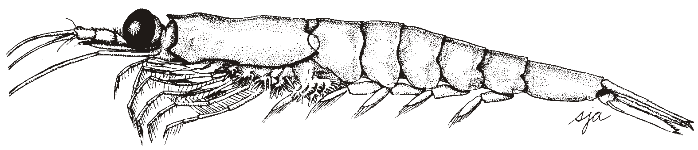
Agenda Item D.2.a
Attachment 1
November 2005



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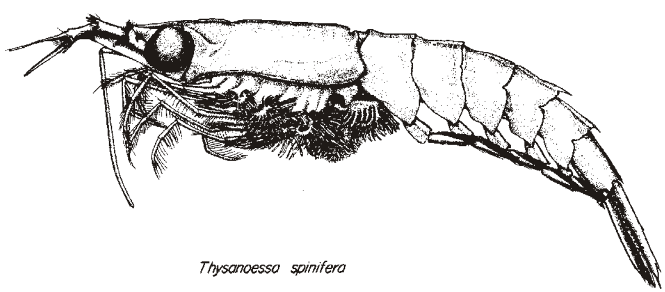
ALTERNATIVES ANALYSIS FOR THE MANAGEMENT OF KRILL FISHING OFF THE U.S. WEST COAST



Thysanoessa spinifera

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ALTERNATIVES ANALYSIS FOR MANAGEMENT OF KRILL FISHING IN THE EXCLUSIVE ECONOMIC ZONE (EEZ) OFF THE U.S. WEST COAST

PREFACE

The Pacific Fishery Management Council (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 Chapter 3 for information on the species involved) to maintain ecological relationships and ecosystem integrity and to minimize the risk of irreversible adverse impacts on managed fish stocks from adverse impacts on the building blocks (such as krill) of the ecosystem in which those fish stocks exist. It is desirable to maintain krill habitat and krill stocks within the bounds of natural environmental variability to the extent practicable. This document has been prepared to further achievement of that goal.

1.0. PURPOSE AND NEED FOR ACTION

1.1 Purpose and Need

This document is intended to provide the Council with information needed to decide how to control fishing for krill in the EEZ off the West Coast. In making these decisions, the Council needs to review this information, which is believed to be the best scientific information available, and to make decisions considering

- the size, distribution, life history characteristics and productivity of the krill resources involved

- the role and importance of krill in the environment,

- the impacts that krill fishing and other activities could have on fish stocks and other living marine resources and on resource users off the West Coast,

- the likely effects and effectiveness of alternative management approaches and measures in conserving krill and other living marine resources off the West Coast, and the effects of those alternatives on the resource users of the West Coast

- the impacts and implications and the benefits and costs of the alternative approaches and measures.

After consideration of this document, the Council will determine its preferred strategy and possible conservation and management measures. If further action is to be considered, the Council will direct the preparation of a management document for public review, including environmental analysis consistent with the National Environmental Policy Act (NEPA). This will ensure adequate documentation as the Council makes decisions.

1.2 History of Action

In September 2004, managers of the national marine sanctuaries off central California requested that the Council consider prohibiting krill fishing in federal waters of the Cordell Banks, Monterey Bay, and Gulf of the Farallones National Marine Sanctuaries administered by the National Oceanic and Atmospheric Administration (NOAA) (see map 1). 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 should be noted that waters in the sanctuaries may not be the only areas in which krill conservation and protection is critical.

The Southwest Region (SWR), National Marine Fisheries Service, National Oceanic and tmospheric 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 Fishery Management Plan for U.S. West Coast Fisheries for Coastal Pelagic Species (CPS FMP) to achieve this control. The Council agreed with this approach, with the commitment that that the SWR would take the lead in overseeing documentation to provide a basis for a regulatory amendment to the CPS FMP 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.

1.3 Management Decisions

This document is intended to evaluate and compare the effects and effectiveness of alternative management approaches and different types of conservation and measures at several different levels of decision making.

1. At the broadest level, the question is whether to propose Federal regulations to manage krill fishing in EEZ waters off the West Coast. The Council has initially agreed that it is appropriate and necessary to exercise its authority under the Magnuson-Stevens Fishery Conservation and Management Act (M-SA) to control krill fishing. This document presents the rationale for that decision and for rejection of the "No Action" alternative. After review and discussion of the information in this document, the Council will have the opportunity to affirm or amend that decision.

2. At the next level the Council would decide the mechanism by which krill fishery management should be implemented. The Council has initially concluded that its preferred approach is to amend its Fishery Management Plan for Coastal Pelagic Species Fisheries off the West Coast (CPS FMP) to include krill in the management unit and to implement krill fishery conservation and management measures consistent with the CPS FMP. This document presents the rationale for that decision and the reasons for rejection of alternative approaches for managing krill fishing. After review and discussion of the information in this document, the Council will have the opportunity to affirm or amend that decision.

3. At the most specific level, the Council would decide whether to allow krill fishing and, if so, the specific conservation and management measures that should be imposed on krill fishing. The Council has not discussed fully the alternatives other than the option presented by central California National Marine Sanctuaries' managers and the alternative of leaving management in the hands of the West Coast States. This document assesses and compares the potential impacts of different measures and their anticipated benefits and costs. After review and discussion of the information in this document, the Council will have a basis for determining the nature and scope of controls to propose.

This document contains information relevant to the specification of maximum sustainable yield (MSY) and optimum yield (OY) for krill; these specifications are required under the M-SA if the Council maintains its selection of amendment of the CPS FMP as the means by which to control krill fishing. This document also identifies alternatives for designation of essential fish habitat (EFH) for krill and of habitat areas of particular concern (HAPC), as required by the M-SA.

After the Council has affirmed or selected its preferred alternatives, a document will be prepared and disseminated for public review and comment. The Council will receive and consider those comments and make final decisions.

1.4 Current Management Controls

At this time, there are no federal regulations that limit fishing for krill either within federal waters around the sanctuary or in the exclusive economic zone (EEZ) generally. The States of Washington, Oregon and California prohibit their vessels from fishing for krill, and these prohibitions prevent landings of krill into a West Coast port by such vessels at this time. 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, is not occurring, and is not likely by West Coast vessels due to the State laws noted that prohibit West Coast vessels from landing krill into West Coast ports. As will be discussed in section 3.5, 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 generally 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. Depending on the source of information, the market for krill and krill products is either slowly growing or on the verge of major growth.

2.0 SUMMARY OF THE ALTERNATIVES

2.1 Prospective Management Objectives

The recommended objectives of the management program and selected management measures are:

2.1.1. Ensure that the stocks of principal krill species are maintained at levels at which the essential role of krill as forage for important fish and other species is fulfilled.

This means that the risk of driving the stocks down to levels below which that role would be fulfilled should be quite low, and that the risk of adverse impacts of fisheries on species that are dependent on or sensitive to the abundance and availability of krill would be low as well.

2.1.2. Ensure that, if a krill stock is reduced below critical levels, exploitation will be curtailed to promote recovery to that critical level within an appropriate time span, e.g., 3-5 years, with the specific timetable possibly being linked to environmental conditions.

This means that the management strategy, which would be intended to ensure some minimal stock abundance sizes (which could vary by species), should have a response mechanism intended to provide a high probability that the stock will recover to a pre-exploitation size level within a short period to control the risk of long-term adverse effects on dependent species.

2.1.3. Ensure that adequate data are collected for any exploitation activities that are allowed.

This is intended to ensure that any fishing activities are effectively monitored, that removals in time and place are fully recorded with reports to NMFS and/or the States, and that this information is available in a manner that will lead to improved understanding of the stocks and the impacts of the fishery on the stocks.

2.1.4. Provide a foundation for future research and data collection

This is intended to promote the design and implementation of a robust and coordinated program of research and data collection among fishery management agencies and other researchers so that there will be more efficient collection and sharing of data and research results. This is especially critical to ensure proper linkage between data collection and research on fishing and monitoring and assessments of dependent fish and other living marine resources.

2.1.5 Provide protection for key krill predator foraging areas (i.e., topographic and oceanographic features that consistently serve to concentrate krill and facilitate predator feeding).

This is intended to ensure that any areas known to be principal foraging areas for higher level predators (and especially species of special concern such as endangered and threatened species) would be protected from any adverse impacts associated with fishing.

2.2. Alternative Management Strategies

2.2.1. No Action (Rely on Existing Laws and Regulations)

This is the "no action" or *status quo* alternative.

No new federal regulations would be established to control krill harvest off the West Coast.

Management of krill fishing by West Coast vessels currently is under the control of the West Coast states, which now prohibit krill fishing by vessels registered in those states. There has been no directed fishing for krill off the West Coast to date.

As directed by Section 305(a) of the Magnuson-Stevens Fishery Conservation and Management Act (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 regulation. Under this regulation, a person is prohibited from fishing in an unlisted fishery. An individual fisherman 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.

In summary, under the no action alternative, management of krill fisheries would remain under state jurisdiction for West Coast. Vessels from other states would not be controlled if trawl gear were used. Such vessels, however, could not engage in fishing for krill with other gears without first notifying the Council and allowing 90 days for consideration of regulatory action.

The Council has rejected this alternative because it does not provide sufficient assurance of protection of krill and the resources which are dependent on krill. The absence of action would potentially set the stage for a fishery with no limits by vessels that are not tied to West Coast ports and have no interest in conservation of resources off the West Coast. While there is no apparent interest in fishing for krill at this time, it is necessary and appropriate to establish safeguards to prevent an uncontrolled fishery from being started.

2.2.2. Strategic Alternatives for Krill Fishery Management

There are several approaches by which krill fishing in the EEZ could be managed if the Council determines that this is necessary and appropriate.

2.2.2.1 Include Krill in Fishery Management Plan for Coastal Pelagic Species off the West Coast (CPS FMP) (Tentative Preferred Alternative)

Under this alternative, the Council would add krill to the management unit of the CPS FMP. The administrative mechanism would be a regulatory amendment consistent with the framework procedures of the CPS FMP. A regulatory amendment can be achieved through a relatively simple management process requiring two or more meetings of the Council and submission and affirmative action on the Council proposal by NMFS (acting on behalf of the Secretary of Commerce). It should be noted that the Council has discussed this matter at two meetings to date, though not at the level of detail of this document. The proposal would have to meet all documentation and process requirements of the M-SA and other applicable law. These other laws include NEPA, the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), the Regulatory Flexibility Act (RFA), and executive orders pertaining to analysis of the economic impacts of regulations. These requirements will be less or more demanding depending on the complexity and controversiality of those controls and the potential magnitude of impacts of the management controls, especially with respect to potential impacts on non-fish protected species. It appears that, in this situation, action that would allow unlimited or intensive fishing would be more controversial than action to prohibit krill fishing due to the important role of krill in the ecosystem as forage for many species (including some Council-managed fish species) and the current lack of fishing activity.

The principal rationale for using the CPS FMP as the vehicle to achieve management of the krill fishery is that the CPS FMP already embodies the concept of protecting or maintaining the forage value of managed resources in the Council's harvest control strategy. That is, for managed species like Pacific sardine and Pacific mackerel, the CPS FMP establishes that directed harvest should not be permitted unless the spawning biomass is above a minimum size. That minimum biomass level is thought to be appropriate both to provide ample adults for reproductive success and to provide sufficient total biomass to support forage needs of other species (fish and non-fish). The same concept could be applied to krill in a consistent manner through this strategic approach. The CPS FMP could establish controls intended to allow fishing only after it is assured that the krill biomass is sufficiently large to ensure continued productivity of the stock and continued availability of forage for dependent species, such as fish, marine mammals, and seabirds. At the same time, the CPS FMP recognizes that there are economic values that society can derive from use of Pacific sardine and Pacific mackerel when the biomass is sufficiently large to support fisheries. Similarly, the management program for krill could allow krill harvest under controlled circumstances when it is certain that such harvest will be consistent with the management objectives of the CPS FMP and would not adversely affect krill stocks or other important resources. There may be times and/or places where krill harvest will provide economic benefits without ecological or economic harm.

The extent to which specific fishery regulations would be needed to carry out this alternative would depend on the types of harvest controls that the Council deemed necessary and appropriate to achieve the objectives of the amendment. A total prohibition of krill fishing might be a relatively simple rulemaking, at least in the short term; allowing krill fishing in certain times and areas would be more complex due to the need to analyze information for determining the times/areas in which krill fishing would be acceptable; and allowing unlimited fishing for krill might be a very complex rulemaking, given the role of krill in the ecosystem and the potential for severe consequences if the krill resource off the West Coast were to be fished heavily and possibly depleted, even if only in the short term.

One of the complexities of this approach is the need to address MSA requirements to specify maximum sustainable yield (MSY) and optimum yield (OY) for managed species in FMPs. There is limited information available about the abundance, distribution and productivity of krill in the Council's management area (see Chapter 3 for a full discussion). One or both species of concern occur not only in the EEZ but in other nations' waters (e.g., Canada, Mexico, Japan) and on the high seas beyond the EEZ. There have not been prior efforts to estimate biomass or MSY for krill throughout its range or in the EEZ. Scientists have been asked for information and views as to how this might be done with available information (see Appendix A). This document contains the best scientific information available at this time though it is recognized there is considerable uncertainty about the prospective abundance and productivity of kill and the role of krill in the environment. The lack of complete and certain scientific information is not meant to be an impediment to needed management action.

