental justice. As noted in 4.11.2.7.4, however, it is possible that allowing a krill fishery could result in adverse effects on other fisheries. If so, this could exacerbate problems arising from declines that have already occurred in other fisheries (e.g., groundfish), and this would most likely have greater effect on fishermen who are less educated and have fewer employment options. These would typically be fishers with low incomes and low savings.

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6.0 AGENCIES AND ORGANIZATIONS CONSULTED

National Marine Fisheries Service, NOAA, DOC
National Ocean Service, NOAA, DOC
U.S. Fish and Wildlife Service, U.S. Department of the Interior
Washington Department of Fish and Wildlife
Oregon Department of Fish and Wildlife
California Department of Fish and Game
Scripps Institution of Oceanography
University of California at Santa Cruz
Point Reyes Bird Observatory

7.0 LIST OF FIGURES

Figure 1. The euphausiids *Euphausia pacifica* and *Thysanoessa spinifera*. From Brinton (1973) Distributional atlas of Euphausiacea (Crustacea) in the California Current region, Part II. CalCOFI Reports Atlas 18; and Brinton (1967) Distributional atlas of Euphausiacea (Crustacea) in the California Current Region, Part I. CalCOFI Reports Atlas 5.

Figure 2. Geographical distribution of *Euphausia pacifica* (from Brinton 1962). Courtesy Pelagic Invertebrates Collection, Scripps Institution of Oceanography.

Figure 3. Geographical distribution of *Thysanoessa spinifera* (from Brinton 1962). Courtesy Pelagic Invertebrates Collection, Scripps Institution of Oceanography.

3.2

Figure 4. Study sectors within the California Current System, including the Central and Southern California sectors (from Brinton and Townsend 2003)

Figure 5. Visual pairing of Multivariate El Nino Southern Oscillation Index (MEI) departures with *E. pacifica* abundances. (a) Arrows face specific MEI negative and positive departures. (b) Arrows extend upward from peak *E. pacifica* densities and align with respective negative MEI departures. (c) PDO index annual departures. From Brinton and Townsend (2003) Decadal variability in abundances of the dominant euphausiid species in southern sectors of the California Current. Deep-Sea Res. II-Topical Studies in Oceanography 50(14-16): 2449-2472. Courtesy Pelagic Invertebrates Collection, Scripps Institution of Oceanography.

Figure 6. Log abundances of *E. pacifica* and *T. spinifera* abundances and sea temperature anomalies, southern California CalCOFI station lines 77-93, Spring collections. From Brinton and Townsend (2003) Decadal variability in abundances of the dominant euphausiid species in southern sectors of the California Current. Deep-Sea Res. II-Topical Studies in Oceanography 50(14-16): 2449-2472. Courtesy Pelagic Invertebrates Collection, Scripps Institution of Oceanography.

Figure 7. Log abundances of *E. pacifica* and *T. spinifera* abundances and sea temperature anomalies, central California CalCOFI station lines 60-73, Spring collections. From Brinton and Townsend (2003) Decadal variability in abundances of the dominant euphausiid species in southern sectors of the California Current. Deep-Sea Res. II-Topical Studies in Oceanography 50(14-16): 2449-2472. Courtesy Pelagic Invertebrates Collection, Scripps Institution of Oceanography.

Figure 8. Antilogged mean and frequency distribution of abundance, *E. pacifica*, CalCOFI southern California (M. Ohman and A. Townsend, 8/6/05, Pelagic Invertebrates Collection, Scripps Institution of Oceanography LTER site, after Brinton and Townsend 2003).

Figure 9. Antilogged mean and frequency distribution of abundance, *E. pacifica*, CalCOFI central California (M. Ohman and A. Townsend, 8/6/05, Pelagic Invertebrates Collection, Scripps Institution of Oceanography LTER site, after Brinton and Townsend 2003).

Figure 10. Antilogged mean and frequency distribution of springtime abundance, *T. spinifera* CalCOFI southern California. (M. Ohman and A. Townsend, 8/6/05, Pelagic Invertebrates Collection, Scripps Institution of Oceanography LTER site, after Brinton and Townsend 2003).

Figure 11. Antilogged mean and frequency distribution of springtime abundance, *T.spinifera* CalCOFI central California (M. Ohman and A. Townsend, 8/6/05, Pelagic Invertebrates Collection, Scripps Institution of Oceanography LTER site, after Brinton and Townsend 2003).

Figure 12. Estimated annual consumption of principal northern California Current forage assemblages (benthic fauna, euphausiids, forage fish and other nekton such as cephalopods and mesopelagics) by generalized predator guilds (commercially important crustaceans, pelagics-including salmon, Pacific hake, groundfish and seabirds/marine mammals). Credit: John C. Field, Groundfish Analysis Team, NMFS SWFSC, Santa Cruz, CA.

Figure 13. Dispersal of energy from euphausiids with respect to other intermediate energy sources in the Northern California Current. The size of the boxes and the width of the bars connecting various boxes are scaled to the log of the standing biomass (within maximum and minimum levels) and biomass flow respectively. The estimated trophic level is along the y axis, and colors representing the alternative energy pathways such that energy derived from euphausiid production is blue and energy from other sources is red. Credit: John C. Field, Groundfish Analysis Team, NMFS SWFSC, Santa Cruz, CA, pers. comm 4/19/05.

Figure 14. U.S. West Coast National Marine Sanctuaries (Courtesy Pam van der Leeden and Dan Howard, NOAA Cordell Bank National Marine Sanctuary).

8.0 LIST OF APPENDICES

- Appendix A Summary of a Meeting on California Current Krill off the U.S. West Coast, June 6, 2005
- Appendix B Information on ESA Listed Species Which May Be Affected By Potential Krill Fisheries in the U.S. West Coast EEZ
- Appendix C Draft Proposed Regulations

9.0 ABBREVIATIONS AND ACRONYMS

CFR	Code of Federal Regulations
CZMA	Coastal Zone Management Act
DEIS	Draft Environmental Impact Statement
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
EO	Executive Order
ESA	Endangered Species Act
FMP	Fishery Management Plan for the Bottomfish and Seamount Groundfish Fisheries of the Western Pacific Region
FR	Federal Register
HAPC	Habitat of Particular Concern
IRFA	Initial Regulatory Flexibility Analysis
MFMT	Maximum Fishing Mortality Threshold
MMPA	Marine Mammal Protection Act
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSST	Minimum Stock Size Threshold
MSY	maximum sustainable yield
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PRA	Paperwork Reduction Act
PRIA	Pacific Remote Island Areas
RIR	Regulatory Impact Review
RFA	Regulatory Flexibility Act

APPENDIX A

**Summary of a Meeting on California Current Krill off the U.S. West Coast
June 6, 2005**

Summary of a Meeting on California Current Krill off the U.S. West Coast, June 6, 2005
NMFS Southwest Fisheries Science Center, Large Conference Room
8604 La Jolla Shores Drive, La Jolla, CA 92037

A meeting was held 6 June 2005 at NMFS' Southwest Fisheries Science Center, in La Jolla, CA, to discuss the euphausiids *Euphausia pacifica* and *Thysanoessa spinifera* in the U.S. West Coast Exclusive Economic Zone (EEZ). The purpose of the meeting was to discuss the status, distribution, existing data sets, potential stock assessment methods, and management research needs for these two species in the EEZ. The Pacific Fisheries Management Council hopes to develop a program to regulate potential krill fishing in federal waters under the Magnuson-Stevens Act. NMFS' Southwest Region is currently assembling a draft document that reviews the available science and presents various options for managing krill, in cooperation with krill experts and the Council's Coastal Pelagics Management Team.

Participating attendees included co-conveners Sue Smith and Svein Fougner (NMFS SWR contractors); project head Mark Helvey (Assistant Regional Administrator for Sustainable Fisheries, NMFS Southwest Region); NMFS/SWFSC Santa Cruz ecosystem modeler John Field; NMFS/SWFSC Pacific Environmental Lab modeler Andrew Leising; Point Reyes Bird Observatory (PRBO) researchers Jaime Jahncke and Ben Saenz; Oregon researchers Leah Feinberg (OSU) and Bill Peterson (NMFS/NWFSC Newport); Scripps Institution of Oceanography (SIO) researchers Mark Ohman, Ed Brinton, and Annie Townsend; U.C. Santa Cruz researchers Don Croll and Baldo Marinovic; Pacific Council CPS Team members Dale Sweetnam and Kevin Hill; and NMFS La Jolla Laboratory researchers Lisa Ballance, Roger Hewitt, and Christian Reiss.

NWFSC and Oregon State University (OSU) Work off Oregon and Washington:

Leah Feinberg reported on euphausiid work being done by Bill Peterson, Feinberg and others at NMFS NWFSC Newport, Oregon, and at Oregon State University (OSU). They have been involved in four main efforts: 1) ongoing sampling since 1996 along the Newport Hydrographic line (NH-line); 2) the Northeast Pacific GLOBEC-LTOP program started in 1997; 3) the GLOBEC Mesoscale project conducted in 2000 and again in 2002; and 4) the Salmon Bonneville Power Association (BPA) funded study of the ecology of juvenile salmonids in relation to the Columbia River plume project, which began in 1998.

Along the Newport Hydrographic line, five stations have been sampled during the day bi-weekly since 1996 out to about 100 m contour line (NH15), and six stations have been sampled both day and night since 2001, out to just beyond the shelf break (NH25). Daytime sampling is done with a half-meter bongo net (200 μ mesh) fished vertically (100-0 m) for copepods and euphausiid eggs, larvae and juveniles. At night, adult and juvenile euphausiids are collected with a half-meter bongo net (formerly with 200 μ , now 333 μ mesh) deployed obliquely from 25m to the surface, where previous MOCNESS sampling indicated most of the adult population occurs at night in this area. Bottom depth

beneath the stations ranges from 60-300 m deep. Live euphausiids have also been collected since 2000 to obtain data on molting rates and egg production; some animals are brought back to the laboratory for extended experiments. Since 2001 they have been able to obtain adult monthly average densities at offshore station NH-25 just beyond the shelf break. *E. pacifica* occurs at an order of magnitude greater abundance than *T. spinifera*, although part of this may be due to patchiness and/or the better avoidance capabilities of the latter. Annual and monthly adult abundance patterns have differed between the two species. Since 2001, greatest densities (approaching or surpassing 4 individuals m⁻³) of *T. spinifera* adults occurred in late summer in 2002 and 2003. Peak densities of *E. pacifica* (over 30 individuals m⁻³) occurred in spring 2002, fall 2001 and 2004, and winter 2002 and 2004.

