



NOAA Technical Memorandum NMFS-AFSC-273

**Benthic Invertebrates of the
Eastern Bering Sea: A Synopsis of the
Life History and Ecology of the Sea Star
*Asterias amurensis***

by
K. R. Smith and C. E. Armistead

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center

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ABSTRACT

Invertebrates constitute an important element in the benthic ecology on the eastern Bering Sea (EBS) continental shelf, playing an important part in the food web supporting not only the benthos, but commercially important demersal fish species as well. The asteroid species *Asterias amurensis* represents a major portion of the benthic invertebrate biomass over most of the shelf, but it is especially prevalent in the inshore domain out to about the 50 m isobath. The species is also native to coastal areas of the northwestern Pacific, including the Tatar Strait, eastern and western Sea of Japan, and the east coast of Japan. It is a predator upon numerous shelled mollusk species, as well as other invertebrates of limited motility, and is also an opportunistic scavenger. Asteroids appear to have few predators, and in food webs *A. amurensis* is a terminal consumer. It therefore competes with some commercially important demersal fish species, as well as commercially important invertebrates such as the king crab *Paralithodes camtschaticus*. A possible mitigating circumstance in its ecological role is the large contribution to secondary production constituted by the release of potentially millions of eggs by each spawning female during the annual reproductive cycle.

With its lack of susceptibility to predation, the species has proven a major threat to the ecological balance in areas where it is not native, but has been inadvertently introduced by such means as release of planktonic larvae in ballast water jettisoned by foreign ships in port; for example, in some coastal waters of southeastern Australia and Tasmania. Here native species of bivalves have proven especially vulnerable to the predator.

This report presents a synopsis of the current knowledge of the life history and ecology of the species, including details of its distribution in the EBS based on maps showing abundance data from the annual bottom trawl surveys of fish and invertebrates on the EBS shelf conducted

from 1983 to 2013 by the National Oceanic and Atmospheric Administration, Alaska Fisheries Science Center, Resource Assessment and Conservation Engineering Division. The biological characterizations are from the available published literature and are based on observations of populations in the native or invaded ranges of the species. This is the second in a series of such Technical Memoranda published to provide information on invertebrate species significant to the ecology of commercially important demersal and benthic fish and invertebrates of the EBS.

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INTRODUCTION

The eastern Bering Sea (EBS) continental shelf is an important and productive ecosystem, comprising essential fish habitat for a number of commercially important fish and invertebrate species (Lauth 2011, Pereyra et al. 1976). From littoral waters off the west coast of Alaska, the shelf extends out to the shelf break at the top of the EBS continental slope, at roughly 200 m depth. The shelf seafloor consists of two or more oceanographic subareas, each with its own benthic assemblage of species (Nagai and Suda 1976, Neiman 1968, MacIntosh and Somerton 1981, Shimek 1984, Yeung and McConnaughey 2006) comprising the animal portion of the biotope. Although assemblages delineated in the region by investigators vary somewhat with methods used in sampling ecological variables, these groups resolve into at least a low-Arctic-Boreal group and a Subarctic-Boreal group, inhabiting the northeastern waters from inshore out to about the 100 m isobath, and the southeastern waters from there out to the edge of the shelf, respectively.

Invertebrates are a significant portion of the total benthic faunal biomass of the EBS shelf, and a significant element in the benthic ecology. This has been shown by annual bottom trawl surveys of demersal and benthic fish and invertebrates, conducted by the Resource Assessment and Conservation Engineering (RACE) Division, Alaska Fisheries Science Center (AFSC), National Oceanic and Atmospheric Administration (NOAA). For example, since 1982 the yearly proportion of total survey catch weight constituted by invertebrates has ranged from 13.5% to 28.4% (K.R.S. observation). Data from these surveys comprise time series from 1971 to the present (Acuna and Lauth 2008, Yeung and McConnaughey 2006). As a group, invertebrate species are pervasive over the shelf, and are congruent with habitat essential to many species of commercially utilized fish and shellfish, including such invertebrates as the crab

genera *Paralithodes* spp. and *Chionoecetes* spp. In this habitat, invertebrates comprise significant prey, predator, and competitor elements in the ecology of these important species. In addition, like many non-target species of fish, non-targeted invertebrates are potentially affected by inclusion in the bycatch of commercial fishing or by incidental injuries or habitat alteration caused by fishing gear (Brown et al. 2005, Dew and McConnaughey 2005, McConnaughey et al. 2005, McConnaughey et al. 2000).