The NMFS Guidelines published at 50 CFR 600 Subpart D recognize that MSY is a theoretical concept and that any MSY values used in determining OY will necessarily be estimates. The Guidelines note that there are many ways to approach the specification of MSY, and that if data are insufficient to estimate MSY directly, there may be other measures of productive capacity that can be used as reasonable proxies for MSY. Further, in the case of a species that extends beyond the EEZ, the specification of OY could be derived by estimating MSY for the species throughout its range and determining OY for the portion of the stock that may be in the EEZ. Therefore, it is anticipated that the lack of a point estimate of MSY at this time will not preclude adoption of the CPS FMP amendment as a viable strategy for exercising control over krill fishing if that is the Council's ultimate choice.

Under this alternative, the Council also would have to designate EFH for krill, evaluate the potential adverse effects of fishing activities on this EFH, and minimize to the extent practicable adverse effects on EFH from fishing if there is evidence that a fishing activity adversely affects EFH in a manner that is more than minimal and not temporary in nature (50 CFR 600.815(a)(2)(i) and (ii)). EFH has already been identified for species in the current CPS FMP; this would provide a point of departure for designating EFH for krill. EFH can only be designated for the EEZ and for waters of the United States as defined in 33 CFR 328.3, though an FMP may describe, identify and propose protection of habitats of managed species beyond the

EEZ. At this point, EFH designation for krill is not thought to be a major problem that would preclude use of the CPS FMP amendment option for controlling krill fishing. Chapter 3 presents alternatives for designation of krill EFH as well as for designation of Habitat Areas of Particular Concern (HAPC) for krill.

Designation of krill as a managed species does not preclude designation of krill as a component of EFH for other species. A comparable situation exists in the Atlantic, where a directed (but controlled) harvest of pelagic sargassum is permitted even though pelagic sargassum is viewed as an EFH component for several fish species managed under FMPs in the Atlantic area.

In any of the scenarios for management measures under the CPS FMP strategy, there could be framework procedures by which krill fishery controls could be modified as more research and possibly experimental fishing results became available. This would presumably be premised on information in periodic Stock Assessment and Fishery Evaluation reports, as called for in the National Standard Guidelines. This would include any results from fishing operations, new research information, and information from any exempted fishing activities permitted in the reporting period. The Council has considerable experience with regulatory amendment procedures, and this is considered in the evaluation of the alternatives.

An option in this alternative is to designate krill as a monitored only species in CPS FMP, similar to northern anchovy. Under this option, there would not be specific fishery controls for krill; the Council would monitor the situation and, if a krill fishery developed, would evaluate the need for conservation and management under the CPS FMP regulatory framework.

2.2.2.2. Designate Krill as Component of EFH for One or More Managed Species

Under the M-SA, each fishery management plan must designate EFH for the species included in the management unit of that FMP. EFH has been designated for all species under management in Council fishery management plans for CPS, groundfish, ocean salmon, and highly migratory species fisheries. EFH can include both non-living (e.g., waters and substrate) and living (e.g., live coral, plankton, forage species) marine resource components. If krill were identified as a component of EFH for one or more managed species, then loss of krill could be an adverse effect on EFH and in turn on managed species because the presence of krill (prey) makes waters and substrate function as habitat for feeding, and the definition of EFH includes waters and substrate necessary to fish feeding. Thus, actions that reduce the availability of a major prey species may be considered adverse effect of EFH if such actions reduce the quantity of EFH.

As krill is a principal forage species for many Council-managed species, krill could be considered as a component of EFH for those species. However, krill has not yet been so designated.

Designation of EFH triggers two requirements that would likely protect krill from harm. First, as noted above, any FMP for which krill is designated a component of EFH would have to evaluate fishing activities that might adversely affect EFH; and identify actions to minimize to the extent practicable adverse effects on EFH from fishing, if there is evidence that a fishing activity adversely affects EFH in a manner that is more than minimal and not temporary in nature. Fishery controls thus might be necessary to ensure that fishing activities (direct or indirect harvest, or incidental impacts) would not have adverse impacts on krill sufficient to adversely affect its ability to be functional EFH . Second, the amendment would have to identify actions other than fishing that may adversely affect EFH. Other Federal agencies would be required to consult with NMFS prior to engaging in any activities (including activities funded or authorized by that agency) that would adversely affect krill as a component of EFH. Those Federal actions might be required to carry out or require permittees or contractors to carry out mitigating actions.

The mechanism by which this alternative would be achieved would be to amend one or more FMPs to identify krill as an EFH component for the species in the management unit involved. Any such amendment would have to meet MSA requirements including consistency with other applicable law as well as documentation requirements of NEPA. Depending on the controls invoked, there could be some need for analyses under E.O. 12088 and the RFA. It does not appear that any requirements under ESA or the MMPA would come into play, especially if krill harvest were tightly controlled as part of the action. Notwithstanding the Council action to date under the EFH provisions of the M-SA, it would still be possible to designate krill as a component of EFH either under the Groundfish FMP or possibly under another FMP. There would not necessarily be any direct linkage to the CPS FMP.

Designation of krill as a component of EFH would not preclude a direct harvest of krill. A comparable situation is that pelagic sargassum in the Atlantic is designated as an EFH component for several managed species, but a directed harvest (albeit at a low level) is permitted. Further, it in not clear if a case could be made that krill as EFH would extend throughout the EEZ. Dependence of species managed under Council FMPs seems limited to species at the shelf and inshore of the shelf.

As acknowledged above, if krill were included in the CPS FMP as a management unit species, then EFH would have to be designated for krill.

The Council has rejected this alternative insofar as EFH for groundfish is concerned. In June 2005, the Council made final selection of alternatives for EFH for groundfish; these will be presented in a final environmental impact statement and will be incorporated as an amendment to the Groundfish FMP. The Council chose not to include krill as a component of EFH for groundfish. This was consistent with the Council decision (subject to amendment) that krill management will be carried out through the CPS FMP.

2.2.2.3. Designate Krill as a Forage Species under One or More FMPs

Under this alternative, the harvest of krill would be controlled or prohibited by designating krill as a forage species under one or more Council fishery management plans (krill is a forage species for many if not most fish species managed under Council FMPs), and establishing conservation and management measures necessary to ensure that the forage values of krill are fully protected under those other plans. These measures could include a prohibition of directed harvest throughout the EEZ or in selected times and areas, depending on the interests of the species that are dependent on krill to some degree. This alternative would be similar to the action taken by the North Pacific Fishery Management Council designating krill and several other species as forage for groundfish. That action also prohibited the direct harvest of krill (and other designated forage species) by any vessel permitted under the North Pacific Council's groundfish FMPs.

Under this alternative, the Council would have to decide whether to limit the forage category to krill or to include other species in the forage category. Krill is only one of several forage species for species managed by the Council. Other such species include other CPS (Pacific sardine and mackerel, northern anchovy, jack mackerel, market squid), the juvenile forms of other managed species, and many fish species managed under States' authorities. Further, other forage components such as lances and herring not managed by the Council could be considered as species in the forage category. The Council could include a measure to allow limited fishing for any forage species including krill. As with the EFH approach, there would also be questions about the ability to designate krill as important forage for managed species throughout the EEZ. Krill may be far more important for species on the shelf, continental slope, and inshore.

The mechanism for carrying out this strategic alternative would be to amend one or more FMPs consistent with the procedural and documentation requirements of the MSA and other applicable law. This might not be a very complex or difficult task. The North Pacific Council was able to complete the documentation for such an action in a fairly short time frame. However, as will be discussed in 4.1.4.10, the legal and factual situation in the north Pacific was quite different from the situation off the West Coast.

The Council has rejected this approach due to its complexity and its limitations. First, implementing this approach would require amendment of all Council FMPs in order to cover all fishing gears under Council management, and even then, there would not be coverage of all fishing vessels that could potentially engage in krill fishing off the West Coast. A vessel from another region could initiate krill fishing. Second, if this approach were adopted, it would be necessary to consider a larger variety of species for forage designation. This could take considerable additional work and the Council does not have the resources to engage in this work at this time. Third, unlike the North Pacific situation in which special M-SA provisions greatly expand the authority of the State of Alaska over non-Alaska vessels in the EEZ, the West Coast States have very little authority over such vessels. It is necessary to implement controls over all vessels in the EEZ under the M-SA to ensure krill conservation throughout the EEZ.

2.2.3 Alternatives Considered but not Analyzed Fully

The Council considered but did not analyze fully the potential for exercising krill conservation on a limited scale within sanctuary waters only through the National Marine Sanctuaries Act. The Council agreed that krill conservation throughout the EEZ is necessary and appropriate and that the M-SA is the appropriate authority for achieving this conservation need.

2.3 Alternative Conservation and Management Measures

The Council has tentatively agreed to include krill as a management unit species under the CPS FMP; therefore, it also needs to decide the appropriate initial conservation and management measures for the fishery. Section 4 evaluates these alternatives fully. In all alternatives that allow fishing for krill in the EEZ, it is presumed that the Council would include permit and reporting requirements to ensure adequate monitoring and future evaluation of the effects and effectiveness of management. In summary, the alternatives evaluated are:

2.3.1 Prohibit Krill Fishing in the EEZ

This alternative would prohibit directed fishing for krill anywhere in the EEZ until and unless the regulations implementing the CPS FMP were amended to specify otherwise. This would not necessarily prohibit fishing under an exempted fishing permit, though any such fishing would be permitted only after opportunity for the Council to review and advise on an application for such fishing.

2.3.2 Prohibit Krill Fishing in Portions of the EEZ within Selected National Marine Sanctuaries but Permit It in the Rest of the EEZ

Under this alternative, krill fishing would be prohibited in the EEZ waters within the Cordell Bank, Monterey, and Farallon Islands National Marine Sanctuaries, but krill fishing would not be limited in other EEZ waters. This would be consistent with the request from the sanctuary managers.

2.3.3 Prohibit Krill Fishing in EEZ Waters in All National Marine Sanctuaries

Under this alternative, krill fishing would be prohibited in the EEZ waters within the Cordell Bank, Monterey, Farallon Islands, Channel Islands, and Olympic National Marine Sanctuaries, but krill fishing would not be limited in other EEZ waters. This would be consistent with the request from the sanctuary managers, except that EEZ waters around the Channel Islands Sanctuary would also be closed to krill fishing. This would establish consistent regulations for all waers within Sanctuaries.

2.3.4 Prohibit Krill Fishing in EEZ Waters in All National Marine Sanctuaries and in Selected Other Predator-dependent Krill Waters (e.g., off Cape Blanco; inshore of Heceta Bank and Bodega Canyon)

Under this alternative, krill fishing would be prohibited in the EEZ waters within the Olympic Coast, Cordell Bank, Monterey Bay, the Gulf of the Farallones, and the Channel Islands National Marine Sanctuaries, and also in inshore of Heceta Bank, Cape Blanco and Bodega Canyon areas. Krill fishing would not be limited in the rest of the EEZ. This would go beyond the request from the sanctuary managers and would encompass additional waters in which krill concentrations appear important for spawning and forage purposes.

2.3.5 Allow Unlimited Krill Fishing Beyond 60 Miles from the Inner Boundary of the EEZ

This alternative would allow krill fishing only in waters 60 miles or more from the inner boundary of the EEZ would be permissible, but krill fishing would not be allowed shoreward of that boundary. This would encompass virtually all waters within National Marine Sanctuaries, the other areas listed in 2.3.3, and waters at or inshore of the shelf break. Thus all waters in which there are or have been krill concentrations would be off limits to fishing. This would go beyond the request from the sanctuary managers and would provide a larger area in which the non-consumptive values of krill would be fully protected.

2.3.6 Allow Unlimited Krill Fishing

Under this alternative, the Council would explicitly decide that any person who wished to do so could engage in fishing for krill in the EEZ without limit as to amount, time, or area fished or gear used. This would effectively supersede states' prohibitions on landing of krill taken by their vessels in the EEZ, though fishing in state waters could still be prohibited.

2.3.7 Controlled Krill Fishing

These are other options under which krill fishing would be allowed subject to more specific limits.

2.3.7.1 Quotas or Harvest Guidelines

The Council could establish an annual or periodic limit on krill harvest, with the limit being set at a minimum level pending more complete information about the species and its potential response to harvests. In setting this level, the Council would have to balance between a catch limit large enough to promote some fishing but small enough to control the risk of adverse effects on krill or on other important resources. Alternatively, the Council could establish a harvest guideline (as it has done in other fisheries) that would serve as a benchmark for determining a need for further consideration of management needs. If fishing occurred at a level higher than the harvest guideline, then the CPS Management Team and advisory subpanel would be asked to review the situation and advise as to the need for a change in conservation and management strategies. Such changes could likely be completed by relatively simple regulatory amendments. Another possible suboption would be to develop a control rule by which, based on a probabilistic model of the likelihood of an exceptional abundance of krill in a given year, the Council would determine whether a fishery should be allowed (and appropriate conditions) based on the likelihood of exceptional krill production. Unfortunately, it does not appear at this time that such a probabilistic model will be developed in the needed timeframe for this action.