From 1997-2003, the GLOBEC LTOP project has sampled ~44 stations along five transects between Crescent City, CA north to Newport, OR, three to five times a year, both day and night. This is large-ship sampling, using a vertically deployed standard 71-cm CalCOFI type bongo net during the day, and sometimes a Tucker trawl net. MOCNESS net sets are made at night to obtain information on vertical distribution of all stages. Day-night MOCNESS pairs have also been made to study diel distribution patterns. During 2000 and again in 2002, Peterson's group was also funded under the GLOBEC Meso-scale program, during which time they conducted finer-scale diel studies, shipboard experiments, and acoustic surveys. They still have many MOCNESS samples from that effort (down to 300 m), and are hoping to work up some of these data this summer. They hoped to continue the GLOBEC sampling transects under the PACOS program, but NOAA has not provided significant ship time for this effort, thus only one or two cruises are scheduled for the next two years. They are committed, however, to continue small-vessel sampling along the NH-Line, to maintain that valuable time series.

The Bonneville Power Association (BPA) Salmon project focuses on sampling juvenile salmon and the prey field (including zooplankton) along various transects out to the shelf break. From this study, they have obtained a valuable time series on euphausiid larval and egg abundance in the Columbia River plume area. One result of those efforts is the finding that euphausiid eggs are on the order of five times more abundant off the Washington Coast than off Oregon. One hypothesis that may account for this difference is related to the presence of large submarine canyons off Washington. Euphausiids could be concentrated at canyon heads and trapped on the adjacent shelf, thus leading to elevated densities of adults and higher densities of eggs in these locations.

In the laboratory, work has been done on growth, molting, brood sizes and brood periodicity. A manuscript on molting and instantaneous growth rates (for both species) will be published next year. More data are available on *E. pacifica* than for *T. spinifera*, since eggs of the latter species are highly adhesive and difficult to work with. Also, *T. spinifera* is more difficult to keep in captivity, apparently requiring a diet of much larger phytoplankton cell particle sizes that can be grown easily in the laboratory. They found that *E. pacifica* produces multiple broods, a trait long inferred but until now never documented. They also found huge variability in brood sizes and interbrood period, which also differs with geographic location. They have had little success studying brood

periodicity with *T. spinifera*, which they can only get to spawn once in the laboratory. In 2004, a lipofuscin aging study of *E. pacifica* reproductive females was conducted, in cooperation with researchers at the University of Maryland. Animals were reared in captivity at the Newport Laboratory, then samples sent to Maryland to determine the level of lipofuscin in the eyes of known-age animals. The principal objective is to develop calibration curves that can be applied to animals collected in the field. While there is a great deal of variability in the resulting lipofuscin data, used selectively, it is thought to be a useful aging tool in instances when traditional methods are impractical, as with euphausiids.

Peterson also provided a “first cut” rough estimate of an adult *E. pacifica* biomass of ~505,000 mt in the EEZ, based on a review of reported euphausiid densities along the West Coast; assuming an average wet weight of ~0.12 g per adult individual; a average adult density of 3 indiv. m⁻³ (60 indiv. m⁻² if one assumes adults are generally concentrated in in the upper 20 m at night); and assuming the main concentration of adults is centered within 20 nautical miles of the shelf break coast-wide (i.e., total area occupied is ~7.0176 x 10¹⁰ m²). He cautioned that this was an extremely rough estimate made as a springboard for discussion, that abundance is highly variable spatially and temporally, methods and units of abundance are far from standardized, and thus the estimate was based on many assumptions which may or may not be valid.

Scripps Institution of Oceanography and CalCOFI Research

Mark Ohman, Ed Brinton, and Annie Townsend reported that survey and demographic data on euphausiids are available for April/May for southern and central California from CalCOFI collections over the past 50+ years. Less complete time series are available for other times of year. A considerable body of work has been published, including a population biology study of *E. pacifica* (Fish. Bull. 74), and a 2003 paper on variability in annual abundances of California Current krill species during the period 1950-2002 (Deep Sea Res. II vol. 50 no.14-16). The latter provides a valuable baseline of knowledge on natural variability in production. Peaks and valleys in abundances were shown to track extreme La Niña and El Niño episodes, respectively, especially off southern California. Brinton presented examples of euphausiid distribution maps he is preparing for an atlas, which illustrate geographical density distribution patterns for both species over the CalCOFI area for most years 1950-2002. These data showed that distribution and abundance patterns of *T. spinifera* do not always track those of *E. pacifica*, the former being generally less abundant than the latter (and particularly less abundant in 1985). In certain years, *T. spinifera* did not occur at all in the samples. This information will be particularly useful for describing essential habitat for the two species off central and southern California. Although considerable material on the CalCOFI krill data has been published, and all spring samples from 1950 through 2004 have been processed and entered into a data base, still much of it remains to be analyzed.

Ohman described various methods changes in the CalCOFI sampling over the years. From 1949-1977 a 1-m diameter ring net with bridle was used, with December 1977

marking the transition to the 71-cm diameter, 505 μ mesh paired bongo net (a laser optical plankton counter is now affixed to the mouth opening of one bongo, the other net opening is unobstructed). Depth of tow was set at 0-70 m from 1949 through 1950, changed to 0-140m from 1951- 1969 and deepened to 0 – 210 m in 1969, which is the current standard. The move to deeper sampling was prompted by growing U.S. interest in assessing abundance of deepwater ichthyoplankton and stocks such as Pacific hake and the *Sebastes* complex. Brinton noted little apparent effect on the euphausiid sampling over the period of these methods changes; results appeared to be about the same with some minor differences. Currently, 66 stations are sampled and 4 cruises conducted a year; winter-spring being two-ship cruises, one covering north, another south. Total displacement volume is taken; samples are archived at SIO. Funding permits only spring samples to be enumerated for euphausiids. Springtime has shown to be generally representative of annual abundances of the most important krill species. In addition to standard CalCOFI bongo sampling, sampling is conducted with a Manta (neuston) net, and Pairovet sampling is conducted in winter and spring for fish eggs. At the SIO-based California Current Ecosystem Long Term Ecological Research (LTER) site, finer mesh net (202 μ mesh) sampling is also conducted, and ADCP data collected continually to obtain information on zooplankton biomass (M. Ohman, project head). As part of the LTER project, SIO is also planning to use an underwater glider equipped with a 450 KHz Sontek ADP to compare backscatter signal from the glider with results of net sampling.

U.C. Santa Cruz Research

Marinovic and Croll reported on four main krill-related research efforts --- the Wind and Whales Program, Monterey Bay CalCOFI sampling, cooperative midwater trawl sampling on NMFS rockfish recruitment cruises, and whale prey consumption modeling. From 1997-2002, CalCOFI bongo net tows (71 cm diam., 505 μ mesh, deployed 0-210 m) and associated acoustic (EK60 50,122,220 KHz) and hydrographic sampling have been carried out quarterly in Monterey Bay along CalCOFI line 67 (out to station 90). Starting in 2003, biannual tows have been conducted summer and fall along both lines 67 and 60, and Tucker trawls are deployed 0-210 m. All euphausiid samples collected over the past 10 years have been processed (krill identification, measuring and staging), along with hydroacoustic data on zooplankton backscatter strength, including krill. They now have a ten-year series on recruitment, growth (LF analyses), and zooplankton backscatter data, from which they are attempting to tease out krill backscatter visually and using Tucker trawls to ground-truth the acoustic data. Marinovic is also looking at midwater trawl catches of large krill collected aboard NMFS/SWFSC Santa Cruz annual juvenile groundfish trawl surveys between Pt. Pinos and Pt. Reyes, to develop a relative abundance index for large adults of both krill species. These surveys have recently expanded to include the southern California Bight, and areas north to Arcata, CA. Euphausiids are also collected as part of the Wind and Whales Program where surveys are conducted in Monterey Bay out to 10 nm from shore for cetaceans, seabirds, zooplankton, and most recently, associated schooling fishes. Hydrographic, oceanographic and acoustic data are also collected on these cruises They are evaluating backscatter data to identify krill “hotspots” or areas of high concentrations.

In addition to the ship sampling, MBARI's M1 Mooring deployed in Monterey Bay, equipped with downward-looking hydroacoustics (freq 120 KHz), records acoustic backscatter signals for three minutes of every hour at a location in the bay known to periodically have high concentrations of krill. Finally, Don Croll has been developing bioenergetics models to obtain information on whale feeding and nutrient demands.

NMFS/SWFSC Protected Resources Research

Lisa Ballance (NMFS, SWFSC, La Jolla) reported that Pacific Coast EEZ marine mammal surveys (ORCAWALE '96 and 2001, CSCAPE 2005) are conducted every 3-4 years by the Center's Protected Species Division. Cruise duration is about 120 sea days, and the coverage is throughout the EEZ out to about 300 nm from shore. CalCOFI-type net tows (71 cm Bongos, 505 μ mesh; obliquely towed 0-200m) and 24-hr continuous acoustic (EK 500 at 38,120,200kHz) and ADCP (150 kHz)sampling are conducted during these cruises, as part of the division's research on the physical and biological habitat, prey, predators, and competitors of marine mammals and other protected species. An oblique bongo tow is made at night, although to date no one has been looking at the euphausiid composition (except during the 1995-1996 Whale Habitat and Prey Study off southern California). Two oceo-techs are assigned to each survey ship. During this year's cruise, in addition to sampling the entire EEZ on a relatively coarse scale, additional fine-scale zooplankton sampling will be conducted in Monterey Bay and the Gulf of the Farallones through cooperation and support of the National Marine Sanctuaries Program. Although only limited data analysis has been carried out using the acoustic backscattering data, Paul Fiedler (SWFSC, PRD, La Jolla) is planning more comprehensive analyses of these data this year. So far there are no current plans for working up the of zooplankton net collections. Ballance suggested that there may be a potential opportunity for adding more comprehensive and targeted work on krill during these cruises, since much of the nighttime is open for other types of survey work. But certain additional resources would have to be obtained for this additional work, and bunk spaces on the ships are limited.