Despite their major presence in the benthos, few studies have observed details of the life histories of invertebrate species in the eastern Bering Sea, and of their relationships with other species. Published observations of limited scope are scattered among numerous sources. Studies somewhat more in-depth have been made of the same or similar species in other high-latitude marine regions in the western Pacific and the northern Atlantic. This report follows that by Smith et al. (2011) as second in a series designed to consolidate such information as it directly or indirectly relates to commercially important EBS invertebrate taxa, and to indicate areas and objectives for further, more detailed study. The literature available at the time of this writing has been examined and the pertinent information collected for inclusion herein.

GENERAL DESCRIPTION

The invertebrate species *Asterias amurensis*, within the class Asteroidea, is also known as the purple-orange (Clark 2006) or the flatbottom sea star (see internet at www.afsc.noaa.gov/Kodiak/photo/staraster.htm). It is a characteristic species of the inshore benthic biotope on the southeastern Bering Sea continental shelf, and also occurs frequently in offshore areas of the southeastern shelf. In bottom trawl surveys of the EBS shelf conducted by RACE in association with the Institute of Marine Science, University of Alaska in fall of 1975

and spring of 1976, the species was prominent. In the fall, at depths ≤ 80 m it was the most ubiquitous invertebrate, occurring at 68% of tows and was the third most abundant species as a percent of total invertebrate catch weight, 17.9%. In the subsequent spring (1976) with most stations at > 80 m in depth, it occurred in 38% of tows and comprised the fourth largest invertebrate contingent, 4.7% (Feder and Jewett 1980). The range of depth inhabited by the species in the northeastern Pacific is 10-180 m (Clark 2006). This pattern of distribution of the species in the EBS has been confirmed by later RACE bottom trawl surveys (see Geographic Distribution in the EBS, below).

Morphology

Asteroids have radially symmetrical bodies, (usually pentamerous) as adults, with a central disk surrounded by five or more rays (arms). Most species are motile (crawling) marine benthic animals. The class is thought to have developed radial symmetry ancestrally as planktonic-cum-sessile suspension feeders, subsequently evolving the re-adoption of motility (Ruppert et al. 2004). Adults are generally carnivorous, eating mostly an array of invertebrates (see section Trophic Interactions). They have a mouth on the oral surface (underside), at the center of the disk. There is often an anus on the opposite, aboral side of the disk, as well as a madreporite venting a water vascular system. Appendages called tube feet on the oral side of arms and disc are employed in crawling (Ruppert et al. 2004).

Asterias amurensis is a medium-large species of sea star, having a broad disk surrounded by five arms of moderate length, each tapering from a broad base to a pointed end. In its usual orientation, the lower, or oral, surface composed by margins of the disc and arms is flat, and has a distinct boundary with the aboral surface. The latter is covered with profuse small spines, and is uniformly purple or rarely orange. Spines can be white or pale orange. Individual size ranges

up to a maximum radius (disc center to arm tip) of about 20 cm (Clark 2006). There often is a discernible line, straight or convoluted and continuous or broken to varying degrees, formed by aboral spines along the center axis of one or more arms from the disc to the arm tip (K.R.S., personal obs.).

Phylogeny

Asterias species are members of the family Asteroiidae, order Forcipulatida, class Asterozoa (sea stars), within the phylum Echinodermata. (Ruppert et al. 2004). Like other phyla of deuterostomes, in early development echinoderm cells display radial cleavage and regulative development (i.e., dependent upon location), and the larval blastopore becomes the anus, with the mouth developing from a different antecedent. Coelom development is by budding off the archenteron. Analysis of rDNA base pair sequence suggests that echinoderms have a common ancestor with hemichordates that is not shared by other deuterostomes such as cephalochordates, urochordates, or vertebrates (Wada et al. 1992).

Range

Asterias amurensis inhabits continental shelf waters of the northeastern Pacific, including the EBS, from as far north as the eastern Chukchi Sea (Feder et al. 2005, Jewett and Feder 1981), south to the Gulf of Alaska (Clark 2006) and British Columbia (Lambert 1981). Although in the eastern Chukchi and Bering Seas the species is generally more abundant in nearshore waters < 50 m depth, in the latter region it occurs out to depths of about 200 m (Feder et al. 2005, Jewett and Feder 1981, Yeung and McConnaughey 2006). It is the most abundant large epifaunal invertebrate in Norton Sound (Fukuyama and Oliver 1985).