2.3.7.2 Limits by Season

Under this alternative, the Council would establish times in which harvest of krill would and would not be permitted. For example, to provide full opportunity for successful reproduction, the Council could prohibit krill fishing in waters off the West Coast or off specific subareas in this time period. However, choosing a season would be difficult. *T. spinifera* is thought to distinct spawning season (May to July) off California, coincident with the strongest upwelling

(Brinton 1981). In this period, it forms extensive inshore surface swarms as fully mature adults during the peak of the upwelling season. These adults are thought to swarm, breed, and then presumably die at the end of their life cycle. Maturing subadults are also known to swarm near the surface in later summer and fall (cites from Smith, p. 2). However, *E. pacifica* can spawn every two months year round. The Council also could decide to prohibit krill fishing at times when key species are known to be feeding heavily. If there is going to be a closed season, it probably would extend from spring through fall, since in the spring and summer in the Gulf of the Farallones, king salmon and Cassins auklets depend on krill (reproductive adults mostly) in that area, and in late summer and fall, the whales move in to prey on swarms of developing juveniles. The timing may also vary from year to year because of the variability in the timing and intensity of upwelling, suggesting a need for longer closures to buffer against this variability.

2.3.7.3 Limits Based on Water Temperatures

Under this alternative, the Council would control fishing triggered by oceanic conditions. This would be analogous to the linkage of the annual sardine harvest guideline to the temperature of the water off the Scripps Pier. It appears that krill are sensitive to extreme El Niño conditions, and as cold water species, do not thrive under warm water conditions. On the other hand, the aggregation and spawning of krill at levels that produce good reproduction and concentrations for feeding by predators may also produce krill at levels sufficient to support fishing without risking either krill or dependent and sensitive species. Therefore, the Council could choose to totally prohibit krill fishing in El Niño years but allow krill fishing in average or cool water years. However, this measure may complicate the management issue unnecessarily, as the direct warm/cold water correlation is an over simplification.

2.3.7.4 Combination of Measures

For the most part, the above listing of management alternatives is limited to one measure at a time. As a practical matter, the Council has indicated a concern about the risk of uncontrolled fishing but has not ruled out the potential of a limited harvest. Therefore, if the Council were to allow any krill fishing, the Council would likely consider a multi-faceted control program, including permits and reporting requirements, a catch limit, time and/or area closures, and observer coverage. The above alternatives are not meant to be mutually exclusive in all instances. Given the many variables involved, it is not possible to evaluate all possible combinations of measures in this document. The general conclusion, however, is that the more "sophisticated" and flexible the combination, the more difficult it would be to implement at a reasonable cost.

2.3.8 Exempted Fishing Permits (EFPs)

There are two options for this element of the management program. First, as currently managed under the CPS FMP, EFPs would be considered under the procedural regulations at 50 CFR 600.675. Under this process, NMFS forwards to the Council (including States, the U.S. Coast Guard, Treaty Tribes, and the U.S. Fish and Wildlife Service) for review and advice any applications that are received requesting an EFP in the CPS fishery. NMFS Regional

Administrators are now authorized to process and issue EFPs, subject to documentation requirements of the M-SA and other applicable law. The Council typically recommends that if a permit is granted, there be reporting and observer coverage to ensure an adequate basis for monitoring and evaluation of the results. It is anticipated that this approach will continue with the addition of krill. The Council might also include a protocol for soliciting and reviewing EFP requests with inputs from the plan team, advisors, and the public as it has done for other FMPs.

However, if the Council so chooses, a separate EFP process could be developed in which EFP applications would be handled like EFP requests in the groundfish fishery. This provides more control and predictability to the process as well as to the types of applications that will be submitted for full Council consideration.

2.3.9 Prohibit Krill Fishing Initially but Establish Process for Future Permitting

As noted above, this alternative is for the Council to prohibit krill fishing in the EEZ until it is demonstrated as a result of research, EFPs, or other analysis that krill fishing can be conducted in a manner that will not adversely affect krill stocks or other living marine resources. Either through existing framework procedures of the CPS FMP or through new framework procedures, criteria and standards for considering opening a fishery would be set and, based on periodic SAFE Reports, the Council would decide whether or not to allow it. This could be limited to allowing fishing at certain times and places to ensure that there is not excessive risk of harm.

2.4 Krill EFH Harvest Controls

If krill were designated as a component of EFH under the Groundfish FMP (or any othe FMP), then harvest controls could be designed to ensure that the EFH value of krill to groundfish would not be harmed by krill harvest. This would entail specification of the EFH value of krill in time and area strata relative to groundfish. It is noted that designation of krill as an EFH component does not preclude some use of krill in a directed or incidental harvest. As demonstrated in the management program for pelagic sargassum of the Atlantic Ocean, limited harvest can occur as long as there is no adverse impact on the EFH value of the resource involved. The Council could consider all of the specific types of harvest controls listed above to minimize the risk of adverse effects. It is not clear if a full prohibition of krill harvest under this alternative would be defensible; if the EFH designation would not extend throughout the EEZ, then it might not be reasonable to conclude that harvest should be limited throughout the EEZ to protect or maintain EFH values.

2.5 Krill Forage Harvest Controls

If krill were designated as forage, then harvest controls could be set to ensure that the forage value for the prey species identified would be protected adequately. This would entail identification of the prey species involved and the times/areas in which predator/prey relationships would appear most important, and designation of controls to ensure that the important prey value is protected and maintained. The Council could consider all of the specific types of harvest controls listed above to minimize the risk of adverse effects. Again, it is not clear that krill serves an important forage function far beyond waters of the shelf break, and therefore, it might not be reasonable to prohibit krill fishing throughout the EEZ to maintain or protect forage values for species under Council FMPs.

3.0 DESCRIPTION OF THE KRILL RESOURCE AND THE AFFECTED ENVIRONMENT

3.1. Krill Biology and Status

3.1.1 Species of Concern and Definition of Krill

Eight species of euphausiid shrimp dominate the krill community in the Transition Zone of the California Current System (Brinton and Townsend 2003), but only two cold-water species, *Euphausia pacifica* and *Thysanoessa spinifera* (Fig. 1), form large, dense surface or near-surface aggregations and are thus likely to become potential fishery targets. 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), Pearcy 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, but is only abundant in U.S. West Coast waters during strong El Nino years, occurring predominantly to the south in Mexico waters (Gendron 1992; Brinton and Townsend 2003). Another euphausiid, *Nematocelis difficilis*, is very abundant in the California Current, but not a vertical migratory, preferring the deeper layers of the thermocline where it is less accessible to harvest than *E. pacifica* and *T. spinifera*. The remaining species (*T. gregaria, E. recurva, E. gibboides, E. eximia*) are less abundant and not likely candidates for exploitation.

The word "krill" comes from the Norwegian 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,’ and when referring to U. S. Pacific Coast euphausiids as a potential management unit, applies only to *E. pacifica* and *T. spinifera*.

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 ºN 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).

3.1.2.2. Horizontal Distribution EEZ

Distribution of both 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 loss 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 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 areal 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 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), although it can also occur further shoreward over the deeper waters of the continental shelf (especially larvae). 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. 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 "hotpots" 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 alifornia (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 ecosystem[1] (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.

3.1.2.5 Growth, Sexual Maturity, Longevity, 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

[1]defined as Cape Mendocino, CA north to the tip of Vancouver Island, Canada.

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 Pearcy 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 $M = 3.0\ y^{-1}$ off California, and much higher ($M = 8.7^{\ y-1}$) 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[2]	*M*	References
E. pacifica	Spring	S. Calif.	6-8 months	4 months	3 yr^{-1}; ~ max. every 2 months[3]	3.0 y-1	Brinton 1976 Siegel&Nicol 2000
E. pacifica	Autumn	S. Calif.	10-13 months	7 months	Max. every 2 months	3.0 y-1	Brinton 1976 Siegel&Nicol 2000
E. pacifica	---	Ore. &Wash.	1+yr	~1 yr	1 yr^{-1}	---	Smiles&Pearcy 1971
E. pacifica	---	Ore	---	---	---	8.7y-1	Siegel&Nicol 2000 Jarre-Teichmann 1996
E. pacifica	---	Wash	-- -	---	2 yr^{-1}; mostly spring, less in late summer.	---	Bollens et al 1992
E. pacifica	---	B.C.	---	---	4-6 yr^{-1} Mar-Oct	0.6-1.9 y^{-1}	Tanasichuk 1998a; Siegel&Nicol 2000 Jarre-Teichmann 1996
E. pacifica	---	Aleu-tians; Kam-chatka	2+ yr	~ 1 yr	1yr^{-1} for 2+ years	---	Siegel&Nicol 2000; Iguchi&Ikeda 1995
E. pacifica	---	NW Pacific	2+ yr	~ 1+ yr	1 yr^{-1} for 2+ years	---	Ponamareva 1966; Nemoto

[2] distinct cohorts; egg release pulses
[3] depending on available food conditions

		; Kam-chatka					1957
E. pacifica	---	NE Japan	15 months	---	1 yr^{-1}	---	Iguchi et al 1993
E. pacifica	---	SW Japan	21 months	---	---	---	Iguchi et al 1993
E. pacifica	---	N Japan	2+yr (♀) 1+yr (♂)	1+yr	---	---	Nicol&Endo 1997
T. spinifera	---	Barkley Sound, B.C.	1-2 yr	1 yr	2 pulses yr^{-1} Mar-July	---	Summers 1993
T. spinifera	---	Barkley Sound, B.C	10 months	---	3-4 pulses yr^{-1} Mar-Oct	---	Tanasichuk 1998b
T. spinifera	---	North Pacific	2+ yr	2 yr	---	---	Mauchline 1980
T. spinifera	---	Subarc-tic Alaska	1+ to 2+ yr	1 yr	1 y^{-1} June-Sept	---	Nemoto 1957

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 fro m 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).

3.1.2.3 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 ecosystem[4] (NCCE), estimated euphausiid average annual phytoplankton consumption (*Q*) 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).

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[4]defined as Cape Mendocino, CA north to the tip of Vancouver Island, Canada.

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.

3.1.3 Status of Principal Species

3.1.3.1 Determination Criteria and Available Data

Each FMP must specify the MSY and OY from the fishery and, to the extent possible, 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. Status determination criteria must be expressed in a way that enables the Council and the Secretary of Commerce to monitor the stock or stock complex and determine annually whether overfishing is occurring and whether the stock or stock complex is overfished. In all cases, status determination criteria must specify both of the following:

- A maximum fishing mortality threshold (MFMT) or reasonable proxy thereof.

The MFMT may be expressed either as a single number or as a function of spawning biomass or other measure of productive capacity. The MFMT must not exceed the fishing mortality rate or level associated with the relevant MSY control rule. Exceeding the MFMT for a period of 1 year or more constitutes overfishing.

- A minimum stock size threshold (MSST) or reasonable proxy thereof.

The MSST threshold should be expressed in terms of spawning biomass or other measure of productive capacity. To the extent possible, the stock size threshold should equal whichever of the following is greater:

One-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years if the stock or stock complex were exploited at the maximum fishing mortality threshold previously specified. Should the actual size of the stock or stock complex in a given year fall below this threshold, the stock or stock complex is considered overfished.

Status determination criteria must be based on the best scientific information available. When data are insufficient to estimate MSY, Councils should base status determination criteria on reasonable proxies thereof to the extent possible. In cases where scientific data are severely limited, effort should also be directed to identifying and gathering the needed data.

After a review of the available literature and individual consultation with California Current krill experts from federal and state government agencies, academia, and the private sector (see Appendix A), it was determined that reliable input parameters for a suitable model to determine minimum stock size threshold and maximum fishing mortality threshold, based on spawning biomass or other measure of productive capacity, still need to be developed for these two species, and agreed upon. Thus a benchmark status determination could not be made as of Sept 1 2005. The control rule management approach implies an ability to determine the level of biomass B relative to its initial biomass level B_0 and relative to B_{MSY} , and to determine the potential level of mortality F relative to some target level like F_{MSY}. 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 such calculations. *MSY* levels of B or F could 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 adequate catch levels of 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.
- Instead of maximizing yield the goal should be to allow sufficient escapement to meet the 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 calculate 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 MSY cannot be determined at this time (and may not be the appropriate management benchmark in any case), 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. To meet minimum M-SA requirements, first-round provisional approximations of B_0 and $B_{MSY,}$ based on rough estimates of average adult krill densities and presumed habitat occupied, are presented in section 3.1.3.4. Other measures of abundance and 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 provisional, pending a more comprehensive stock assessment. It should be noted that available methods and units of 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.