Ecosystem modeling

John Field (NMFS,SWFSC Santa Cruz) reported on work with euphausiids and modeling the NE Pacific Ecosystem (north of Cape Mendocino) in collaboration with Robert Francis, Kerim Aydin, and Sarah Gaichas, collaborators involved in similar work in the Gulf of Alaska and Bering Sea. They've constructed a model of ecosystem consumption and production rates for the area between Cape Mendocino and Cape Flattery, with emphasis on groundfish. Field said the models help evaluate, visualize and manipulate systems, although often there are serious data limitations and accompanying oversimplifications (as in single-species models), so are limited in their predictive value. Nonetheless, with cautious interpretation and adequate definition of the models limits, results can be useful to inform or guide management. The modeling framework uses Ecopath with Ecosim and a static, mass-balance snapshot of energy flow through the system where the production of a prey species is more or less equal to the

consumption of that species by predation. Ecosim is a dynamic model that turns those properties into a series of rates that are again consumption-based, and the main factors that change abundance of a species are food availability and predation. Top-down estimates of consumption requirements for upper trophic level predators are derived and calibrated to the extent possible by existing assessments of plankton and nektonic standing stocks and productivity. In the model, Field et al. estimate krill compose >10% of the diet by volume for 24 species groups and >50% of the diet for 9 species groups in the area between Cape Mendocino and Cape Flattery. Pacific hake and certain groundfishes (e.g., Pacific Ocean perch, canary rockfish, etc.) are particularly krill-dependent in the northern part of the EEZ. Baleen whales accounted for relatively small portion of total krill consumption in the presented model, but Field pointed out that these runs were based on 1960s predator abundance data when whales were not as abundant as they are now in the EEZ. He noted that in the late 1990s, euphausiids in hake stomachs samples declined considerably, concurrent with a substantial increase in hake cannibalism. Hake was subsequently determined to be overfished a few years later.

Field also described an approach for using modeling as a tool in evaluating ecosystem impacts such as harvest, one that also helps deal with parameter uncertainty. He assigned different levels of data quality based on levels of parameter uncertainty, and then drew random ecosystems from uniform distributions around the base parameters set by these uncertainty values, so that standing biomass values as well as rates were attributed to some level of uncertainty. A basic thermodynamic hypothesis was applied that said everything had to have enough to eat, and that no species would go extinct or increase or decrease 1000 times or more over simulated runs of 30 years. The resulting parameter sets were kept as the most plausible set for the ecosystem, which was then perturbed. For the meeting, Field did some preliminary simulations of a krill harvest of 300,000 mt/yr (roughly equivalent to the scale of the Pacific hake fishery) and the potential impact on krill stocks and krill predators. The response to fishing was an average decline of 5% in krill stocks (with a range of roughly 3 to 14%), and an average decline of 2 to 4% (range 1 to 8%) in most commercially important predators of krill (coastal pelagics, hake and rockfish). However, the krill biomass suggested by the model was as much as an order of magnitude greater than the “first-pass” biomass estimates from Peterson described earlier, suggesting that the model may underestimate potential impact to predators. He concluded that this type of approach could help account for uncertainty in mass balance parameters as well as dynamic parameters, particularly with regard to the direction and general magnitude of impacts for many species groups, despite being limited by the quality of input data. Citing Walters et al. (2005), he pointed out that other multispecies models have identified potential ecosystem impacts when single species management strategies have been applied to all species in an ecosystem, particularly forage species, and that such models tend to demonstrate that there is value in protecting forage species.

Field was asked whether the North Pacific model could be expanded to the entire EEZ, or comparatively, for the area south of Cape Mendocino. He suggested it would take about six months to one year of work. He could employ a “bottom up” or middle-tier (vulnerability) approach, perhaps using initial “first cut” krill biomass estimates

provided by Peterson at the meeting. High frequency and geographic variability would also be critical, and it was not yet clear how to deal with these factors. The effects of oceanographic characteristics were hard to determine, and impacts on growth and age structure could not be determined. The role or impacts of gyres and offshore transport mechanisms would also be difficult to incorporate into a model, and it is still uncertain whether these mechanisms do indeed affect the maintenance of a healthy gene pool for the stock or stocks. Also, Field said that even if a sustainable yield estimate could be obtained through modeling, more emphasis should probably be on protecting 'hot spots' of abundance, and only allowing harvest elsewhere (if at all).

Point Reyes Bird Observatory Euphausiid-Seabird Research

Jaime Jahncke and Ben Saenz presented information on PRBO's seabird-krill research. The primary goal of the research is to identify the persistence of predator-prey aggregations and potential areas of high trophic transfer, and to provide a scientific basis for marine reserve design. Seven research cruises were conducted in 2004 and three in 2005. The survey grid consists of 7 east-west transect lines that cover most of the Cordell Bank and Farallons Sanctuary boundaries, with an additional two short transect lines through the north and southeast Farallon Islands. Vertical tows (71 cm diam bongo net, 505 μ mesh) and continuous zooplankton backscatter (SIMRAD ER60--38, 120, and 200 KHz) data and oceanographic information are collected during the day, sampling 0-50 m in the water column. Targeted Tucker Trawls are also made along the shelf break where the echosounder indicates concentrations of zooplankton. Counts of birds and marine mammals are made along the transect lines. Echosounder data have so far been only used for information on backscatter strength, but this summer Saenz hopes to get some preliminary biomass estimates from these data. One of the many drawbacks of day sampling for euphausiids is that the echosounder may be missing krill aggregated close to the seafloor, to where much of the population is thought to descend during the day. Tucker trawl sampling have shown extreme patchiness and demographic variation even along the same transect lines, which will make interpretation of the backscatter data that much more difficult. The deeper the thermocline, the deeper krill appear to be distributed, though these two species appear to be more associated with bathymetric features such as the shelf break or a particular depth contour, than with the thermocline itself.

Birds are often associated with krill patches; 80% of the Cassin's Auklet's diet consists of euphausiids, both *E. pacifica* (early in breeding season) and *T. spinifera* (late in breeding season). The species appears to have wide flexibility in onset and completion of breeding, although it generally lays eggs in late May and chicks hatch in mid June (but can begin breeding as early as January). In May, high densities of auklets are usually seen at upwelling fronts (although not this anomalous year in May 2005). Along these fronts they aggregate close to the shelf break, also over Cordell Bank and recently upwelled water. This year (2005) there was warmer than normal water in May, which was coincident with a die-off of Common Murres, which may have been a "food limited" event.

Discussions on Krill Distribution and Essential Habitat

Although distribution based on past systematic research sampling indicates a broad distribution throughout the US. West Coast Exclusive Economic Zone (EEZ), Brinton remarked that based on his CalCOFI distributional data, it appears that the bulk of the *E. pacifica* seems closely linked to more inshore waters within the inner half of the EEZ, although the distribution within the southern California Bight is more diffuse, even extending beyond the Santa Rosa-Cortez Ridge. Peterson indicated that off Oregon adult euphausiids (the most likely life phase to be targeted) appear to be concentrated in a relatively narrow band within 20 nautical miles of the shelf break. *T. spinifera* appears to be most abundant of the two species inshore along the outer edge of the continental shelf, and along the shelf break, but it, too, can occur offshore.

The question was raised whether concentrations of krill larvae in gyres would essentially be lost to the stock and would be transported to areas that would not provide suitable habitat for recruitment to the stock or future production. One participant noted that there could be a reverse drift which might return the larvae to the stock as juveniles or subadults; another suggested that transport of some individuals to the south and west via upwelling filaments or eddies may help to interconnect regional subpopulations and enhance gene flow among isolated stocks. The extent to which populations are advected depends on oceanographic conditions, which may vary considerably on areal and temporal scales, and vulnerability of larvae in the upper water column. It was noted that there are definitely geographically identifiable areas where krill tend to be concentrated, where bathymetric and/or hydrographic features no doubt help to maintain local populations in optimum food-rich habitat in these locations (e.g., Monterey Bay, the Gulf of the Farallons, and southern California Channel Islands). It appears fairly well documented that the West Coast NOAA Marine Sanctuaries have exceptionally high krill densities and/or major concentrations of krill predators.

In addition to wide variability in abundance, significant year-to-year variability in north/south distribution occurs. While not fully predictable, in general, distribution of *T. spinifera* is thought to shift northward during El Niño years. It more commonly swarms at or near the surface, and is more coastal in the eastern North Pacific than *E. pacifica*. Also, *T. spinifera* is very efficient at avoiding nets, especially the larger juveniles and adults, such that they are hard to detect even in some instances when present. The differences in amount of survey work done in different areas may account for the apparent variability in distribution along the coast; and it could be that krill concentrations occur but have not been sampled sufficiently in some of the more northerly areas of the U.S. West Coast EEZ where sampling has not been as intense.

There was considerable discussion and individual opinions offered about what might constitute “Essential Fish Habitat” for krill. Certainly shelf break, bank, canyon and island features bathed by rich upwelled water were important, but some participants felt that offshore jets and filaments (at least areas where these consistently formed) were also important as conduits for Ekman transport of larvae. Some participants suggested

that from Cape Blanco north, the species are more segregated than they are to the south, where they tend to overlap more in their respective distributions. The question was raised as to whether all areas of “presence” are equally identifiable as “essential”? This is not clear and more study is needed.

Krill Importance in Food Web

The importance of krill in the food web seems fairly clear, judging from the reported incidence of both species in the diet of a wide variety of California Current marine species (fish, cetaceans, seabirds), although accurate quantitative estimates of predator requirements are needed. Good documentation exists on whale feeding on krill off the coast; less documentation on the consumption requirements of other species. With regard to fishery resources, krill seem to be very important to hake, spiny dogfish, rockfish and herring in the north, and to salmon, hake, rockfish and squid along the central coast. Seabird predators such as Cassin’s Auklet and Sooty Shearwater depend heavily on krill. Krill may also be a major predator on fish eggs and larvae.

Life History Characteristics

The life history characteristics of krill are quite unusual and complex. Leah Feinberg and Bill Peterson remarked that larval and juvenile life stages and molting patterns are not often predictable, which complicates the study of age and growth patterns. Size at age ratios vary within a cohort, as do sex ratios, at least for animals in captivity. There is both positive and negative growth observed in both winter and spring-summer sampling periods. Both species are known to shrink in size in winter when food is scarce, and *E. pacifica* has also been observed to also shrink in summer during the reproductive season. They can also regressively lose their sexual characteristics. There is a huge range of ages at any given size---females at a given age can vary in size as much as 10 mm. They can also skip developmental stages or molt several times while remaining at the same stage. These characteristics can have a big impact on field calculations. A manuscript on this subject is currently *in press*.

Individual Suggestions re Assessment Approaches

Marinovic suggested that it might be possible to develop an “index” of recruitment by sampling larvae or juvenile krill. Some participants thought this might be a reliable index to use in assessing potential yield, though it was not clear how to keep things geographically/spatially focused and whether the parental stock–larval recruitment relationship was strong enough. It was noted that, in productive times, the populations may “explode” and expand their distributions, while in less favorable times, the stock(s) might retreat to more concentrated grounds. Females seem to produce very different brood sizes over time, with differing frequency; and it is difficult to equate eggs to adult abundances with any confidence. There is also a question of standardizing the variables. Nonetheless, most participants indicated that there was a relatively clear inverse correlation of abundance with warm water/El Nino conditions, at least in waters where

krill have historically been found. It was noted that during this non-El Niño year 2005, krill spring-early summer production off California plummeted as in extreme El Niño years, breaking this pattern, but certain El Niño-like conditions, such as weak or non-existent coastal upwelling, deepening of the thermocline and anomalously warm water temperatures in certain localized areas were also observed this year.