In the northwest Pacific the species is widespread, occurring throughout the Sea of Japan and Tatar Strait on both east and west shores, and on the east coast of Sakhalin Island. Areas

inhabited include Chaivo Bay (east coast of Sakhalin Island) and De Kastri Bay (west Tatar Strait), as well as Peter the Great Bay on the mainland and Aniva Bay on the south end of Sakhalin Island (Dautov 2006, D'yakonov 1968). They are also in waters off Tongyeong, South Korea on the Korea Strait (Paik et al. 2005). In Japanese waters specifically, they range from Hokkaido and northern Honshu (e.g., Mutsu Bay; Kim 1968) on the north to the Kii Peninsula on the south, on the Pacific side, and from Hokkaido to Toyama Bay on the Japan Sea side (Hatanaka and Kosaka 1959). They have been reported in Kure Bay, Hiroshima Prefecture (Asakawa et al. 1997) and as far south as the Ariake Sea (Fisher 1911-1930; *A. amurensis versicolor*), but D'yakonov (1968) considered the latter population to be a separate species (*A. versicolor* Sladen). D'yakonov (1968) reports that the bottom depth inhabited by the species in the northwestern Pacific is mainly 0-40 m, with less frequent occurrence at 50-60 m. Their preferred bottom is mainly sand or coarser, more consolidated material, and they are often found in the littoral zone.

The species has also invaded several new areas, where it had not occurred previously. It has appeared in coastal waters of southeastern Tasmania and in Port Philip Bay, southeastern Australia (Byrne et al. 1997b). The apparent method by which the species spread to these areas was as planktonic larvae in ballast water carried by commercial vessels sailing from waters where the species is native, such as Japan.

DISTRIBUTION OF *ASTERIAS AMURENSIS* IN THE EBS

Methods

The RACE EBS bottom trawl surveys provide an index of the abundance of each taxon caught at each sampling station by calculating the catch per unit of effort (CPUE; i.e., the

number of organisms and/or the average aggregate weight, called biomass, of catch divided by the area of bottom swept by the footrope). The standard surveys observed herein were done during summer, no earlier in the year than the 23rd of May, nor later than the 6th of October, with trawling occurring during daylight. Area swept equals the average width of the net mouth at the footrope times the distance trawled. Efficiency of the trawl gear at catching asteroids is unknown. Certainly, bottom trawls are not efficient samplers of benthic infauna; however, they are deemed sufficient for monitoring relative abundance of certain epifaunal species (MacIntosh 1980, Yeung and McConnaughey 2006). The estimates of absolute abundance thus derived may be thought of as minimums for species generally presenting such a low profile in the net path as do sea stars, but nevertheless as relative abundance indexes.

RACE Bottom Trawl Survey Design

Methods and gear used in these surveys are generally consistent from year to year. The present configuration of standard sampling stations and trawl gear design was first adopted in 1982 under the Bering Sea-Aleutian Islands Groundfish Fishery Management Plan (Acuna and Lauth 2008, Yeung and McConnaughey 2006). The annual surveys conducted since then have covered an area divided into a standard grid of 330 squares each comprising 20 nautical miles (nmi) \times 20 nmi (37.04 km \times 37.04 km), thus representing a total area of roughly 452,747 km². The standard trawl stations of the survey include 330 located at the respective centers of these squares, plus an additional 16 stations northeast of the Pribilof Islands as well as 10 stations southwest of St. Matthew Island, at the corners of select grid squares. These extra stations were added to increase sampling density in areas historically having significant concentrations of *Paralithodes* species (king crab). An additional 20 squares with 20 respective stations at the

centers were added at the northwest margin of the grid in 1988 to extend the standard survey area northwest and provide further information on the distribution of *Chionoecetes opilio* (snow crab) and *Gadus chalcogrammus* (walleye pollock; Acuna and Lauth 2008). This established a current standard survey design of 376 stations in a grid of 350 squares covering roughly 480,187 km² (Fig. 1). This grid spans the EBS shelf from the Alaska Peninsula in the southeast to approximately 62° N near St. Matthew Island in the northwest, and cross-shelf from the 20 m isobath to the 200 m isobath (Smith et al. 2011).