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 26º and 38ºN (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 x 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 x 10m $^{-2}$ (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) that 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 (D_0) and MSY ($0.5D_0$) 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 Ni2o 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 $m^{-3)}$
E. pacifica	El Niño (warm)	335	168
E. pacifica	Non-El Niño (cooler)	1,518	759
T. spinifera	El Niño (warm)	4.15	2
T. spinifera	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 km^2) 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 km^2) 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 km^2), 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 m^{-2} (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 10^{10} m^2). 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 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.

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[5], for two habitat area assumptions[6]. 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[7] (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)
E. pacifica	6.8	136	0.064	8700	610,531	1,766,535	305,266	883,268
T. spinifera	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[8])					1,221,301	3,533,759	610,651	1,766,880

[5] *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).

[6] Habitat assumption A assumes area main krill concentration 70, 176 km^2 (W. Peterson, *ibid*., see text); Assumption B assumes area of main krill concentration within inner quarter EEZ (~203,050 km^2)

[7] 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).

[8] 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[4].

Species	Est. B_0 Habitat Assumption A Miller 1966 Preserved (mt)	Est. B_0 Habitat Assumption A 90% H_20 Fresh (mt)	Est. B_0 Habitat Assumption B Miller 1966 Preserved (mt)	Est. B_0 Habitat Assumption B 90% H_20 Fresh (mt)	$0.5B_0$ (*MSY*) Habitat Assump. A 90% H_20 Fresh (mt)	$0.5B_0$ (*MSY*) Habitat Assump. B 90% H_20 Fresh (mt)
E. pacifica	610,531	1,031,584	1,766,535	2,984,826	515,792	1,492,413
T. spinifera	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 should be used with extreme caution. Among many tentative assumptions, it does 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 0.9*MSY*. 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 Scripps Institution of Oceanography 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 Feinberg[4] 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.

Finally, and most importantly, because of the great disparity of available estimates regarding biomass, the Council must not use the numbers presented here, especially overall ‘average’ estimates of biomass and provisional MSY, for specification of MSY as a basis for OY or for setting harvest guidelines or quotas.

3.1.3.5 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.

3.1.3.6 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.

Field[9] 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 potential impact 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.

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[9] 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."

3.2 ROLE OF KRILL IN THE ECOSYSTEM OFF THE U.S. 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. As major California Current herbivores, they act as particularly efficient conduits of nutrients and primary production from the upwelling zone off our 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 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 Pearcy 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 Pearcy 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; Kiekeffer 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. spinfera* 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. 2005[10], 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).

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 (%)[11]
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

In a more recent modeling exercise, Field et al.[12] 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

[10] 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

[11] initial estimates as of original publication, 1995.

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

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 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 EXISTING AND POTENTIAL FOR EXPANSION OF KRILL FISHERIES

3.3.1 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).

3.3.2 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).

3.3.2.1 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).

3.3.2.2 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.

3.3.2.3 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).

3.3.2.4 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 0º 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 love red color 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 at al 2000).

3.3.2.5 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.

3.3.2.6 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 premenstral 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 calcuim intake and depostion 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 etablish a very large market for krill or krill products in the near term.

3.3.3 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.

3.4 EXISTING STATE MANAGEMENT OF KRILL FISHERIES ALONG THE U.S. WEST COAST

3.4.1 California

California imposed a ban on landing and krill fishing in state waters in 2000.

3.4.2 Oregon

Oregon imposed a ban on landing of krill and krill fishing in state waters in 2003. Fishing beyond state waters may not be feasible because of rough ocean fishing conditions which constrain krill fishing operations.

3.4.3 Washington

Currently, no krill fishery takes place in Washington, and there has been no interest expressed in harvesting krill in state waters. Washington law prohibits the landing and sale of commercial quantities of krill, which is designated an unclassified species with very limited take options. Given recent discussions relating to krill harvest in other Pacific coast areas, the state may consider additional modifications that might make future commercial harvest of krill in Washington even more unlikely.

3.5 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 been 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 65-70°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.

3.5.1 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 2000 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 t 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 t, 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 tonnes per annum. Since then, Chile has also stopped fishing for krill. The current krill catch is in the range of 90,000–100,000 t 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 t, 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 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

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

  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. But to be applied in management so that a precautionary total allowable catch (TAC) can be set, an estimate of B_0 is required, which 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 $\gamma 1$ 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 $\gamma 2$ 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 $\gamma 1$ and $\gamma 2$ 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 620,000 t (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 subdivided into 277,000 t west of 115ºE, and 163 000 t east of 115ºE, respectively.

3.5.2 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 aquiculture operations, and amounts to some 100,000 tons (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 t 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 t in 1978, 80,000t in 1987, and 100, 000 t 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 coats 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 tons to 200 t. 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 t 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).

3.5.3 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 t in a season. Nets used have mouth areas of around 80 m^2, 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 t 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 t; 500 t for the Strait of Georgia and 20 to 75 t 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 t for the mainland inlets and 215 t for the Strait of Georgia. That year, 56 licenses were issued, of which 17 reported landings of 530 t 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 t of euphausiids were reported landed in 1993 with a total landed value of Can $41,000. This decline in landings from 381 t reported in 1992 was a function of market conditions rather than any decline in krill stocks. Preliminary landings of euphausiids reported for 1994 were in excess of 300 t, with a value of Can$ 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 t quota for the Strait of Georgia and mainland inlets is expected to remain fixed for the foreseeable future (Morrison 1995).

3.5.4. 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 m^2 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 t 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 000t to 1 million t (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 1,000t 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.

3.6 POTENTIAL BYCATCH ISSUES

As krill fisheries have developed in places such as the Antarctic and Canadian waters, in addition to concern about krill-dependent predators, concern has been expressed over bycatch of non-target fish and invertebrates, particularly larval and juvenile fishes (Everson et al. 1991; Moreno 1995, Runge and Joly 1995). Nonetheless, it is still unclear whether fish and/or invertebrate bycatch is a major or minor problem to the stocks involved, and this will have to be addressed before any fishery is considered. Nicol and Endo (1997) report that bycatch (particularly that of larval fishes) has been a significant issue in the Antarctic krill fishery, particularly because of the severe depletion of some of the fish stocks in the South Atlantic. But operators reportedly avoid areas where there is likely to be a contaminating catch of fish, and large Antarctic krill aggregations tend to be monospecific. In the British Columbia krill fishery, bycatch has also been a concern, and for this reason, the season was restricted to November through March to minimize the incidental catch of larval and juvenile fish and shellfish (e.g., young salmon and shrimp).

In coastal areas off Oregon, Washington and California, juvenile salmonids (including endangered stocks), pelagic juveniles of *Sebastes* spp., herring and other juvenile and larval fishes, squid, pelagic invertebrates, and night-feeding seabirds would likely be vulnerable to small-mesh krill trawls fished at night. The extent to which the fishery would impact these potential bycatch species is not known without a description of fishing methods, areas, times and gear, and the amount of effort expended.

3.7 POTENTIAL PROTECTED SPECIES INTERACTIONS AND IMPACTS IN THE MANAGEMENT AREA

This section provides a short summary of potential effects of krill removal on species listed under the ESA and MMPA that are known to feed on one or both of the California Current species *Thysanoessa spinfera* and *Euphausia pacifica*. A more detailed description of each species is provided in Appendix B of this document.

3.7.1 Marine Mammals

3.7.1.1 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. 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.

3.7.1.2 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. Since these whales congregate for feeding 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 in fashioning any krill fishery controls for a future fishery.

3.7.1.3 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. Blues have been observed feeding on dense swarms of euphausiids (dominated by either *Thysanoessa spinifera* or *Euphausia pacifica*) near Monterey and the Farallones between July and October, and over deep submarine canyons in southern California and around the Santa Barbara Channel Islands. 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 would occur or 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.

3.7.1.4. Fin whale (*Balaenoptera physalus*)

This species has been listed as endangered under the ESA since 1970. The estimated 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. 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.

3.7.1.5 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. 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.

3.7.1.6. Northern Right Whale (*Eubalaena glacialis*).

Right whales are listed as endangered under the ESA. 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.

3.7.1.7 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 have a diverse diet, including many species of fish species and squid, although the primary prey appears to be copepods. 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.

3.7.1.8 Guadalupe fur seal (*Arctocephalus townsendi*).

This seal is a protected species in California and is listed as a threatened species. These seals now primarily breed and pup at Isla Guadalupe, Mexico. In the West Coast 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 or injury to Guadalupe fur seals, but there have been no documented reports of mortalities or injuries of pinnipeds in krill net fisheries elsewhere.

3.7.1.9. 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 (37ºN latitude). Steller sea lions prey primarily upon schooling fishes, such as pollock and herring, as well as invertebrates, such as squid and octopus. 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.

3.7.2 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.

3.7.2.1 Coho Salmon (*Oncorhynchus kisutch*).

Three Evolutionarily Significant Units (ESUs) of coho are listed as threatened--the Southern Oregon/Northern California Coasts, Oregon Coast, and Central California ESUs. 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

3.7.2.2 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). 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.

3.7.2.3 Chum Salmon (*O. keta*).

Two ESUs of chum are listed, the Hood Canal (Threatened) and Columbia River (Threatened) ESUs. 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.

3.7.2.4 Sockeye Salmon (*O. nerka*).

The Ozette Lake ESU (Threatened) and Snake River (Endangered) ESU of sockeye salmon are protected under the ESA. 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. 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 46º N latitude).

3.7.2.5 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 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.

3.7.3 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, murres, auklets, murrelets, storm petrels, phalaropes, skuas, gulls, terns, puffins, and guillemots. 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 dabbing or making shallow dives. Still others (e.g., murres, 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. 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 affected by oceanic regime shifts. The most krill-dependent seabirds are thought to be the Cassin's auklet, *Ptychoramphus aleuticus,* which suspends breeding when available krill levels diminish, and the sooty shearwater, *Puffinus griseus*. The common murre, *Uria aalge*, is also known to feed on krill.

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

3.7.3.1 Short-tailed Albatross (*Phoebustria albatrus*).

This species is listed as endangered. 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 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.

3.7.3.2 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. They feed on fishes (usually freshwater or nearshore salt water or anadromous species) and 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.

3.7.3.3 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 feeds on small ocean fish such as sand lance and herring, and invertebrates such as decapods and cephalopods. It is thought that any potential krill fishing will likely take place outside Marbled Murrelet feeding areas, but the possibility of fishery interactions do exit where krill-rich submarine canyons areas approach the coast.

Of the other 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 set nets, 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. 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.

3.7.3.4 California Least Tern (*Sterna antillarium (=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. 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.

3.7.3.5 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. 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 krill fishing practices or proposed actions, being primarily affected by disturbance of shore beach/dune habitat and by predation.

3.7.3.6 Brown Pelican (*Pelecanus occidentalis*).

This 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. Adults continue to feed young for some time after they leave colony. It is possible that an inshore krill fishery could have incidental interactions with this species, but this species is generally thought to occur in areas closer to shore that the primary krill swarming areas or potential harvest areas beyond 3 nautical miles from shore.

3.7.4. Sea Turtles

3.7.4.1 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. Green turtles are declining virtually throughout the Pacific Ocean, with the possible exception of Hawaii. 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.

3.7.4.2 Leatherback Turtle (*Dermochelys coriacea*).

This species is listed as endangered throughout its range. Leatherbacks are the most frequently sighted marine turtle off the northern and central California coastline, and take of this species in drift net and longline fisheries is of considerable concern and are the proximate cause of strict regulation of those fisheries. Though not generally known to occur in association with inshore krill swarms (as they feed on gelatinous organisms), they occur over slope and shelf water areas off California in August when krill swarms are often observed. Therefore, there would be a potential for interaction with any proposed krill fishing activity in the same areas. The extent to which these interactions would occur and/or would have adverse impacts is not known at this time.

3.7.4.3 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. 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.

3.7.4.4 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. Olive ridleys feed on tunicates, salps, crustaceans, other invertebrates and small fish. 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.

3.8 ESSENTIAL FISH HABITAT FOR KRILL

3.8.1 Introduction and Need for Action

Section 303(a)(7) of the M-SA requires that fishery management plans (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 M-SA 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-SAset 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.

3.8.2 Methods and Data Sources

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).

3.8.3 Description and Analysis of EFH Alternatives: Proposed Options and Analysis

Option 1. Status Quo. Do not designate EFH.

If krill are incorporated as a MUS in the CPS or other FMP, this is not an option, since the M-SA requires designation of essential fish habitat for all MUS in FMPs.

Option 2. Adopt EFH as described in section 3.8.6.

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 in 3.8.6. 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.

3.8.4 Habitat Areas of Particular Concern (HAPCs)

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.

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)

The following HAPC options are proposed:

HAPC Option 1. Status Quo–Do not designate HAPCs

HAPC Option 2. Designate for krill and feeding baleen whales and other krill predators 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. These sanctuaries encompass the most important consistently krill-rich, predator feeding 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 for krill and feeding baleen whales and other krill predators 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 for krill and feeding baleen whales and other krill predators 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 additionally other inshore island, shelf, bank and slope areas along the coast suspected of supporting high densities of krill and krill predators within the EEZ.