Ohman concluded that distribution and abundance (at specific time/area points), and production and variability of abundance over time, space and oceanographic conditions may be tractable; but setting an absolute allowable catch based on MSY seems beyond our capability at this time. Northwest researchers may be able to develop estimates of production and variability in their sampling area, but this is probably not feasible for the CalCOFI area at this time; since cruise work time is already tightly scheduled with existing tasks. Many participants agreed it would be difficult to develop a point MSY estimate, since seasonal and inter-annual variability is so high. Peterson suggested it might be possible to approach MSY as a range, maybe by sub areas along the coast. It may be more feasible to look at trends rather than absolutes, especially for some areas such as off Oregon coast. Concerning standing stock estimates, day and night and seasonal values obtained from net sampling change dramatically, although it could be possibly to focus on times of major spawning and at night only for the different species. It might also be feasible to focus on the shelf break areas where the highest densities of adults appear to congregate. Participants noted the high risk of error given the short life cycle, high variability in time and space, differing degrees of catchability, etc. Also, more standardization and better calibration is needed in interpreting bioacoustic data for use in conjunction with net sampling. Any standing stock estimates must also accommodate advective losses and other sources of mortality, including effects of El Nino/La Nina conditions, and must also incorporate the different characteristics of the two species, which do not behave the same or co-occur in time and space. Finally, existing sampling methods may not be obtaining truly representative samples of the two populations, because of considerable large and small-scale patchiness. Ohman pointed out that to resolve abundances of the two species we would need to substantially increase sampling effort, which would probably require usage of optical scanning equipment such as ZOOSCAN to process samples, even if we have to sacrifice some degree of taxonomic detail.

Some meeting participants also noted that even if a yield estimate could be calculated, fishermen would likely be more efficient at finding krill than scientific surveys, and will also likely encounter other animals in the harvest area, creating bycatch or protected species interactions problems. It may be much more important to limit harvests in special geographic areas to avoid this bycatch and interactions with commercially and recreational important fish such as salmon, and feeding whales and krill-dependent seabirds.

Hewitt suggested that the Council might choose to take a probabilistic approach for determining the likelihood of safe harvest instead of estimating the biomass that could be taken sustainably, since there is a large range of uncertainty concerning input parameters. The model would estimate the probability of a highly productive krill year

occurring (e.g. one in ten years), in which a safe harvest of either or both species might be made. Certain very cool, biologically rich oceanographic years might produce an adequate surplus production (beyond predator and system needs) to support a limited amount of removals, but presumably these events (with probabilities greater than zero), would be relatively rare. The likelihood of this fishable surplus occurring could be estimated by using probability density functions for biomass, productivity, and predator demand and a yield equation incorporating krill yield, krill biomass, instantaneous krill growth rate, predation needs of predators, and natural mortality other than predator removals. Probability distributions could be specified for each to allow for uncertainty. Starting values or suggested bounds for these parameters to initiate computer runs needs to be obtained (including suggestions from meeting participants), and work would be needed to run the Monte Carlo simulations to obtain the PDFs, pending assignment of resources. Hewitt pointed out that with this approach, the greater the uncertainty about a parameter (e.g., growth, productivity or predator demand), the broader the probability distribution on the output side in terms of allowable catch or whatever one is trying to optimize for a management approach. He also pointed out that before developing any harvest strategies, it will be important to specify objectives, e.g., probability that spawning biomass will fall below some threshold value and a guarantee of rebuilding to a size certain in a short period to ensure that forage value would not be jeopardized. Potential data sources for bounding estimates for this model might include: Mortality (*M*)-*E. pacifica* (Brinton 1976); Siegel and Nicol (2000) citing Jarre-Teichmann and data from Brinton; krill biomass (*K*) - M. Ohman, E. Brinton, A. Townsend, SIO, La Jolla, CA; W.T. Peterson NMFS, NWFSC and Leah Feinberg, Oregon State University, Newport, OR; Productivity (*r*) - *E. pacifica* (Brinton 1976); Ross 1982; Predation demand (*P*) - John Field, NMFS, Santa Cruz, Ca; Don Croll, UC Santa Cruz and others.

List of Suggested Needs Proposed by Participants:

- A. Standardization of collecting and processing methods so net collection and acoustic data are comparable and can be combined for different geographic areas. This includes:
- A meeting among a team of krill bioacoustic experts to decide on and develop standardized methodology for calibrating, measuring, surveying and interpreting zooplankton acoustic backscatter for the primary purpose of estimating distribution and biomass of both species in the West Coast EEZ, and integrating with net collection data.
 - Standardizing krill body length to weight/carbon conversion factors by krill size group is needed. *E. pacifica* length-carbon relationships available from SIO especially for *E. pacifica* and some data are available for *T. spinifera* from Patricia Summers' 1993 Master's thesis, Univ. Victoria, B.C. Canada.

- Expert agreement as to the spatial bounds of primary krill habitat from which density and subsequent biomass conversions can be expanded to obtain initial estimates of biomass of *E. pacifica* and *T. spinifera* standing stocks.
- Analyses (and scientific agreement) to determine which krill life stage of what species might best serve as a proxy of adult abundance in future sampling.
- Lab metabolic experiments to refine estimates of productivity, growth and turnover rates.

B. Single-species probabilistic modeling to determine the likelihood of a fishable krill surplus occurring, using probability density functions for biomass, productivity, and predator demand and a yield equation incorporating krill yield, krill biomass, instantaneous krill growth rate, consumption needs of predators, and natural mortality other than predator removals.

- Bounding estimates for yield model input parameters for Monte Carlo analysis for determining the likelihood of a harvestable krill surplus production occurring (beyond predator needs and population stability). Need 1) range of estimates krill biomass, instantaneous krill growth rate, predation needs of predators, and natural mortality, and 2) funding, staff, and time to coordinate and run model simulations.

C. Expansion of the Eastern North Pacific Ecosystem Ecopath/Ecosim Model to include the entire West Coast EEZ, and a perturbation version of this model to estimate effects of various harvest levels.

- More reliable data on predator abundance needed. A problem with existing “Top-down” models is that the high demand estimated for krill predators often does not agree well with available estimates of krill biomass, and this may be due to overestimates of predator standing stocks.
- ‘Bottom-up’ runs (based on rough estimates of adult krill biomass from observed krill densities) are needed to compare with ‘top down’ runs.
- SWFSC assignment of work (funding, staff time 6 mo-1 yr) to assemble additional data and run models needed.

APPENDIX B

Information on ESA Listed Species Which May Be Affected By
Potential Krill Fisheries in the U.S. West Coast EEZ.

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Protected species listed under the ESA and MMPA that are known to feed on one or both of the California Current species *Thysanoessa spinifera* and *Euphausia pacifica*, or might be affected by any potential krill harvesting operations include :

A. Marine Mammals

1. Southern Sea Otter (*Enhydra lutris nereis*). The southern (California) sea otter was listed as threatened in 1977 under the Endangered Species Act of 1973, as amended. This species generally forages over rocky or soft-sediment ocean bottom, primarily in water depths 82 ft deep or less within 1.2 miles of shore. The population historically ranged from Northern California and Oregon south to Punta Abreojus, Baja California, Mexico. The southern sea otter population now contains about 2,000 individuals and ranges between Half Moon Bay south to Gaviota, California. Approximately 14-20 otters, including pups, are at San Nicolas Island as a result of translocation efforts to establish an experimental population. Estimates of carrying capacity in California range between 13,500 to 30,000 individuals. The population is recognized as depleted pursuant to the Marine Mammal Protection Act. Reduced range and population size, vulnerability to oil spills, and the oil spill risk from coastal tanker traffic were the primary reasons for the threatened status. Incidental drowning in set gill nets and trammel nets was once considered a problem, but since the early 1990s, State restrictions on inshore netting have removed these operations from otter areas. It is possible that krill fishing operations could take this species, but this may depend on the method employed, and would have to be carefully reviewed if any fishery should develop.

2. Humpback whale (*Megaptera novaeangliae*). The humpback whale has been listed as an endangered species under the United States Endangered Species Act (ESA) since 1970. It obtains food by straining krill and schools of small fish with its baleen, and is one of the major predator species seen in association with krill swarms off California. The estimated daily prey biomass requirement per whale has been estimated by Croll et al (in press) to be 532 kg day⁻¹. The California feeding population is thought to consist of about 1,000 animals, and the population appears to be growing at about eight percent per year. In California, Oregon, and Washington, most survey sightings occur in the inshore third of the EEZ. During their seasonal migrations, humpback whales may frequently be seen along the California coast from April through November. Some individuals appear to remain in California year-round. In the Gulf of the Farallones, humpbacks may be observed feeding during May and November. Off southern California, humpbacks often migrate along submarine ridges (e.g., Santa Rosa-Cortez Ridge) and occasionally enter the coastal waters of the San Pedro and Santa Barbara Channels. There appear to be multiple populations of humpback whales in the North Pacific (Carretta et al. 2002; Forney et al. 2000). Aerial,

vessel and photo-identification surveys and genetic analyses indicate that within the U.S. West Coast and Alaska EEZ, there are at least three relatively separate populations that migrate between their respective summer/fall feeding areas and winter/spring calving and mating areas, with some limited interchange among certain breeding areas. The stock that primarily occurs off the U.S. West Coast spends winter/spring in coastal Central America and Mexico and migrates to off California, Oregon and Washington in summer and fall. Another winter-spring population that originates in Japan, also migrates to areas west of Kodiak, Alaska in summer/fall. Overall, the eastern Pacific stock appears to be increasing in abundance. The Alaska feeding population migrates to its breeding grounds in Hawaii and offshore islands in Mexico. Since these whales congregate in krill swarming areas for feeding, the potential for interaction with any potential krill fishing operation exists, but the extent to which these interactions will have adverse impacts is not known at this time, but should be considered should a krill fishing activity be developed or considered in the future.