3.8.5 Affected Environments

3.8.5.1 Biological 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, murres, 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, The 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.

3.8.6 Description of Designated Essential Krill Habitat in the U.S. West Coast EEZ

The following sections describe essential habitat for the two species. It was not possible at this time 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 Scripps Institution of Oceanography 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 macroplanktonic species with fixed bottom topography, other than that discussed under section 3.1.2.2. Horizontal Distribution EEZ.

3.8.6.1 *Euphausia pacifica* EFH (Fig. 16)

Larvae, juveniles and adults: From the inner boundary of the U.S. West Coast EEZ (beyond 3 nm) 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.

3.8.6.2 *Thysanoessa spinifera* EFH (Fig. 17)

Larvae, juveniles and adults: From the inner boundary of the U.S. West Coast EEZ (beyond 3 nm) seaward 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).

3.8.7 Possible Adverse Impacts to EFH from Fishing Activities

At this time it is not known what types of gear might be chosen for harvesting krill off the U.S. West Coast, since various types of methods have been used world fisheries - beam trawl, small midwater trawl, bow scoop net, purse seines, etc. But because gear would likely be deployed in midwater to the surface, physical damage to the water column habitat is not anticipated at this time.

3.8.8 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.

3.9 SUMMARY OF POTENTIAL IMPACTS TO KRILL AND AFFECTED ENVIRONMENT

Based on the information presented, there are several impact factors the Council will need to consider in determining the necessary and appropriate controls on krill fishing. These include:

- Possible negative impacts on food supply of krill-dependent predators (whales, seabirds,important commercial and recreational fishes such as groundfishes, salmon, squid, etc), with subsequent lower abundance of commercial fish and squid stocks, and reduced food levels for federally protected marine mammals and birds.

- Potential negative impacts with other commercial stocks and protected species due to gear interactions with certain krill-dependent predators that co-occur in the same high-density krill swarm areas.

- Potential bycatch of juvenile salmon, squid and other CPS and other commercially important larval and juvenile fish and invertebrates.

- Possible increase in algal blooms of phytoplankton, whose growth in nutrient-rich upwelling systems like the California Current is held in check largely by grazers (would depend on the amount of harvest removals).

- 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.

- Possible localized disruption of carbon, nitrogen and Vitamin A cycling in the sea through removals of significant numbers of krill. Disruption of carbon flux and food availability to small pelagic and benthic organisms dependant on the fragmentation of sinking organic particles (“Marine snow”) created by the collective rapid beating of krill appendages in the water column. Marine snow can comprise as much as 60% of water column particulate organic carbon.

- Potential negative fishing gear/user group interactions between krill vessels and commercial and recreational vessels and whale and bird watching vessels.

- Loss of associated goods and services that depend on our regional ecosystem resources and quality.

3.10 RESEARCH NEEDS

The following research needs were identified after a review of the literature and available data, and individual consultation with California Current euphausiid researchers.

3.10.1 MSY-OY Specification Needs

To reduce uncertainties in the specification of MSY (and thus improve the basis for specification of OY) and meet the requirements of the M-SA, the following research analyses are needed:

1. Construction of a single-species probabilistic yield model 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 are needed for the model input parameters for Monte Carlo simulations to determine the likelihood of a harvestable krill surplus production occurring (i.e., production beyond predator needs and population stability). This means that funding, staff and support must be committed to coordinate and run model simulations.

2. Construction of a multispecies ecosystem model(s) to estimate effects of various harvest levels. This would involve 1) expanding the existing Eastern North Pacific Ecosystem Ecopath/Ecosim Model (Field et al. 2001; Field and Francis In press; Field et al in press) to include the entire West Coast EEZ, and 2) running a perturbation version of this model (i.e., a model in which fishery removals of krill would be the change in the ecosystem). This is expected to take 6 months to one year after assignment of work and allocation of resources.

3.10.2 Standing Biomass Estimation and Survey Needs

Standardization of collecting and processing methods is required before net density and acoustic data from different geographic regions can be combined and converted to coast-wide, or even regional, biomass estimates. The following are needed:

1. 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.

2. Standardization of krill body length to weight/carbon conversion factors by krill size group. *E. pacifica* length-carbon relationships are 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.

3. 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.

4. 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.

5. Laboratory metabolic experiments to refine estimates of productivity, growth and turn-over rates.

4.0 ENVIRONMENTAL CONSEQUENCES OF ALTERNATIVES CONSIDERED

4.1 Impacts of Strategic Alternatives

4.1.1 No Action

4.1.1.1 Effects on Krill

This alternative will have no predictable impacts on krill resources. It is not known if a krill fishery would develop within the West Coast EEZ in the absence of new management controls.

If a fishery were to develop, it would be by non-West Coast vessels that are not registered under any West Coast state laws and are not subject to state restrictions when operating in the EEZ or beyond. Such a fishery (assuming the use of trawl and not purse seine) would not be dependent on clearance through the 90-day review period provided by the List of Fisheries regulation. There would be no limit on the catch of krill or on the time or area in which fishing occurs, and krill fishing could occur within portions of the EEZ that are within national marine sanctuaries off the West Coast. There would be no permit or reporting requirement and there would be no requirement for observers, and thus no information would be collected for any fishing that occurred. The potential for decreasing the spawning biomass to levels that threaten successful reproduction would depend on the level of harvest and the times and areas at which harvest was conducted. The risk of stock declines may be greater for *T. spinifera*, which has a 3-year cycle and limited spawning periods. If the fishery were relatively small and/or limited to areas which have no major importance to the long-term survival of krill, the risk to the krill stocks could be low.

4.1.1.2 Effects on Other Fish Species

This alternative would have the highest probability of adverse impacts on other fish species. If a fishery developed without controls, it could harvest krill at levels that could reduce the availability of krill to other fish species. As indicated in Chapter 3, some Council-managed (hake, spiny dogfish, rockfishes) species are fairly dependent on krill, either year round or on a seasonal basis, and these species would be more at risk than species for which krill is not important or for which there might be adequate substitutes for krill in their diet. In the absence of good information on the fishing activities (where, when and how much), there would be great difficulty relating declines in other species to the removal of krill by a fishery.

4.1.1.3 Effects on Other Living Marine Resources

It is not known though it is likely that, at some level, krill harvest would become an issue in terms of adverse effects on species of special concern, such as species listed under the ESA or MMPA or species of seabirds. It is possible that a large harvest, especially in times or areas in which whales actively feed on krill masses, would result in stress to those whale populations and possibly in decreased growth or reproductive success or feeding of juveniles. The risk of such impacts increases in relation to the level of harvest and the coincidence of harvest of krill with times and areas in which krill are most important to such other species. If krill fishing is not controlled and monitored, the ability to relate a krill fishery with changes in abundance, distribution, reproductive success, or other factors related to major predators is very limited or non-existent. This may be especially important in areas such as the marine sanctuaries in which krill concentrations and whale concentrations appear to coincide.

Krill also appear to be important forage for some marine bird species such as Cassin's auklet. The availability of krill in prime hatchling feeding periods would be most important. This availability is probably greatest in the spring and summer, and those periods of krill concentrations would probably coincide with periods when fishing would be most likely. An uncontrolled krill fishery could result in high risk to such bird species.

4.1.1.4 Effects on Other Fisheries

It is not known though it is likely that, at some level, krill harvest would become an issue in terms of adverse effects on at least some fish species under Council management such as hake or some other groundfish. It is especially noteworthy that some groundfish species that are overfished (e.g., canary rockfish) appear to be significant feeders on krill. It is possible that a large harvest, especially in times or areas in which these fish species actively feed on krill, would result in stress to those fish populations and possibly in decreased growth or reproductive success or survival of juveniles. The risk of such impacts increases in relation to the level of harvest and the coincidence of harvest of krill with times and areas in which krill are most important to such other fish species. If krill fishing is not controlled and monitored, the ability to relate a krill fishery with changes in abundance, distribution, reproductive success, or other factors related to these other fish species is very limited or non-existent, though it is possible that food habit studies in conjunction with existing survey work (e.g., CalCOFI) would provide some insight into the relationship (if any). Unlimited krill fishing would pose a high risk of adverse effects.

4.1.1.5 Economic Effects

This alternative would have the greatest potential to result in a krill fishery with attendant economic benefits and potential economic costs. As noted, there is some (though unknown) potential for a krill fishery off the West Coast. The price of krill at this time appears not to offer a substantial enough reward to warrant an investment in a new fishery. However, with the increasing potential for offshore aquaculture (the Administration is supporting legislation that could promote such activity in the EEZ on a broader level), there would be increasing potential for a krill fishery.

It is not clear if a krill fishery in the EEZ alone by a factory/processing vessel that does not deliver its product to a West Coast state would be subject to landings laws and taxes.

4.1.1.6 Effects on Data Collection

This alternative would be unlikely to generate useful data assuming that state landing laws and reporting requirements would not apply if the active operated in the EEZ and did not land any products into West Coast ports..

4.1.1.7 Effects on Bycatch

It is not known if a krill fishery would have any bycatch, as there has been no krill fishing and thus there are no data at this time to indicate if bycatch would be a significant issue.

4.1.1.8 Effects on Habitat

Krill fishing (especially with midwater trawl) would not likely have any significant impacts on non-living components of habitat. There would be no predictable impacts on EFH for any Council-managed species under current designations of EFH for those species.

4.1.1.9 Effects on Protected Species

As noted above, this alternative has the potential to adversely affect protected species by reducing the availability of important prey. This is most pronounced for certain whale species and bird species. Large harvests would be possible under this alternative. Such harvests, especially if they coincided in times and areas when krill were most important to other living marine resources, could adversely affect other species by reducing food availability, perhaps in turn adversely affecting reproductive success and growth or even juvenile survival. There could also be direct impacts through fishery interactions with krill fishing gear.

4.1.1.10 Administrative Considerations

This would be the least costly alternative. There would be no need for further Council consideration of action or regulatory action by the U.S. Government.

SUMMARY: This alternative is not responsive to the request from the NOAA Sanctuary Managers, and it would leave a high risk of adverse effects on krill and on resources dependent on or sensitive to the abundance and availability of krill. While it is not predictable that a krill fishery will develop, it is predictable that, if a party were interested in krill fishing, then fishing would occur first in waters where krill tend to concentrate. These are the same waters in which such species as whales and seabirds would be most dependent on krill. Thus, any fishery would have a high probability of adversely affecting a wide variety of resources.

4.1.2 Include Krill in CPS FMP (Preferred Alternative)

4.1.2.1 Effects on Krill

The effects on krill would depend on the nature of the controls (e.g., amount of harvest allowed, times and places in which harvest is allowed, etc.) placed on krill fishing. If a conservative harvest strategy (especially an initial strategy prohibiting harvest until more is known) were adopted, the risk of serious short- or long-term harm to krill stocks would be minimal. On the other hand, allowing large harvests of krill without restrictions on times or areas would have a higher risk of long-term adverse effects on krill stocks. Inclusion of krill in the CPS FMP provides a basis for a managed fishery that adapts controls over time as more information becomes available, just as the Council approaches management of many other species. Also, the information that would be collected if permits, reporting and observer requirements were applied (as with other FMP fishery components) to krill fishing could greatly improve the understanding of krill as a species and as a component of the ecosystem if a fishery were to occur. This would further reduce the risk of harm to the krill stocks from incorrect management decisions.

4.1.2.2 Effects on Other Fish Species

Depending on the controls placed on the fishery, this alternative would control the risk of adverse effects on other fisheries from krill removals in a fishery. The greater the control and the greater the collection of information, the less the risk of long-term damage to any fish species from a krill fishery.

4.1.2.3 Effects on Other Living Marine Resources

Depending on the controls placed on the fishery, this alternative would control the risk of adverse effects on other living marine resources from krill removals in a fishery. The greater the control and the greater the collection of information, the less the risk of long-term damage to any other living marine resource species from a krill fishery.

4.1.2.4 Effects on Other Fisheries

To the extent other fish stocks are protected from harm, this alternative would protect fisheries on these other species from harm. This may be especially important in the sense that the relationship between krill and other species could be better understood by collecting data from a controlled fishery that is closely monitored over time.

4.1.2.5 Economic Effects

This alternative would appear most likely to result in optimum economic effects. A fishery management program could be constructed that might allow controlled and observed fishing, thus prospectively benefiting fishers, while ensuring that fishing only occurs in a manner (gear, time, place, amounts) that provides substantial assurance that the productivity and values of krill and other living marine resources are fully protected from long-term harm.

4.1.2.6 Effects on Data Collection

This alternative would be most likely to generate data needed to better understand the productivity of krill, the role of krill in the ecosystem, and the relationship between krill and the productivity and yield of other fisheries. Again, a controlled and closely observed fishery will result in better information to support improved management decisions in the future than an uncontrolled and unobserved fishery.