3. Blue whale (*Balaenoptera musculus*). The blue whale has been listed as endangered under the ESA since 1970. The majority of the eastern north Pacific population spends the summer on feeding grounds between central California, the Gulf of Alaska and the Aleutian Islands. Like all baleen whales, the blue whale seasonally migrates to lower latitudes in the winter to calve and breed. Historically, the North Pacific population may have been comprised of over 5,000 individuals before its severe depletion by modern whaling operations. An estimated 1,700 to 1,900 blue whales currently inhabit the eastern North Pacific Ocean. It is estimated that the California feeding population is comprised of at least 1,700 whales, and perhaps as many as 2,000-2,250 blue whales occur off California (Barlow 1994, Calambokidis and Steiger 1995). Estimated prey biomass requirement per whale in the North Pacific is 1,120 kg day⁻¹ (Croll et al in press). Others estimate a blue whale can consume about 40 million individual euphausiids daily, amounting to a total weight of 3,600 kg. Blue whales may move along the entire California coastline during fall searching for euphausiid prey. Euphausiid swarms are often seen in great concentrations in Monterey Bay, due in part to physical mechanisms (e.g. upwelling, fronts, canyons, vertical walls) which may concentrate euphausiid prey (Harvey 1978, Schoenherr 1991). Blues have been observed feeding on dense swarms of euphausiids (dominated by either *Thysanoessa spinifera* or *Euphausia pacifica*) near Monterey (Schoenherr 1988, 1991) and the Farallones between July and October (Rice 1977, Kieckhefer 1995), and over deep submarine canyons in southern California and around the Santa Barbara Channel Islands (Fieldler et al). No information exists on the rate of growth of blue whale populations in the Pacific. Migratory routes generally follow the continental shelf and slope, but blue whales are occasionally found in deep oceanic zones and shallow inshore areas. Blue whales are usually seen off the California coast traveling alone or in pairs, from May to January, although they have been observed in every month of the year. There are no reports of fishery-related mortality or serious injury in any of the world-wide blue whale stocks, although it is possible that some may carry away gear undetected. Since

these whales congregate in krill swarming areas, the potential for interaction with any potential krill fishing operation exists, but the extent to which these interactions will have adverse impacts is not known at this time, but should be considered should a krill fishing activity be developed or authorized in the future.

4. Fin whale (*Balaenoptera physalus*). This species has been listed as endangered under the ESA since 1970. It is a relatively common, large cetacean occurring off the U.S. West Coast. The species is distributed throughout the world's oceans, but little is known of its seasonal movements in the North Pacific. The North Pacific population reportedly winters between central California southward to 20° N latitude and summers from Baja California to the Chukchi Sea. This species uses its baleen to filter krill, capelin, sand lance, squid, herring, and lanternfish from the water. Approximately 1,000 fin whales are estimated to be off California. Its estimated prey biomass requirement in the North Pacific is 901 kg day⁻¹ (Croll et al in press). There is some indication that fin whales have increased in abundance in California coastal waters, but the trends are not statistically significant. Fin whales are a deep-diving, temperate coastal species and have been observed in every month of the year in California, with an increase in abundance during summer. They tend to be distributed further offshore than humpback or grey whales, but are both a nearshore and offshore species, sometimes occurring in water as shallow as 30 meters. Underwater sills or ledges may be an important feature of fin whale feeding habitat, as are areas of upwelling and interfaces between mixed and stratified waters. Though not as frequently observed in association with inshore krill swarms as humpback and blue whales, the potential for interaction with any proposed krill fishing activity exists, but the extent to which these interactions will have adverse impacts is not known at this time.

5. Sperm whale (*Physeter macrocephalus*). The sperm whale has been listed as an endangered species under the ESA since 1970. It is widely distributed across the entire North Pacific, occurring off all three Pacific Coast states, and is found year-round in California waters. Unlike the other large whales, the sperm whale does not feed with baleen (and on krill), but is a toothed whale. It is the largest of the toothed cetaceans with males reaching a length of 60 feet and females 40 feet. Sperm whales are noted for their ability to make deep dives, which can last up to an hour and a half and can be as deep as two miles below the surface. They feed mainly on squid, including the giant squid. Abundance appears to be fairly stable with approximately 1,000 to 1,200 sperm whales estimated to be off the coast of California (Forney et al. 2000). They reach peaks in abundance from April through mid-June and from the end of August through mid-November. Their distribution off our coast appears to be continuous with animals observed farther west out to Hawaii. Sperm whales are thought to shift poleward in spring and summer, returning to temperate and tropical portions of their range in fall. Their habitat may be as deep as 1,000 m or more. Sperm whales usually live offshore, but may occur close to coasts where water depths exceed 200 m. They are most

common in submarine canyons at the edges of the continental shelf, but also occur in mid-ocean. The sperm whale is known to interact with longline gear, and may actively seek out vessels and gear in its search for food. In 1997, the first entanglement of a sperm whale in Alaska's longline fishery was recorded, although the whale was not seriously injured. Observers aboard Alaska sablefish and Pacific halibut longline vessels have documented sperm whales feeding on longline-caught fish in the Gulf of Alaska (Perry et al. 1999 citing Hill and Mitchell). Similar behavior has been reported in longline fisheries off South America, where sperm whales have become entangled in gear, have been observed feeding on fish caught with the gear, and have been reported following vessels for days (ibid.). Nonetheless this species may be least likely of the large whales to be affected by any potential krill fishing operation unless perhaps drawn to squid and other larger prey attracted by krill swarms.

6. Northern Right Whale (*Eubalaena glacialis*). Right whales are listed as endangered under the ESA. Historically, in addition to occurring in the southern hemisphere, right whales ranged across the entire North Pacific north of 35° N latitude (Perry et al. 1999). These whales were heavily fished by the whaling industry until legally protected in 1935. After over 65 years of protection, sightings are still scarce and geographically scattered in the North Pacific. Since 1998, the North Pacific stock has been divided into eastern and western management units. Right whales prefer shallow coastal waters, but their distribution is strongly correlated with the distribution of their zooplankton prey, particularly copepods in the northern hemisphere. In both hemispheres, they have been observed in low latitudes and nearshore waters during winter, where calving takes place, then tend to migrate to higher latitudes in summer. There are no data on trends in abundance, but the paucity of sightings in the North Pacific strongly suggests there has been little or no growth in this population (Perry et al. 1999). Although there have been sightings in recent years, this may only be linked to increased survey effort. The only population estimate from the North Pacific is for the Okhotsk Sea, a northern right whale summering area. Preliminary data have indicated this population likely includes only a few hundred animals (Perry et al. 1999 citing Brownell). A lone right whale was sighted off San Clemente Island, CA in 1992, which was only the twelfth reliable right whale sighting of this century in the eastern North Pacific. Other sightings have been made recently in the Bering Sea and elsewhere, but the species is still considered extremely rare (Carretta et al. 1994). Before they were heavily exploited by commercial whalers, northern hemisphere concentrations of northern right whale were found off Alaska with sightings reported as far south as central Baja California. Off the coasts of Oregon, Washington and California, there have been extremely few sightings of this species since the mid 1950s. Data are scant for fisheries interactions with North Pacific right whales. Although there are two fishery-related mortalities reported from Russian waters, fishery-related interactions are not known to be a problem in the eastern North Pacific. In the Atlantic, gillnets, lobster pots, seines, longlines and fish weirs are reportedly the main gear types that are known to entangle right whales, so it is possible that seine net krill fishing

operations might entangle an animal, . Vessel strike-related mortality rates for stocks in the North Pacific are unknown (Perry et al. 1999).

7. Sei Whale (*Balaenoptera borealis*). These baleen whales are distributed far out to sea in temperate regions and do not appear to be associated with coastal features. The sei whale is listed as endangered under the ESA and rare in West Coast EEZ waters. Sei whales feed near the surface of the ocean, swimming on their sides through swarms of prey. They have a diverse diet, including many species of fish species and squid, although the primary prey appears to be copepods. They are often found in the same area as other copepod feeding whales, including right whales. Unlike other rorqual whales (those with pleats and a dorsal fin), sei whales will sometimes feed by skimming along, mouths opened, as they feed on plankton. They are among the fastest of cetaceans, swimming at speeds of up to 50 kilometers per hour. They are found predominantly in temperate oceanic waters, and in the eastern Pacific they occur in summer from central California north through the entire Gulf of Alaska. At least some of those off California are thought to migrate to the waters off British Columbia. They reportedly winter from at least Piedras Blancas, CA south to near the Revillagigedos Islands off Mexico (Leatherwood and Reeves 1983). There are no data on trends in sei whale abundance in the eastern North Pacific (Forney et al. 2000). Although the population in the North Pacific is thought to have grown since given protected status in 1976, the possible effects of continued take elsewhere in the Pacific and incidental ship strikes and net mortality are unknown (Forney et al. 2000). Like the right whale, it is possible that seine net krill fishing operations might entangle an animal, but this species is generally not attracted to coastal krill swarms off our coast and thus is not as likely as the blue and humpback whale to interact with or compete with krill fishing operations in pursuit of euphausiid swarms.

8. Guadalupe fur seal (*Arctocephalus townsendi*). This seal is a protected species in California and the ESA lists it as a threatened species. The population has been estimated to be growing at approximately 13.7 % per year. The Guadalupe fur seal has a limited range along the Pacific Coast, extending from San Nicolas Island off southern California to Guadalupe Island off Baja California. Before the sealers of the nineteenth century nearly exterminated it, the Guadalupe fur seal was common on the Farallon Islands off the central California coast and south to the Mexican coast. The species was extirpated from California waters by 1825, with commercial sealing continuing in Mexican waters through 1894. After that, it was thought to be extinct, until a lone male was found on San Nicolas Island in the 1950s. An expedition from Scripps Institution of Oceanography discovered a small breeding colony on Guadalupe Island in 1954. Current populations are thought to number 200-500, mostly on islands off the Mexican coast. Its habit of keeping to sea caves may have saved it from extinction. These seals now primarily breed and pup at Isla Guadalupe, Mexico. In our region, a few Guadalupe fur seals are known to inhabit southern California sea lion rookeries in the Channel Islands. It is possible that krill fishing operations could cause incidental mortality of Guadalupe fur seals, but there have been no reports of

mortalities or injuries of pinnipeds in krill net fisheries. (check) Juvenile female Guadalupe fur seals have stranded in central and northern California with net abrasions around the neck, fish hooks and monofilament line, and polyfilament string (Fourney et al. 2000 citing Hanni et al. 1997).

9. Steller Sea Lion (*Eumetopias jubatus*). This species, listed as endangered, ranges along the North Pacific Ocean rim, from northern Japan, to a centered abundance and distribution in the Gulf of Alaska and the Aleutian Islands, south to California, with the southernmost rookery being Año Nuevo Island (37° N latitude). Steller sea lions are not known to migrate, but they do disperse widely during the breeding season. Males breeding in California appear to spend the non-breeding months (September - April) in Alaska and British Columbia. Steller sea lion numbers in California, especially southern and central California, have declined significantly, from 5,000-7,000 non-pups from 1927-1947, to 1,500-2,000 non-pups between 1980-1998. While overall counts of non-pups in northern California and Oregon have been relatively stable since the 1980s, counts of non-pups in Southeast Alaska and British Columbia have increased by an average of 5.9% (1979-97) and 2.8% (1971-98), respectively. Steller sea lions have been reclassified into two separate stocks within U.S. waters: an eastern U.S. stock, which includes animals east of Cape Suckling, Alaska (144° W longitude), and a western U.S. stock, which includes animals at and west of Cape Suckling. The western U.S. stock is considered endangered and the eastern stock is threatened on the ESA list. Steller sea lions are highly gregarious on land and use the same sites for breeding, pupping, and resting year after year. The most well known Steller sea lion habitats are rookeries, where adult animals gather to breed and give birth from late May to early July. Rookeries and haulouts are usually located on relatively remote islands where access by predators is limited. Steller sea lions prey primarily upon schooling fishes, such as pollock and herring, as well as invertebrates, such as squid and octopus. They can be found throughout the North Pacific Ocean from the Kuril Islands and Okhotsk Sea, through the Aleutian Islands and Bering Sea, and south along the North American coast to central California. About 70% of the worldwide Steller sea lion population resides in Alaska. Of the listed species that occur in the HMS fishing area, the Stellar sea lion is the only for which Critical Habitat has officially been designated. This habitat includes the area 0.9 km above the areas historically occupied by the species at each major rookery in California and Oregon, measured vertically from sea level. Also, an aquatic zone that extends 0.9 km seaward in State or Federally managed waters from the baseline or base point of each major rookery in California and Oregon. These rookeries are those at Pyramid Rock on Rogue Reef and Long Brown Rock and Seal Rock on Orford Reef in Oregon; and Ano Nuevo Island, Southeast Farallon Island, Sugarloaf Island and Cape Mendocino in California. Like other pinnipeds, this species has been vulnerable to set net and drift gillnet fishery in the past and may possibly be vulnerable to krill seine operations, especially if drawn to krill swarms in pursuit of herring or other fish prey feeding on euphausiid aggregations outside its protected zones.

B. Salmonids

Pacific salmonids in their oceanic habitat (including juvenile stages) are known to depend heavily on *T. spinifera* and *E. pacifica* for food and to seek out dense swarms of these species. They would likely compete with, as well as be vulnerable to incidental catch in, any net fishery targeting dense krill swarms within the U.S. West Coast EEZ.

1. Coho Salmon (*Oncorhynchus kisutch*). Three Evolutionarily Significant Units (ESUs) of coho are listed as threatened--Southern Oregon/Northern California Coasts, Oregon Coast ESU (Threatened), and Central California ESU. Coho spend approximately the first half of their life cycle rearing in streams and small freshwater tributaries. The remainder of the life cycle is spent foraging in estuarine and marine waters of the Pacific Ocean prior to returning to their stream of origin to spawn and die. An estimated ten percent of California's threatened coho salmon population feed in the outer Gulf of the Farallons Marine Sanctuary alone where they feed heavily on euphausiid swarms during the ocean phase of their life history before returning to spawn in Lagunitas Creek and its tributaries. Most adults are three-year-old fish, however, some precocious males known as "jacks" return as two-year-old spawners. *Ocean Habitat*: Coded-wire and high-seas tag data for Washington and Oregon suggest that oceanic migration for these coho stocks can extend as far south and west as 43° N latitude and 175° E longitude around the Emperor Sea Mounts, believed to be an area of high prey abundance. While juvenile and maturing coho are found in the open north Pacific, the highest concentrations appear to be found in more productive waters of the continental shelf within 60 km of the coast. Coho salmon have been occasionally reported off the coast of southern California near the Mexican border

2. Chinook Salmon (*O. tshawytscha*). Nine chinook salmon ESUs are identified as either endangered or threatened. These include Sacramento River Winter-run (Endangered), Snake River Fall-run (Threatened), Snake River Spring/Summer-run (Threatened), Central Valley Spring-run (Threatened), California Coastal (Threatened), Puget Sound (Threatened), Lower Columbia River (Threatened), Upper Willamette River (Threatened), and Upper Columbia River Spring-run (Endangered). Chinook are easily the largest of any salmon, with adults often exceeding 40 pounds; individuals over 120 pounds have been reported. They are prized by commercial, sport, and tribal fishers alike. Chinook salmon have two distinct races: stream-type and ocean-type fish which relates to the duration of their freshwater residence as juveniles. *Ocean Habitat*: Available research suggests that ocean-type juvenile chinook salmon are found in highest concentration over the continental shelf. Ocean-type juvenile chinook appear to utilize different marine areas for rearing than stream-type juvenile chinook that are believed to migrate to ocean water further offshore early in the ocean residence. Coded-wire-tag recoveries of chinook salmon from high-seas fisheries and tagging programs provide evidence that chinook salmon utilize areas outside

the continental shelf. Catch data and interviews with commercial fishers indicate that maturing chinook salmon are found in highest concentrations along the continental shelf within 60 km of the Washington, Oregon, and California coast lines. Recently listed populations of chinook salmon also feed in the Gulf of the Farallones as adults before returning to the Sacramento River drainage to complete their life cycle.

3. Chum Salmon (*O. keta*). Two ESUs of chum are listed, the Hood Canal (Threatened) and Columbia River (Threatened) ESUs. Chum spawn in the lowermost reaches of rivers and streams. They migrate almost immediately after hatching to estuarine and ocean waters, in contrast to other salmonids, which migrate to sea after months or even years in fresh water. The species has only a single, sea-run form, and does not live in fresh water. *Ocean Habitat:* Studies of juvenile chum salmon (300-400 mm FL) captured and tagged in June in central Puget Sound, found that juveniles moved northward to the Strait of Georgia and the west coast of Vancouver Island shortly after release. They appear to migrate northward along the coast in a narrow band about 32 km in width. Available data on the distribution, migration, and growth of chum salmon in their first year at sea and indicates that chum, pink and sockeye salmon juveniles tended to group together and remain nearer shore (within 36 km) than juvenile coho and chinook salmon and steelhead. It has been hypothesized that some chum salmon may not make an extended northwest migration along the British Columbia/Alaska coast, but may instead proceed directly offshore into the north Pacific Ocean. It has been reported that North American chum salmon are rarely found west of the mid-Pacific Ocean (beyond 175° E longitude). Limited information exists on stock- or population-specific migrational patterns, and distributions of chum salmon during their oceanic phase are limited. Maturing chum salmon in the North Pacific begin to move coastward in May and June and enter coastal waters from June to November. No region-specific information on chum salmon migrations to Washington and Oregon has been reported.

4. Sockeye Salmon (*O. nerka*). The Ozette Lake ESU (Threatened) and Snake River (Endangered) ESU of sockeye salmon are protected under the ESA. Sockeye is one of the most complex of any Pacific salmon species because of its variable freshwater residency (one to three years in fresh water), and because the species has several different forms: fish that go to the ocean and back, fish that remain in fresh water, and fish that do both. Sockeye is the only Pacific salmon that depends on lakes as spawning and nursery areas. The primary spawning grounds in North America extend from the tributaries of the Columbia River to the Kuskokwim River in western Alaska. *Ocean Habitat:* Ocean distribution of sockeye salmon has been studied using tagging, morphological, parasitological, serological, and scale pattern analyses. Season, temperature, salinity, age, size, and prey distribution also affect sockeye salmon movements in the open ocean. Initially, sockeye salmon juveniles travel northward from Washington and British Columbia to the Gulf of Alaska staying in a migratory band relatively close to the coast. Once in the Gulf of Alaska, offshore movement of juveniles is conjectured

to occur in late autumn or winter. In general, the center of North American fish abundance is east of 175° E longitude. Although there is also considerable overlap in distribution among sockeye salmon originating all the way from the Alaska Peninsula to the Columbia River, scale pattern analyses indicate that sockeye salmon from central Alaska are distributed much further to the west than populations from southeast Alaska, British Columbia, and Washington. British Columbian and Washington populations of sockeye salmon utilize the area east and south of Kodiak Island in concert with Alaskan stocks, but tend to be distributed further to the south than the Alaskan stocks (down to 46° N latitude).

5. Steelhead (*O. mykiss*). Ten ESUs of steelhead are listed on the ESA including Upper Willamette River (Threatened), Middle Columbia River (Threatened), Southern California (Endangered), South-Central California Coast (Threatened), Central California Coast (Threatened), Upper Columbia River (Endangered), Snake River Basin (Threatened), Lower Columbia River, (Threatened), Central Valley, California (Threatened), and Northern California (Threatened). Steelhead are considered by many to have the greatest diversity of life history patterns of any Pacific salmonid species, including varying degrees of anadromy, differences in reproductive biology, and plasticity of life history between generations. *Ocean Habitat*: Steelhead habitat requirements change as they go through different life phases, but the most critical are thought to be related to watershed habitat (rivers, bays, estuaries throughout Washington, Oregon, California and Idaho. Adult steelhead in their oceanic existence also need adequate forage and productive environmental conditions in order to grow and survive and return to natal rivers and streams to spawn. They also need access to and through these rivers and streams. This means that waterways must be free of barriers to migration, as the majority of spawning occurs in the upper reaches of tributaries. Adults also need access to spawning gravel in areas free of heavy sedimentation with adequate flow and cool, clear water. Steelhead utilize gravel that is between 0.5 to 6 inches in diameter, dominated by 2 to 3 inch gravel. Escape cover for spawning adults is also important. Cool, clean water is essential for the survival of steelhead during all portions of their life cycle.

C. Seabirds

Over seventy species of pelagic birds occur in the pelagic environment offshore Washington, Oregon and California. These include Northern Fulmar, Brown Pelican, albatrosses, shearwaters, loons, grebes, murrelets, storm petrels, phalaropes, skuas, gulls, terns, puffins, and guillemots (Ainley and Leet 2001). Some, like the albatrosses, cover vast expanses of the ocean in search of food. Others have more restricted foraging ranges, taking their prey (e.g., small fishes and/or invertebrates like euphausiids) from at or near the sea surface by dabbling or making shallow dives. Still others (e.g., murrelets, loons) dive to depths greater than 300 feet in pursuit of prey. Often birds seek areas where ocean processes concentrate their prey along fronts and areas of convergence, or near the shelf break where large aggregations of krill and other prey converge and rise

to near the surface. Seabird distribution at sea and breeding success is often heavily influenced by the changing physical oceanography of the area that affects the distribution of prey. According to Anderson et al. (1992) and others, seabird populations have a number of characteristics in common which make them susceptible to harm caused by environmental and human-induced changes in their habitat. Resident seabirds concentrate their nesting efforts over several months at small areas, and they traditionally use the same nesting areas year after year, where they can be susceptible to predation and other coastal disturbances. Some birds (e.g., pelican, cormorants, gulls) also concentrate in roosts or resting sites when not at sea. Many seabirds depend on concentrated food supplies, where food and game fish also concentrate and where the birds may compete or interact with fishers or anglers and their operations. Seabirds also tend to be closely dependent on prey resources such as euphausiids that are highly effected by oceanic regime shifts. The most krill-dependent seabird is thought to be the the Cassin's auklet, *Ptychoramphus aleuticus*, which suspends breeding when available krill levels diminish. The sooty shearwater, *Puffinus griseus*; and the common murre *Uria aalge*, also are known to feed on krill.