4.1.2.7 Effects on Bycatch

This alternative would be more likely to result in good data about bycatch (if any) in a krill fishery.

4.1.2.8 Effects on Habitat

Krill fishing would not be expected to have any effects on marine habitat or any components of essential fish habitat for any managed species.

4.1.2.9 Effects on Protected Species

This alternative would be less likely to result in adverse impacts on any protected species than would be likely with an uncontrolled fishery, but the likelihood of impacts would depend in large part on the types of controls placed on the fishery. A management program that controls the fishery in time and space to prevent fishing in association with marine mammals and/or sea birds would be less likely

4.1.2.10 Administrative Considerations

This alternative requires the completion of an FMP amendment and associated rulemaking by NMFS, assuming approval of the Council proposal. This entails completion of the necessary documentation, including environmental analysis, completion of economic and regulatory analyses, and potentially consultation under the ESA. A final Council decision would require approximately six months (allowing for Council adoption of a preferred alternative in November, publication and distribution for public review of a proposed amendment over the winter, and

Council approval of a proposed FMP amendment in March 2006). Once in place, the krill management program would be subject to annual review and adjustment as more information becomes available. The cost of this alternative is low to moderate, depending on the nature and complexity of management controls ultimately adopted.

SUMMARY: This alternative would provide a basis for actions to reduce the risk of adverse effects from an uncontrolled krill fishery. It would integrate krill fishery management into the management framework of the CPS fisheries, from which any West Coast krill fishers would likely originate. The basic management principle of the CPS FMP would be followed, that is, that fishing would be permitted only after the stock is demonstrated to be sufficiently large to support stock maintenance and forage for fish and other species and to achieve other important ecosystem functions (e.g., contributing to the Vitamin A cycle, detrital mixing). This alternative would also establish a framework for rapid adjustments in management as well as for permits and reporting to support monitoring and future management of the resources. A krill fishery management program can effectively manage to reduce the risk of adverse impacts on krill, dependent resources, habitat and bycatch. The cost of this approach is low to moderate but the reduction of risk to krill and dependent or sensitive species could be substantial. Depending on the specific controls implemented, this alternative could be consistent with or even go beyond the request of NOAA Sanctuary managers.

4.1.3 Designate Krill as Component of Groundfish Essential Fish Habitat

4.1.3.1 Effects on Krill

This alternative would provide some protection for krill depending on the nature of the specification of krill as groundfish EFH. To the extent the specification includes krill over a large area and not just in waters near the bottom where krill may be more critical for groundfish, the protection for krill would be greater.

4.1.3.2 Effects on Other Fish Species

To the extent that krill protection as a component of groundfish EFH helps maintain krill populations throughout the marine environment, other fish species that are dependent on or sensitive to krill abundance will be protected indirectly by this alternative.

4.1.3.3 Effects on Other Living Marine Resources

To the extent that krill protection as a component of groundfish EFH helps maintain krill populations at healthy levels throughout the marine environment, other living marine resources (e.g., cetaceans, seabirds) that may be dependent on or sensitive to krill abundance will be protected indirectly by this alternative.

4.1.3.4 Effects on Other Fisheries

Designation of krill as a component of groundfish EFH should provide some benefits to the groundfish fishery by reducing the risk that krill harvest would adversely affect groundfish stocks by removing a key food source. To the extent that this benefits other fish stocks as well, the fisheries on those stocks will receive some benefit.

4.1.3.5 Economic Effects

This alternative would generally have some positive benefits by reducing the risk of stock declines in any fish stocks dependent on or sensitive to krill abundance in waters off the West Coast. Further, to the extent protection of krill under this alternative benefits cetaceans and seabirds, especially in important wildlife viewing areas (e.g., National Marine Sanctuaries), there could be benefits for businesses that support wildlife watching tours in those areas. There would be no direct adverse impacts on existing fisheries or other economic users of krill as there are no such activities now. However, this alternative might preclude development of any krill fishery in the future or make such fishing less productive by designating certain areas as not available for krill fishing.

4.1.3.6 Effects on Data Collection

This alternative might result in increased research on krill off the West Coast, as it would be important to have a better understanding of the role of krill as a component of groundfish EFH. However, this might be limited to the role of krill relative to groundfish and not to a broader community of resources for which krill might be important.

4.1.3.7 Effects on Bycatch

This alternative would not be expected to have significant impacts on bycatch of any species.

4.1.3.8 Effects on Habitat

This alternative would provide some protection for habitat for groundfish and for any other resources that are dependent on the habitat shared with groundfish.

4.1.3.9 Effects on Protected Species

This alternative would provide some benefits to protected species to the extent that the alternative would protect krill populations in areas important to those species.

4.1.3.10 Administrative Considerations

This alternative would require amendment of the groundfish FMP and associated rulemaking by NMFS. It would require two Council meetings (including the November meeting). Protection for krill would be limited to those geographic areas covered by the groundfish EFH designation. Protection beyond those waters would be dependent on other actions (e.g., designation as an EFH component for other species or amendment of the CPS FMP).

SUMMARY: This alternative, at least as it might pertain to groundfish fisheries, has been rejected by the Council through its decisions dealing with actions for Groundfish EFH designation. The Council has not indicated an interest in designating krill as a component of EFH for any other managed fish species. The Council has concluded that this approach is not necessary and appropriate for krill conservation and management at this time. It could be administratively difficult and complex and would raise the prospect that other living marine resources should also be designated as components of EFH for managed fish species. The degree to which this approach could reduce the risk of adverse effects on krill and associated resources from a fishery is not known as it has not been tested.

4.1.4 Designate Krill as a Forage Species

4.1.4.1 Effects on Status of Krill

This alternative could but is not assured of maintaining the krill stock at healthy levels. The problem is that this approach would have to be carried out on a FMP-by-FMP basis. If krill were identified as forage for groundfish through a Groundfish FMP amendment, then only vessels fishing for groundfish would likely be affected by any harvest controls that maintain or protect that forage value. The Groundfish FMP amendment could not control directed harvest of krill by vessels not subject to the Groundfish FMP. If all relevant FMPs were amended, then substantially complete control would be achieved, assuming that only a vessel already on the West Coast and engaged in another fishery under management would be interested in development of a krill fishery. On the other hand, if a non-West Coast vessel were to engage in krill fishing and not be engaged in any non-managed fisheries off the West Coast, then this alternative would likely not achieve conservation benefits for the krill stock.

4.1.4.2 Effects on Other Fish Species

To the extent that this alternative is effective in controlling krill harvest, the stocks of fish dependent on or sensitive to krill abundance will likely benefit.

4.1.4.3 Effects on Other Living Marine Resources

To the extent that this alternative is effective in maintaining the krill population at levels that provide sufficient forage for dependent or sensitive species, this alternative will have beneficial effects on other living marine resources.

4.1.4.4 Effects on Other Fisheries

To the extent that this alternative is effective in maintaining the krill population at levels that provide sufficient forage for fish species that are the target of fisheries, this alternative will provide benefits to (or at least not adversely affect) other fisheries.

4.1.4.5 Economic Effects

To the extent that this alternative is effective in maintaining the krill population at levels that meet forage needs of dependent or sensitive fish stocks, this alternative will likely have positive economic effects. Also, such activities as wildlife viewing (whale watching, bird watching) will likely be enhanced (or at least not harmed) by this alternative if it results in healthy krill populations that support non-fish resources.

4.1.4.6 Effects on Data Collection

This alternative is not expected to result in substantial increases in data collection or research.

4.1.4.7 Effects on Bycatch

This alternative would not be expected to have significant effects on bycatch. To the extent bycatch might occur if krill fishing were permitted, the restriction of krill fishing to maintain forage values would likely reduce or prevent such bycatch.

4.1.4.8 Effects on Habitat

This alternative would likely have minor but beneficial impacts on habitat.

4.1.4.9 Effects on Protected Species

To the extent that this alternative maintains and protects the stock of krill at high levels, it would likely benefit protected species.

4.1.4.10 Administrative Considerations

This alternative may be more difficult and complex than the other action alternatives because of the issues involved. First, to achieve full protection of forage values through this approach, it may be necessary to amend all Pacific Council FMPs. To understand this problem, it is important to note that the legal and factual context was somewhat different for the North Pacific Fishery Management Council when it decided to designate krill as forage in its groundfish FMPs. That is, the MSA provides much broader authority for State management in the EEZ off Alaska in the absence of Federal regulations under the MSA. The State of Alaska has authority to manage fisheries in the EEZ, even if by non-Alaska registered vessels, that are not managed under North Pacific Fishery Management Council FMPs. West Coast States do not have similar authority. Therefore, the Pacific Council would likely have to designate krill as forage under several FMPs to extend control of krill fishing across the range of managed fisheries off the West Coast; and even this would not address the potential for a fishery by vessels not currently under any FMP management program.

Second, there is the issue of which species to include in the "forage" category. In the North Pacific Council case, there was broad agreement as to the mix of species to include in the forage category; this does not appear to be the case on the West Coast. At this point, there has been no suggestion that other species be formally included as "forage" for any managed species, though there is no question that other species (including sardines and mackerel) fill a forage role for other species (and each other to some extent). However, designation of krill alone as forage could raise the question of whether the Council is being consistent and reasonable. Therefore, this alternative is likely to take more time and resources to achieve krill conservation than the other alternatives discussed above.

SUMMARY: This alternative is more complex than it initially appeared. The legal and administrative context is different from the North Pacific Council situation. It would likely be necessary to engage in a more complex assessment of all prospective forage species, some of which may be targets of existing fisheries. This approach could reduce the risk of adverse effects from krill fishing, but at the same time would seem to both preclude krill fishing and put at risk losses from closing other forage species. Much would depend on the management controls that were ultimately chosen by the Council for regulating fishing for krill and other forage species (note that CPS are already regulated but other forage candidates are not in the Council FMPs).

4.2 Impacts of Alternative Conservation Measures

This section assesses the potential impacts of different types and levels of control through fishery conservation and management measures imposed on krill fishing. Some of these conservation and management measures could be implemented under any of the strategic alternatives described above but most if not all are generally considered in the context of the alternative to manage krill fishing under the CPS FMP. As indicated above, it is presumed that if any fishing is to be allowed, there would be permit and reporting requirements as well as authority for NMFS to place observers on board krill fishing vessels.

4.2.1 Prohibit Krill Fishing in the EEZ

4.2.1.1 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 events other than fishing.

4.2.1.2 Effects on Other Fish Species

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

4.2.1.3 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.

4.2.1.4 Effects on Other Fisheries

This alternative would likely provide benefits to other fisheries to the extent that the prohibition of fishing for krill prevents any adverse effects of krill stock reduction on any other targeted fish species.

4.2.1.5 Economic Effects

This alternative would provide benefits to existing fisheries and to businesses and entities involved in such activities as whale watching. However, it would preclude fishing for krill and thus any potential economic benefits from such fishing.

4.2.1.6 Effects on Data Collection

This alternative would have no benefits in terms of added data collection and research.

4.2.1.7 Effects on Bycatch

This alternative would preclude any problem of bycatch in krill fishing in the EEZ.

4.2.1.8 Effects on Habita

This alternative would prevent any adverse impacts on habitat from fishing in the EEZ.

4.2.1.9 Effects on Protected Species

This alternative would provide benefits to, or at least prevent adverse effects of krill fishing on, protected species.

4.2.1.10 Administrative Considerations

This alternative would be relatively simple to carry out. It is consistent with existing West Coast states' laws. It is "precautionary" in that it would prevent rise of a fishery when there is little or no information about the likely risk of stock depletion from fishing and about the consequences of such a condition. It would go beyond the request of the National Marine Sanctuaries Program. While a complete prohibition of fishing might raise some concern, it is noted that there is now no krill fishing and thus no party is directly prohibited from engaging in an activity already underway. This should reduce the likelihood of objections on economic grounds. A prohibition of krill fishing is also relatively easily enforced. This alternative could be more attractive if there were a provision promoting the use of EFPs to allow very tightly controlled and monitored fishing at times and/or in places in which the risk of adverse impacts on important resources (e.g., protected species, overfished species) would be very low. There is no krill fishing now that would be eliminated so there would not be adverse social impacts that would raise concerns.

4.2.2 Prohibit Krill Fishing in EEZ Waters of National Marine Sanctuaries

This alternative would be consistent with the request of the NOAA National Marine Sanctuary officials from central California but would also include EEZ waters within the Channel Islands National Marine Sanctuary (off California) and the Olympic Coast National Marine Sanctuary (off Washington). Note that krill fishing would be prohibited under State laws in any State waters of these Sanctuaries. Krill fishing in other EEZ waters would not be prohibited but would be subject to permit, reporting and possible observer coverage requirements.

4.2.2.1 Effects on Status of Krill

This alternative would provide substantial protection to krill off the West Coast. Waters within the National Marine Sanctuaries are among the waters in which krill concentrations for spawning are most likely and in which krill concentrations supporting feeding by whales and seabirds are most critical.