Only a few seabirds are listed under the ESA, under jurisdiction of the U.S. Fish and Wildlife Service. They are as follows:

1. Short-tailed Albatross (*Phoebastria albatrus*). This species is listed as endangered. It is the largest and, as adults, the only white-backed albatross in the north Pacific. Length: 84-91 cm (33.6-36.4 in); wingspan: 213-229 cm (7-7.5 ft); average life span: 12-45 yrs. Short-tails breed on Torishima, an island owned and administered by Japan. They have also been observed (non-breeding behavior) on Minami-Kojima in the Senkaku Islands of Southern Ryukyu Islands, also owned and administered by Japan. The Short-tail population dropped dramatically due to feather hunters in the late nineteenth century. Over 5 million adults were hunted and killed. In 1939, their breeding grounds in Torishima were buried under 10-30 meters of lava as a result of a volcanic eruption. Population numbers dropped to 10 nesting pairs. The world population of Short-tailed Albatross is currently estimated at approximately 1,500 individuals, of which approximately 45% are currently breeding birds (K. Rivera, NMFS, AR, Juneau, AK and H. Hasegawa, Toho Univ., Chiba, Japan, pers. commun. 12 Dec 2002) with only 180 birds mature enough to breed (Cousins, 1999). The average age of first breeding is 6 years. Short-tailed Albatross are monogamous and have known to create a new pair bond if original mate disappears or dies. Return to natal colony or may disperse to breed (e.g., adults on Midway Atoll). The first adults return to the colony in late October. Short-tails build their nests with surrounding sand, shrubbery or volcanic debris. Lays one egg. Incubation lasts approximately 65 days and is shared by both parents. Both adults feed the chick by regurgitating a mixture of flying fish eggs and squid oil. Sometime between late May and mid-June, chicks are almost full-grown and adults begin to abandon their nests. Chicks fledge soon after the adults leave the colony. The historic range is the North Pacific Ocean and Bering Sea, Canada, China, Japan, Mexico, Russia,

Taiwan, U.S.A. (AK, CA, HI, OR, WA). Date first listed June 2, 1970. Current range: AK, CA, HI, OR, WA; Northern Pacific Ocean, Japan, U.S.S.R. In the eastern North Pacific it is currently most abundant off British Columbia and Alaska, being sighted only rarely off the Pacific coasts of the United States and Mexico in recent history. But since it has historically occupied U.S. West Coast EEZ waters, it will likely return to its former range as its population recovers (and may have already begun to do so). In spite of recent favorable recruitment at the only extant colony in Tori Shima, Japan, the world population is estimated at less than 1,000 birds. Of the 23 sightings of this species within the CA/OR/WA EEZ since 1947, 74% have been made in the last two decades (1983-2000) with 88% occurring from August through January. Six short-tailed albatrosses have been killed by the Alaska bottom longline fleet and it is possible that interactions could occur within the U.S. West Coast EEZ, as has been postulated for the Hawaii-based longline fishery, where reportedly two individuals visit the Northwestern Hawaiian Islands each year. The species is a surface feeder and the diet consists of flying fish eggs, shrimp, squid, and crustaceans. Birds feed primarily during daybreak and twilight hours and have been known to forage as far as 3,200 km (1,988 miles) from their breeding grounds. Like other albatrosses, their surface feeding, scavenging habits may make them vulnerable to fishing operations. The possibility of krill fishing gear interaction with this species, though remote, does exist and may warrant further examination.

2. Bald Eagle (*Haliaeetus leucocephalus*). Bald Eagles, listed as threatened under the ESA, range from Alaska south to Baja California, Mexico, living near large bodies of open water such as lakes, marshes, seacoasts and rivers. Recently (July 2002) eight bald eagles were re-introduced to Santa Cruz Island, California, which was once home to one of the heaviest concentrations of Bald Eagles in the United States (Whitaker 2002). They feed on fishes (usually freshwater or nearshore salt water or anadromous species). They also feed on carrion. Off Washington, Oregon and California, eagles are generally not known to feed outside enclosed bays and nearshore areas beyond three miles from shore. Thus krill fishing operations, would not be considered a significant threat to this species.

3. Marbled Murrelet (*Brachyramphus marmoratus marmoratus*). The Marbled Murrelet, listed as threatened under the ESA, is a small seabird found in coastal areas of the eastern Pacific Ocean from Alaska to central California. It spends the majority of its time at sea, where it feeds on small ocean fish such as sand lance and herring. In summer, this murrelet forages close to shore in shallow water, usually less than 95 ft deep. In nonbreeding season, they often forage farther from shore. They will also consume non-euphausiid invertebrates such as decapods and cephalopods. Unlike other members of the family Alcidae, the marbled murrelet nests on branches of old growth trees. The reproductive rate of this species is extremely low as only one egg is laid each year and nest predation by jays, crows and ravens is high. Marbled Murrelets fly up to 50 miles inland to nest in the canopy of ancient trees. It is a ground-nesting bird in Alaska, and it was not

known where Murrelets nested in California until the 1980s. Researchers discovered that females do not build nests, but lay a single egg directly in a natural depression of a large, moss-covered limb, which is the reason they are dependent on large, old growth trees. During incubation, the female and male take turns sitting on the egg for 24-hour shifts, making sure the egg is attended at all times. Pairs return to the same forest grove year after year and sometimes nest repeatedly in the same tree. When these trees are cut down, they may never successfully relocate or nest again. Drastic logging of old growth redwood forests is thought to have greatly diminished nesting habitat, and fluctuations in ocean productivity and vulnerability to nearshore gill nets have also been identified as sources of murrelet mortality. The U.S. Fish and Wildlife Service Marbled Murrelet Recovery Plan stresses that the species' survival depends on the protection of all occupied nesting habitat that currently exists. It also stresses there should be very little loss of forests that could develop into murrelet habitat over the next 100 years. At the present time, the bulk of the North American marbled murrelet population is located in Alaska, where their numbers reach 250,000. British Columbia holds an estimated 45,000-50,000 birds, located in highest density on the west coast of Vancouver Island. In Washington, murrelet numbers decrease to approximately 5,000 birds that are concentrated in northern Puget Sound; and in Oregon, only 2000-4000 birds remain, mostly in the central coast region. The smallest population of murrelets exists in northern coastal California, where there are only 1400-1700 birds left. The Marbled Murrelet is currently considered to be *endangered* in California and *threatened* in Oregon, Washington and British Columbia. When not nesting, the birds live at sea, spending their days feeding nearshore and then moving several kilometers offshore at night. In general, however, they feed relatively close to shore, their distribution related to food supplies and proximity to suitable nesting habitat. Aerial surveys off Oregon and California are being conducted to better define murrelet at-sea distribution. It is thought that any potential krill fishing will likely take place outside Marbled Murrelet feeding areas, but the possibility of fishery interactions do exist where krill-rich submarine canyons areas approach the coast.

Of the murrelets, only Xantus' (*Synthliboramphus hypoleucus*) is most likely to range into potential krill fishing areas. It may be vulnerable to small mesh krill fishing gear, as it is to small mesh drift gillnets and setnets, especially near colonies. This murrelet is not listed, but is under consideration for threatened status. The species persists in very low numbers with an estimated population of less than 10,000 breeding individuals (Drost and Lewis 1995; Whitworth et al. 1995). A significant portion of this small population nests on the southern California Channel Islands, while the remainder nests on islands along the northwest coast of Baja California, Mexico. The small (25 cm) diving seabird occurs in a very narrow range along the Pacific Coast of North America, from the southern tip of Baja California Mexico, north to about San Francisco CA, and as far north as Washington during post-breeding dispersal. It usually occurs a few miles offshore, but is known also to feed 60 or so miles out on the ocean, returning to land only to breed. Nests in colonies on rocky sea islands and ledges,

although occasionally amid dense vegetation. At sea, it does not occur in flocks, and adults are rarely found in groups larger than two. Numbers breeding at the largest colony at Santa Barbara Island probably have declined between the mid-1970s and 1991. The decline may have occurred because of many factors, including census differences. Poor reproduction, however, has occurred because of high levels of avian and mammalian predation that has probably led to this decline. Other suspected threats, especially for members of the smaller colonies, are oil spills from offshore platforms in Santa Barbara Channel and oil tanker traffic into Los Angeles harbor. Nonetheless, the primary threats to this species still appear to be rodents and feral cats. Larger numbers of nesting birds are now suspected in southern California than previously thought, but the population is still relatively small with a limited range. This candidate species may be considered for federal and state listing in the near future.

4. California Least Tern (*Sterna antillarum* (=albifrons) browni). This species is listed as endangered. These terns traditionally nest on open, sandy, ocean-fronting beaches that are often near the mouths of estuaries; they seldom occur far out to sea, away from their lagoon or estuary with its dependable food supply. During the breeding season the birds can be found in Baja California, Mexico and California. It is believed they spend winter along the Pacific coast of Central America. They usually live in colonies of 30-50 nesting pairs. Once nested widely along the central and southern California coast and the Pacific coast of Mexico. Now nesting is limited to San Francisco Bay, and various areas along the coast from San Luis Obispo County to San Diego County. Largest concentrations of breeding pairs nest in Los Angeles, Orange, and San Diego counties. Sometimes seen around Salton Sea. Primary threats and reasons implicated in decline are dredging, filling and water pollution that degrade estuarine and coastal foraging areas, shoreline development, and predation by domestic and wild animals. Least terns are opportunistic feeders known to capture more than 50 species of fish, however, these birds feed predominately on small schooling fishes near the surface in relatively shallow, nearshore waters and coastal brackish/ freshwater ponds, channels, and lakes, so are unlikely to interact with any potential krill fishing operations.