4.2.2.2 Effects on Other Fish Species

Species of fish that occur in Sanctuary waters and that are dependent on or sensitive to the abundance and availability of krill in those waters will benefit from this alternative. Species that are not dependent on or sensitive to krill abundance and availability may benefit to the extent that krill fishing would not adversely affect habitat or result in bycatch of those species. There could be some indirect benefits if, by preventing fishing, this alternative ensures that the habitat enhancing role of krill (see 3.2.4) is maintained within Sanctuary waters at the least, which should benefit all resources in those waters.

4.2.2.3 Effects on Other Living Marine Resources

Other living marine resources in Sanctuary waters would benefit to the extent the protection of krill is important to these resources. This may be especially important to some seabirds.

4.2.2.4 Effects on Other Fisheries

Participants in other fisheries would benefit to the extent that the protection of krill in Sanctuaries helped maintain the stocks of the target species and the prohibition of krill fishing ensured that there would be no bycatch of those target species.

4.2.2.5 Economic Effects

This alternative would prevent adverse effects of krill fishing on other fisheries. This alternative also could have positive economic benefits if the protection of krill in Sanctuaries provided a basis for continued non-consumptive acctivities such as whale watching trips in or near Sanctuaries. It is likely that krill fishing in Sanctuary waters at some level would reduce concentrations of krill and thereby reduce krill feeding by whales. Whether this would reduce whale migrations into or through Sanctuaries is not known.

4.2.2.6 Effects on Data Collection

This alternative would have minor impacts on data collection. To the extent this alternative resulted in less krill fishing with attendant data collection/reporting, there would be less information for use in future management. To the extent this alternative ensures the continued migration of whales into or through Sanctuaries and thus enhances whale watching, it also would likely result in improved data collection.

4.2.2.7 Effects on Bycatch

This alternative would prevent any bycatch in krill fishing in Sanctuary waters. Whether there would be any bycatch in the first place is not known.

4.2.2.8 Effects on Habitat

This alternative would prevent any adverse effects of krill fishing on habitat in the Sanctuaries. This could include preventing indirect adverse effects that krill fishing might have on the habitat enhancing role of krill (see 3.2.4). It would not prevent adverse effects of krill fishing (if any) on habitat outside the Sanctuaries.

4.2.2.9 Effects on Protected Species

This alternative would prevent any adverse effects on protected species from krill fishing in the Sanctuaries. This could include the indirect effects that krill fishing could have through the reduction of krill abundance and availability for whales and seabirds within the Sanctuaries.

4.2.2.10 Administrative Considerations

This alternative would be fairly simple to implement through the amendment of the regulations for the CPS FMP. It would be responsive to the request of the NOAA National Marine Sanctuary officials from central California but would go beyond that request to include EEZ waters within the Channel Islands National Marine Sanctuary (off California) and the Olympic Coast National Marine Sanctuary (off Washington). It would provide substantial certainty of protection to krill and krill-dependent resources in the Sanctuaries, though there could be some remaining risk in adjacent waters. Whether it would be consistent with the ESA would be determined through consultations on the proposal. There is no krill fishing now that would be eliminated so there would not be adverse social impacts that would raise concerns.

4.2.3 Prohibit Krill Fishing in EEZ Waters in All National Marine Sanctuaries and in Selected Other Predator-dependent Krill Waters (e.g., off Cape Blanco; inshore of Heceta Bank and Bodega Canyon)

4.2.3.1 Effects on Status of Krill

This alternative would even more protection to krill off the West Coast. Waters within the National Marine Sanctuaries are among the waters in which krill concentrations for spawning are most likely and in which krill concentrations supporting feeding by whales and seabirds are most critical. Waters off Cape Blanco and inshore of Heceta Bank and Bodega Canyon are also known as areas of intense congregations of krill from time to time. Thus this alternative would prevent krill fishing and stock declines in more of the areas in which spawning concentrations are known to occur regularly and therefore would prevent adverse effects of fishing on spawning and reproduction in these waters. It appears this would provide very substantial protection for krill though there are other areas that may also be important for krill.

4.2.3.2 Effects on Other Fish Species

To the extent these area closures assure krill availability to other fish species dependent on or sensitive to krill abundnace and availability, they will support and protect those other species. There are no doubt other areas in which species that feed on krill could be adversely affected if krill fishing were to occur.

4.2.3.3 Effects on Other Living Marine Resources

To the extent these area closures assure krill availability to other living marine resources, fish species dependent on or sensitive to krill abundance and availability, they will support and protect those other species. There are no doubt other areas in which species that feed on krill could be adversely affected if krill fishing were to occur.

4.2.3.4 Effects on Other Fisheries

This alternative could benefit other fisheries to the extent that the target species benefit from either greater abundance and availability of krill or from any reduction in bycatch in krill fishing.

4.2.3.5 Economic Effects

This alternative would benefit existing fisheries but would preclude benefits from a krill fishery in the waters that would be closed. It is not known if krill fishing would occur if these known areas of kril concentration were closed to fishing. To the extent these closures benefit other living marine resources such as whales, they could result in benefits to activities that are oriented to those resources, such as whale watching.

4.2.3.6 Effects on Data Collection

This alternative would be less likely to result in krill fishing and associated data collection and reporting.

4.2.3.7 Effects on Bycatch

This alternative would prevent any bycatch in the closed areas.

4.2.3.8 Effects on Habitat

This alternative would preven any adverse effects on habitat from krill fishing in the closed areas. To the extent this maintains the idirect habitat enhancing effects of krill, the habitat will gain from this alternative.

4.2.3.9 Effects on Protected Species

This alternative will provide additional protection for protected species from adverse effects of krill fishing, both direct and indirect.

4.2.3.10 Administrative Considerations

This alternative would be fairly simple to implement through amendment of the regulations for the CPS FMP. It would go beyond the request from the NOAA National Marine Sanctuary officials and would almost cover the full prohibition of krill fishing in West Coast States' laws. It would provide substantial certainty of protection for krill and other living marine resources dependent on or sensitive to the abundance and availability of krill in the closed waters. Whether it is consistent with the ESA would be determined through consultations. There is no krill fishing now that would be eliminated so there would not be adverse social impacts that would raise concerns.

4.2.4 Allow Unlimited Krill Fishing Beyond 60 Miles from the Inner Boundary of the EEZ

This alternative would allow krill fishing only in waters 60 miles or more from the inner boundary of the EEZ would be permissible, but krill fishing would not be allowed shoreward of that boundary. This would encompass virtually all waters within National Marine Sanctuaries, the other areas listed in 4.3.3, and waters at or inshore of the shelf break. Thus all waters in which there are or have been observed krill concentrations would be off limits to fishing. This would go beyond the request from the sanctuary managers and would provide a larger area in which the non-consumptive values of krill would be fully protected.

4.2.4.1 Effects on Status of Krill

At this time, this alternative would not be expected to result in a substantial krill fishery. The available information from resource surveys and research suggests that krill are more likely found in concentrations in waters closer to shore, i.e., on the shelf break and around islands. There may be areas and times, however, when krill are present and concentrated in offshore waters, and this alternative would allow vessels to engage in directed and unlimited harvest of krill in those waters. It is conceivable this could provide a seasonal opportunity for large trawl vessels when not active in hake or pollock fisheries. It is not believed that this would affect the status of the krill resources closer to the West Coast, though this is not certain.

4.2.4.2 Effects on Other Fish Species

This alternative would be expected to maintain the benefits that other fish species in the closed areas gain from continued abundance and availability of krill. It would not be expected to result in significant effects on other fish species more than 60 miles from shore off the West Coast.

Krill may be one of many food sources for open ocean fish, but there is no information suggesting a dependence on or sensitivity to the abundance and availability of krill by such species as tuna and swordfish, though their role in the diet of such species as squid is not known.

4.2.4.3 Effects on Other Living Marine Resources

This alternative would not be expected to result in significant effects on other living marine resources more than 60 miles from the West Coast. However, this is somewhat uncertain. It may be that cetaceans feed on krill on the open ocean at least opportunistically. Also, some species of seabirds may feed on krill as they make more extensive at sea migrations.

4.2.4.4 Effects on Other Fisheries

This alternative would not be expected to affect other fisheries; to the extent these fisheries rely on species for which krill are important, there should be some benefit from prevention of adverse effects on target stocks due to krill fishing.

4.2.4.5 Economic Effects

This alternative is not expected to have significant economic impacts on existing fisheries. It would likely preclude establishment of a new krill fishery. This alternative could have positive benefits for activities associated with such species as whales that are dependent on krill and that are the target of non-consumptive uses (e.g., whale watching). To the extent this alternative maintains the continued availability of krill that attract whales, whale watching will be enhanced.

4.2.4.6 Effects on Data Collection

This alternative is not expected to result in any significant increase in data collection as it is not expected that a significant fishery will develop.

4.2.4.7 Effects on Bycatch

This alternative would preclude bycatch from krill fishing in the closed areas. If it results in no krill fishing anywhere, then clearly there will be no bycatch at all.

4.2.4.8 Effects on Habitat

This alternative would prevent adverse impacts on habitat from a krill fishery in the closed areas. To the extent this alternative results in continued abundance of krill, the habitat enhancing role of krill will be maintained.

4.2.4.9 Effects on Protected Species

This alternative would be expected to prevent any adverse effects (direct and indirect) of krill fishing on protected resources in the closed areas. Since the closures encompass most if not all waters in which these protected species occur and have involvement with krill, this protection could be significant

4.2.4.10 Administrative Considerations

This alternative would be relatively simple to implement. It would go beyond the limit requested by the National Marine Sanctuary Program and therefore would likely be approvable on policy grounds. It would be consistent with the prohibition on krill fishing in states' waters and thus consistent with states' coastal zone management plans. Whether it is consistent with ESA requirements would be determined through consultations in NMFS. There is no krill fishing now that would be eliminated so there would not be adverse social impacts that would raise concerns.

4.3 Alternative Controls on Krill Fishing

While area closures appear to be the most administatively simple management control for krill fishing, the Council should also consider the potentials of other controls that could provide some opportunity for fishing without serious risk to krill and associated resources.

4.3.1 Catch Limits (Quotas)

4.3.1.1 Effects on Status of Krill

The probability of any effects on krill would depend on the quota level set. A low quota would not likely have significant long-term effects on krill stocks; a large quota would have a higher probability of adverse effects. The risk of adverse effects may also vary depending on the quota level in relation to oceanic conditions. If krill are sensitive to ocean temperatures, it may be important to have a low or zero quota in warm water years, while allowing for greater harvests in cold water years. To the extent krill abundance is linked to oceanographic conditions, it could be difficult to establish a quota system that is sufficiently robust to deal with all oceanographic scenarios.

4.3.1.2 Effects on Other Fish Species

Other fish species are more or less likely to be affected in correlation with impacts on krill. To the extent a quota ensures that krill stocks will be maintained at or above some minimal level (sufficient to meet forage requirements), fishing at that quota level will presumably not result in adverse impacts on these other fish species.

4.3.1.3 Effects on Other Living Marine Resources

Other living marine resources are more or less likely to be affected in correlation with impacts on krill. To the extent a quota ensures that krill stocks will be maintained at or above levels that meet the forage requirements of these other living marine resources, fishing at that quota level would not likely result in adverse effects on those resources.

4.3.1.4 Effects on Other Fisheries

This alternative would not likely affect other fisheries so long as the quota is set at a level that ensures that forage requirements for targeted fishery stocks are met.

4.3.1.5 Economic Effects

This alternative (assuming the quota level were set to maintain krill stocks at healthy levels) would likely have positive economic impacts in terms of maintaining the values of existing fisheries and non-consumptive activities related to other resources dependent on or sensitive to the abundance and availability of krill in the EEZ. This alternative would likely preclude any significant krill fishery, thus, the economic activity that could be associated with such a fishery will not occur.

4.3.1.6 Effects on Data Collection

This alternative, if it resulted in a small fishery, would make minor contributions to the data base for a better understanding of the productivity of krill and its role in the environment. Assumikng a low quota, however, this alternative would likely not result in a fishery that would demonstrate the impacts of reduced populations of krill in the environment.

4.3.1.7 Effects on Bycatch

This alternative would not likely result in substantial bycatch as any fishery would be expected to be fairly small. However, there would likely be observers documenting whatever bycatch occurred; this would be beneficial information.

4.3.1.8 Effects on Habita

This alternative would not be expected to result in any impacts on habitat from krill fishing. If the quota were set at a low level, then any habitat-enhancing role of krill would not likely be affected.

4.3.1.9 Effects on Protected Species

This alternative would not be expected to impact protected species. However, this is not certain. A quota alone might not be sufficient to fully protect some species. Even a fishery for a low quota level could be detrimental to protected species if fishing were permitted in times and/or areas where protected species would most likely be dependent on krill abundance and availability. For example, if seabirds have a limited foraging range during nesting, it might be important to ensure that no fishing (even for a low quota) be permitted within that foraging range during the nesting period.

4.3.1.10 Administrative Considerations

This alternative would be somewhat complex to carry out. First, there would need to be a decision on the quota itself; there is a limited information base for setting a quota that would ensure that no long-term harm to krill stocks would result from fishing at that level. In addition, there are two krill stocks involved; the Council could have to decide a quota level for each or possibly for the two in combination. Third, the Council would have to consider the need for other measures to be implemented with the quota. As noted above, time or area constraints may also be critical. Finally, the rationale for the quota(s) and associated controls would have to be set forth with such factual information as exists, and there would have to be environmental and economic analysis of the alternatives. On the other hand, the Council has considerable history using quotas or other catch limits so this would not be a dramatically new management measure.

4.3.2 Limits by Season

It may be possible to identify specific times in which krill fishing (at some level) would be possible with low risk of adverse effects on krill.

4.3.2.1 Effects on Status of Krill

If krill aggregations are critical to successful spawning and reproduction or other critical life history stages, and aggregations are linked to time of year, this alternative could have protective benefits for krill by preventing harvest activities that might disrupt or adversely affect these processes. As noted above, krill congregations for spawning tend to be seasonal,though seasonality varies by species and area along the coast.

4.3.2.2 Effects on Other Fish Species

To the extent this alternative helps ensure the long-term abundance and availability of krill, other fish species that are dependent on or are sensitive to the abundance and availability of krill will benefit.

4.3.2.3 Effects on Other Living Marine Resources

To the extent this alternative helps ensure the long-term abundance and availability of krill, other living marine resources that are dependent on or are sensitive to the abundance and availability of krill will benefit.

4.3.2.4 Effects on Other Fisheries

To the extent this alternative helps ensure the long-term abundance and availability of krill and thus the abundance and availability of targeted fish species, fisheries for those targeted species will benefit.

4.3.2.5 Economic Effects

This alternative is likely to help maintain the economic values associated with fisheries and non-consumptive resource uses that are tied to the abundance and availability of krill. To the extent this alternative prevents a krill fishery that would otherwise occur, there would be a reduction in economic activity. However, it is not clear that there would be any economic losses.

4.3.2.6 Effects on Data Collection

This alternative is not likely to substantially affect the future collection of data, except that there would be no data collected to provide a basis for determining if disruption of aggregations would affect the stock in any way.

4.3.2.7 Effects on Bycatch

This alternative would not be expected to affect bycatch except to the extent that bycatch might be greater during aggregating periods than other periods in which krill might be harvested.

4.3.2.8 Effects on Habitat

This alternative would not be expected to have any impact on habitat.

4.3.2.9 Effects on Protected Species

To the extent this alternative protects the long-term abundance and availability of krill, this alternative is likely to benefit protected resources that are dependent on or sensitive to the abundance and availability of krill.

4.3.2.10 Administrative Considerations

This alternative would be somewhat difficult given the variability of spawning times and the fact that spawning times vary between species and areas of the coast. It would be necessary to establish a scientific basis for the selected closed or open seasons and to evaluate the benefits and costs of alternative closed and open seasons. This documentation would be difficult but not impossible. However, to the extent seasonal aggregations are driven as much by calendar as by oceanic conditions, it could be difficult to establish open and closed seasons that work well under all oceanographic scenarios. This alternative would not provide as much certainty of effective control as other alternatives such as area closures and low quotas.

4.3.3 Exempted Fishing Permits

4.3.3.1 Effects on Status of Krill

This measure could have long-term benefits for krill conservation if (a) EFPs are well structured and controlled, with limited size and scope and (b) activities under EFPs are well monitored such that the information base is improved for a better understanding of the krill resource and its role in the marine environment. In the short term, there should be little impact on the krill resource assuming control over the size, timing, and areas of operations under an EFP.

4.3.3.2 Effects on Other Fish Species

This alternative should have little or no impact on other fish species provided that activities under EFPs are sufficiently controlled and observed. The risk of adverse effects could be reduced by some sort of trigger condition that would curtail or terminate the EFP if certain impacts on other fish species were observed (e.g., takes of salmonids or overfished groundfish above a certain level).

4.3.3.3 Effects on Other Living Marine Resources

This alternative should have little or no impact on other living marine resources provided that activities under EFPs are sufficiently controlled and observed. It would be important to ensure that krill fishing would be precluded or at least very limited in times and areas in which cetaceans or seabirds might be especially dependent on krill abundance for forage. The risk of adverse effects could be reduced by some sort of condition that would curtail or terminate the EFP if certain impacts on other living marine resources were observed (e.g., interactions with cetaceans or a take of seabirds).

4.3.3.4 Effects on Other Fisheries

This alternative should have little or no impact on other fisheries provided that the activities under EFPs are sufficiently controlled and observed.

4.3.3.5 Economic Effects

This alternative is not likely to have direct economic effects. The long-term effects will depend on whether EFPs or other controls result in fishing and future management changes that then control fishing activities.

4.3.3.6 Effects on Data Collection

This alternative will make contributions to data collection to the extent that fishing under EFPs occurs with good observations, reporting and analysis of data generated by the fishing.

4.3.3.7 Effects on Bycatch

This alternative could be beneficial in terms of documenting potential bycatch levels if a krill fishery were to be allowed.

4.3.3.8 Effects on Habitat

This alternative would not be expected to have substantial impacts on habitat.

4.3.3.9 Effects on Protected Species

This alternative would not be expected to have direct effects on protected species, but it could result in better data on the relationship and co-occurrence of krill and protected species.

4.3.3.10 Administrative Considerations

This alternative is not especially complex. The Council has substantial experience with EFPs, and has established protocols for soliciting and processing EFP applications. Further, NMFS has delegated responsibility for EFP processing to the Regional Administrators, simplifying the decision process. EFPs have proven to be an effective tool for promoting research-oriented fishing by interested parties with little risk to the resources involved or to the resource users involved. As with most other measures, however, there remains a requirement for adequate documentation of the likely benefits and costs of the EFP and the impacts of EFP fishing on the variety of resources of concern.

4.3.4 Prohibit Krill Fishing in the EEZ Initially but Establish Process for Future Permitting

Under this alternative, the Council would adopt a conservative stance with the expectation that, through resource surveys and research cruises and with the addition of results of EFPs and other activities, there would ultimately be a sound, scientific basis for determination of conditions under which krill fishing could be reasonably permitted. At that time, the Council would amend its management strategy as necessary and appropriate so that fishing could occur if there were times, places, amounts, or other limits on that fishing to ensure that there would be no subtantial harm or excessive risk of harm to the marine resources that the Council has responsibility for. This alternative would have the same effects as alternative 1 for the present time. Future effects would depend on future management changes.

4.3.5 Combinations of Measures

The Council could conclude that a combination of measures could be adopted at this time that would allow krill fishing without excessive risk of substantial harm to the marine resources for which the Council has responsibility. It is conceivable a mix of time and area controls and harvest limits, with attendant permit, reporting and observer requirements, would allow fishing, provide sufficient protection for krill, provide sufficient protection for other living marine resources, and generate needed data for future management decisions. Unfortunately, there are dozens of possible scenarios and it is not possible to develop and evaluate them at this time. The Council would have to provide more guidance as to the range of combinations to be evaluated and possibly priorities among the objectives of the management program. This could be a very complex undertaking, and the resources required could be substantial. This alternative is not considered further at this time.

4.4 Environmental Justice Concerns

There do not appear at this time to be any environmental justice concerns associated with the prospective action to conserve and manage krill resources off the West Coast. After Council action on this document, this issue will be revisited for confirmation.

4.5 Coastal Zone Management Act Concerns

Upon selection of preferred alternatives, a request for consistency determination under the CZMA will be sent to each coastal state.

4.6 American Indian Religious Freedom Act

None of the alternatives are expected to have any effects related to this Act.

4.7 Cumulative Impacts

Generally, in combination with existing fishery controls and existing measures to protect other marine resource components, all of the action alternatives considered would likely add to the

overall conservation of important living marine resources (and associated users) along the West Coast.

5.0 MITIGATION AND UNAVOIDABLE ADVERSE IMPACTS (To be completed after Council decisions)

5.1 Mitigating Measures

5.2 Unavoidable Adverse Impacts

5.3 Irreversible and Irretrievable Commitment of Resources

6.0 CONSIDERATION OF NOAA AND CEQ SIGNIFICANT IMPACT CRITERIA

NOAA Administrative Order 216-6 (NAO 216-6) identifies nine criteria, in addition to the Council on Environmental Quality's (CEQ) regulations at 40 C.F.R. § 1508.27, for determining the significance of the impacts of an action for purposes of NEPA. For the alternatives presented in this document, the NAO 216-6 and CEQ criteria are addressed as follows:

1. Can the action be reasonably expected to jeopardize the sustainability of any targeted fish species? None of the alternatives would be expected to directly and significantly affect any targeted fish species in the area of the management action. However, the No Action alternative and the "uncontrolled fishing for krill" alternative could both result in adverse impacts on targeted fish stocks through the reduction of necessary forage.

2. Can the action be reasonably expected to jeopardize the sustainability of any non-target species? None of the alternatives would be reasonably expected to jeopardize the sustainability of any non-target species, though the risk of adverse impacts on such species as cetaceans and seabirds that are dependent on krill would be greater under the No Action and uncontrolled krill fishing alternatives. Whether these would jeopardize

the continued existence of any species listed under the Endangered Species Act (ESA) would be assessed for a consultation under that act prior to approval or implementation of any such alternative.

3. Can the action be reasonably expected to allow substantial damage to the ocean and coastal habitats and/or essential fish habitat (EFH) as defined under the Magnuson-Stevens Act and identified in FMPs? None of the alternatives would be expect to alter the expected impacts to ocean and coastal habitats and/or essential fish habitat (EFH) as defined under the Magnuson-Stevens Act for currently targeted species as designated in existing FMPs for West Coast fisheries, except that one alternative would expand the EFH designation for West Coast groundfish to include krill. There also would be no effect on any property or place listed in or eligible for listing in the National Register of Historic Places, nor would it cause loss/destruction of significant scientific, cultural, or historic resources.

4. Can the action be reasonably expected to have a substantial adverse impact on public health and safety? None of the alternatives would be expected to affect public health and safety. U.S. vessels are subject to U.S. Coast Guard safety requirements and those would not be affected by this rule.

5. Can the action be reasonably expected to have an adverse impact on endangered or threatened species, marine mammals, or critical habitat of these species? All of the alternatives except the No Action alternative and the uncontrolled fishing" alternative would be expected to contribute to protection and conservation of endangered or threatened species, marine mammals, and critical habitat of these species. A formal consultation is expected to be conducted under the ESA once the Council has decided on a proposed course of action. It is anticipated that an informal consultation addressing the potential impacts of krill fishing (if any) allowed under that proposed action will conclude that there is no need for further consultations.

6. Can the action be reasonably expected to result in cumulative adverse effects that could have a substantial effect on the target species or non-target species? None of the alternatives except the No Action alternative and the unrestricted fishing alternative would be expected to result in cumulative adverse effects that could have a substantial effect on the target species or non-target species.

7. Can the action be reasonably expected to have a substantial impact on biodiversity and ecosystem function within the affected area (e.g., benthic productivity, predator-prey relationships, etc.)? None of the alternatives except perhaps the No Action and unrestricted fishing alternatives could reasonably be expected to have a substantial impact on biodiversity and ecosystem function within the affected area (e.g., benthic productivity, predator-prey relationships). No effects in terms of introduction/spread of nonindigenous species would be expected under any alternatives.

8. Are significant social or economic impacts interrelated with significant natural or physical environmental effects? There are no identifiable significant adverse individual

or cumulative social or economic impacts associated with any of the alternatives.

9. To what degree are the effects on the quality of the human environment expected to be highly controversial? There are no known highly controversial effects on the quality of the human environment. To the extent krill fishing were to occur with little or no control, there would be more uncertain effects or a higher risk of effects that involve unique or unknown risks. Depending on the Council's final choice of action, there could be a new precedence set and possibly some impact on State or local regulations outside the EEZ.

7.0 LIST OF PREPARERS

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8.0 LIST OF AGENCIES AND PERSONS CONSULTED

National Ocean Services, NOAA
West Coast National Marine Sanctuaries Managers
National Marine Fisheries Service
U.S. Fish and Wildlife Service
U.S. Coast Guard
West Coast Treaty Tribes

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10.0 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)

Figure 15. Chlorophyll along the California, Oregon, and Washington coasts, September 21, 2004, detected by Sea-viewing Wide Field-of-view Sensor (SeaWiFS), indicating coastal upwelling was strong that day. High concentrations of phytoplankton have colored the ocean waters dark green in the natural color image shown on the left; on right panel highest concentrations (dark red) are shown near the shore, especially in the northern part of the EEZ. (NASA images courtesy the SeaWiFS Project, Goddard Space Flight Center, and ORBIMAGE)

Figure 16. Essential habitat *Euphausia pacifica,* indicated in grey shading.

Figure 17. Essential habitat *Thysanoessa spinifera,*indicated in grey shading..

ATTACHMENTS

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