5. Snowy Plover (*Charadrius alexandrinus nivosus*). Western Snowy Plovers, listed as threatened, are small shorebirds that breed along the Pacific coast of the United States and northern Mexico, and interior sites in several western states. The population nests in Washington, Oregon, California, and Baja California, Mexico, and is associated with coastal wetlands and coastal dune habitat. They prefer coastal beaches that area relatively free from human disturbance and predators. In California, these plovers also breed on San Nicolas and Santa Rosa Islands. As much as half of the Pacific coast population may breed in Mexico. This population winters along the coasts of southern Oregon, California, and Baja California, Mexico. Some Snowy Plovers that nest along the coast of California do not migrate in winter but remain on their breeding grounds. The decline and loss of Western Snowy Plover populations along the Pacific coast have been

attributed to habitat loss and habitat and nesting disturbance caused by urbanization. At northern sites, the invasion of non-indigenous beach grasses has reduced available breeding habitat, including dunes with scant vegetation, dredge-spoil islands, natural salt panne, and salt evaporation pond levees. The greatest loss of plover habitat has occurred along the southern California coast. In southern California, many of the plover's nesting sites are associated with breeding colonies of California Least Terns. The breeding range along California's coast has been significantly interrupted by the loss of all historical breeding sites in Los Angeles County and most of Orange County. Loss of habitat in these areas has been attributed to high levels of recreational beach use and the raking of beach sand (for removal of debris) on a regular basis, and predation by coyotes, foxes, skunks, ravens, gulls and raptors. Snowy Plovers are not known to feed in or traverse the marine pelagic environment except in areas immediately adjacent to the coast, therefore they are not likely to be affected by HMS fishing practices or proposed actions, being primarily affected by disturbance of shore beach/dune habitat and by predation.

6. Brown Pelican (*Pelecanus occidentalis*). The species, listed as endangered, occurs along the coast in Oregon and Washington in summer and in California year round, especially south of Point Conception, CA. It ranges south to Brazil and Chile. After the breeding season, flocks move north along the coast and return southward by winter. Small numbers of immature birds wander inland in summer, especially in California. Habitat is salt bays, beaches and the nearshore ocean. It occurs mostly over shallow waters along the immediate coast, especially in sheltered bays, although occasionally is seen well out to sea. Nests in colonies on islands. Diet is almost entirely fish and includes smelt and anchovy; also crustaceans, although no known reports of euphausiid prey. Forages by diving from the air, plunging onto the water headfirst and coming to the surface with fish in its large expandable bill. It tilts the bill down to drain water out of its pouch, then tosses its head back to swallow prey. Sometimes scavenges and will become tame, approaching anglers for handouts or attempting to steal bait from hooks. Incubation by both sexes is roughly 28-30 days. Both parents feed young. Young may leave ground nests after about 5 weeks and gather in groups, where returning parents apparently can recognize own offspring. Age at first flight varies, reportedly 9-12 weeks or more. Adults continue to feed young for some time after they leave colony. 1 brood per year. This species declined drastically in mid-20th century, as pesticides caused eggshell thinning and failure of breeding. After banning of DDT, the species made a strong recovery; now common and increasing on southeast and west coasts. Pelicans can interact most often with the inshore recreational fishery, becoming hooked when scavenging bait or hooked fish, and have been seen occurring and interacting with purse seine operations during setting and retrieval on schools of fish. These birds are not common in most offshore areas. Most birds that interact with the recreational and purse seine fishery are thought to be released alive and unharmed, but more documented observations are needed to confirm this. It is possible that an inshore krill fishery may have incidental interactions with this species, but this species is

generally thought to occur in areas closer to shore than the primary krill swarming areas.

D. Sea Turtles

1. Green Turtle (*Chelonia mydas*). This species is listed as threatened except for breeding populations found in Florida and the Pacific coast of Mexico, which are listed as endangered. The genus *Chelonia* is generally regarded as comprising two distinct subspecies, the eastern Pacific (so-called “black turtle,” *C. mydas agassizii*), which ranges from Baja California south to Peru and west to the Galapagos Islands, and the nominate *C. m. mydas* in the rest of the range. Green turtles are declining virtually throughout the Pacific Ocean, with the possible exception of Hawaii. This is a circumglobal and highly migratory species, nesting mainly in tropical and subtropical regions. It prefers waters that usually remain about 20°C in the coldest month. It is also presumed that drift lines or surface current convergences are preferential zones due to increased densities of likely food items. The primary green turtle nesting grounds in the eastern Pacific are located in Michoacán, Mexico, and the Galapagos Islands, Ecuador. Tag returns of eastern Pacific green turtles (often reported as black turtles) establish that these turtles travel long distances between foraging and nesting grounds. The northernmost reported resident population of green turtles occurs in San Diego Bay, where about 30-60 mature and immature turtles concentrate in the warm water effluent discharged by a power plant. This species is more likely to occur in the U.S. EEZ during warm water El Niño events, at a time when euphausiid production would likely be greatly diminished, as would commercially profitable krill densities and interest in krill fishing.

2. Leatherback Turtle (*Dermochelys coriacea*). This species is listed as endangered throughout its range. Leatherbacks are the largest of the sea turtles, have a circumglobal distribution and commonly range farther north than other sea turtles, probably because of their ability to maintain warmer body temperature over longer time periods and the widely dispersed nature of their primary food source (e.g., jellyfish, siphonophores, salps, and pyrosomas). Leatherbacks are considered the most common sea turtle north of Mexico and their appearance in southern California coincides with the summer arrival of the 18-20° C isotherms. Their occurrence further north off the Pacific Northwest usually coincides with the arrival of albacore during late summer months. Leatherbacks are sometimes seen in coastal waters, but they are essentially pelagic. Current evidence suggests that adults migrate between temperate and tropical waters to optimize foraging and nesting, however, specific leatherback foraging grounds have not been identified. The Pacific coast of Mexico is generally regarded as the most important leatherback breeding ground in the world. Nesting in Mexico extends from November to February. Aerial surveys in California, Oregon, and Washington have shown that most leatherbacks occur in slope waters, while fewer occur over the continental shelf. Leatherbacks occur north of central California during the summer and fall when sea surface temperatures are highest.

Leatherback sightings peak in August along the coast of California, which may reflect a southward movement of adults for winter breeding in Mexico. Leatherbacks are the most frequently sighted marine turtle off the northern and central California coastline, and takes of this species is of considerable concern in the drift gillnet and high seas longline fisheries, where takes are known to occur. Though not generally known to occur in association with inshore krill swarms (as they feed on gelatinous organisms), the fact that their occurrence over slope and shelf waters peaks off California in August when krill swarms are often observed, the potential for interaction with any proposed krill fishing activity exists. But the extent to which these interactions will have adverse impacts is not known at this time.

3. Loggerhead Turtle (*Caretta caretta*). The loggerhead is a circumglobal species and is listed as threatened under the ESA. In the eastern Pacific, loggerheads are reported as far north as Alaska, and as far south as Chile. Occasional sightings are also reported from the coast of Washington, but most records are of juveniles off the coast of California. Southern Japan is the only known breeding area in the North Pacific. The loggerhead inhabits continental shelves, bays, estuaries and lagoons in subtropical, temperate and occasionally tropical waters. Although life history information is limited, habitats where Pacific basin loggerheads develop and grow appear to be widely separated from rookery sites. One hypothesis is that west Pacific hatchlings may become entrained in the central ocean gyre, and ultimately drift south with the California Current to Mexico. Juvenile and subadult loggerheads are omnivorous, foraging on pelagic crabs, molluscs, jellyfish, and vegetation captured at or near the surface. In the eastern Pacific, the largest known aggregations of loggerheads are juveniles off the west coast of Baja California, Mexico. Southern California is apparently the northern extent of its range, however, in 1991 a loggerhead stranded dead in Alaska and occasional sightings occur off Washington although most sightings are from off California. Takes of this species have been of concern in the drift gillnet and high seas longline fisheries, especially during warm water El Niño years. As with the green turtle, this species is more likely to occur in the EEZ in extreme warm water years at a time when euphausiid production would likely be greatly diminished, as would commercially profitable krill densities.

4. Olive Ridley Turtle (*Lepidochelys olivacea*). This is the smallest living sea turtle with populations nesting on the Pacific coast of Mexico listed as endangered under the ESA (all other populations are listed as threatened). Its range is essentially tropical. In the eastern Pacific, nesting takes place from southern Sonora, Mexico, south at least to Colombia. Non-nesting individuals occasionally are found in waters of the southwestern United States. The olive ridley has been recorded occasionally from Galapagos waters, but it is essentially very rare throughout the islands of the Pacific, and indeed even in the western Pacific it is scarce everywhere, although widespread low-density nesting occurs. Olive ridleys appear to forage throughout the eastern tropical Pacific Ocean, often in

large groups, or flotillas. They are occasionally found entangled in scraps of net or other floating debris. Young turtles may move offshore and occupy areas of surface current convergences to find food and shelter among aggregated floating objects until they are large enough to recruit to the nearshore benthic feeding grounds of the adults. Olive ridleys feed on tunicates, salps, crustaceans, other invertebrates and small fish. Although they are generally thought to be surface feeders, olive ridleys have been caught in trawls at depths of 80-110 m. While they generally have a tropical range, individuals do occasionally venture north, some as far as the Gulf of Alaska. But stranding records from 1990-99 indicate that olive ridleys are rarely found off the U.S. West Coast (off California). For this species, the potential for interaction with any proposed krill fishing activity exists, but the probability of encounters and the extent to which these interactions will have adverse impacts is not known at this time.

Appendix C Draft Proposed Regulations

1. The authority citation for part 660 continues to read as follows:

Authority: 16 U.S.C. 1801 *et seq.*

2. Section 660.502 is amended by adding the definition of “Krill” and “Prohibited Harvest Species” as follows:

' 660.502 Definitions.

* * * * *

Krill means all species of euphausiids that occur in the EEZ off the West Coast.

* * * * *

Prohibited harvest species means species that may not be taken as target species in any fishery in the EEZ off the West Coast. All krill are placed in the prohibited harvest species category.

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3. In ' 660.505, paragraphs (n) and (a) are added to read as follows:

' 660.505 Prohibitions.

* * * * *

(n) Fish for, possess, land or transship, shoreward of the outer boundary of the EEZ off the West Coast, any prohibited harvest species.

(o) Land krill in excess of any incidental catch limit set by the Regional Administrator under § 660.511(g).

4. In §660.511, paragraph (g) is added to read as follows:

§ 660.511 Catch restrictions.

(g) An incidental catch limit of krill that may be landed incidental to target catch in other fisheries shall be set and announced by the Regional Administrator at the start of each calendar year.