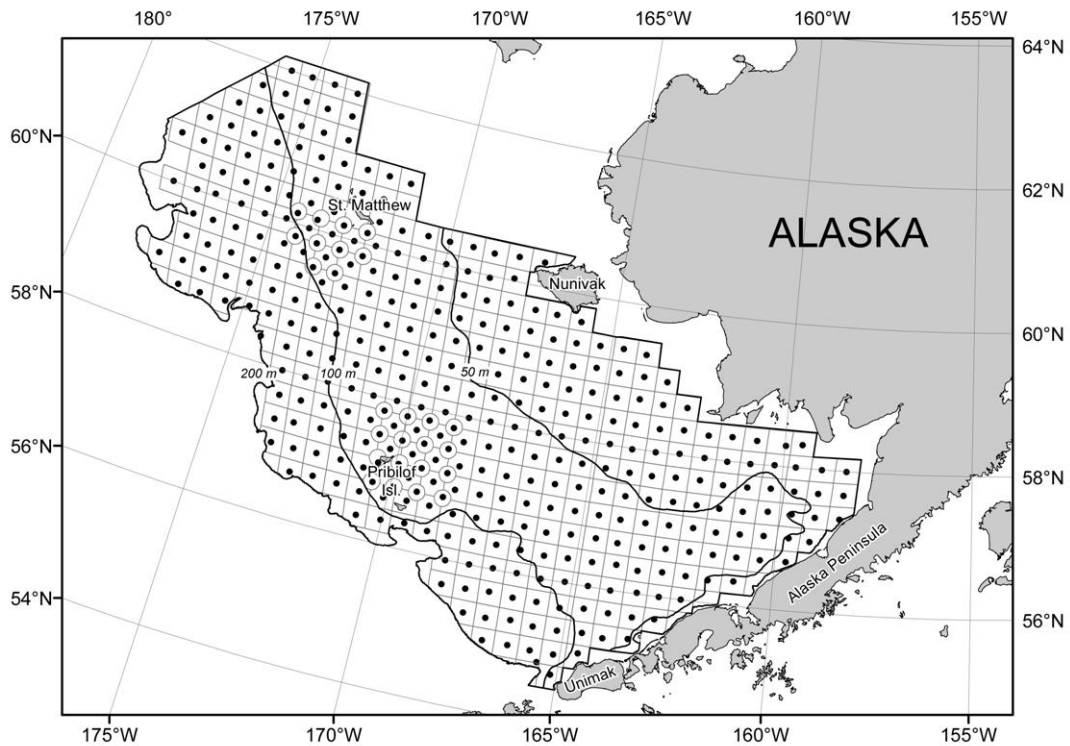


Figure 1. -- Map of sample station grid for the eastern Bering continental shelf bottom trawl survey. Dots indicate stations.

Abundance

Asterias amurensis has consistently been among the most dominant invertebrate taxa, according to both biomass and frequency of occurrence, in trawl catches of the annual RACE bottom surveys of stocks of demersal fish and benthic invertebrates on the eastern Bering Sea continental shelf (Yeung and McConnaughey 2006). Moreover, like many benthic invertebrates in the region *A. amurensis* is not uniformly abundant over the EBS shelf. Along with other species, this species generally occurs as a component of regional complexes of taxa, likely the result of differing preferences for environmental elements such as temperature, depth, bottom type, and prey (MacIntosh and Somerton 1981, McConnaughey and Smith 2000, Nagai and Suda 1976, Neiman 1968, Shimek 1984). Based on the data from the surveys of 1982 through 2002, Yeung and McConnaughey (2006) ranked invertebrate taxa in each year's survey according to each of two variables: 1) average abundance (weight-CPUE of the taxon, averaged over all survey hauls) and 2) frequency of occurrence (% of hauls where present). *Asterias amurensis* was consistently ranked in the top 50 taxa for both variables in each year. The study also found that the benthic invertebrates encountered on the southeastern Bering Sea shelf comprised two distinct regional faunal communities, each occupying its own environmental domain as well as including a characteristic assemblage of taxa. The inshore domain corresponds basically to the shelf waters from subtidal depths (~20 m) out to the 50 m isobath, while the offshore domain is from the 50 m isobath to the outer shelf edge at depths of roughly 200 m. In exception of the general boundaries, along the northwestern coast of the Alaska Peninsula the inshore domain extends southwest to about the 100 m isobath. Together both domains generally cover the extent of the EBS survey area from the Alaska Peninsula to the northern survey boundary at approximately 62° N latitude. *Asterias amurensis* was a member of both assemblages, but was

much more dominant in the inshore domain where it was consistently the most abundant taxon, in most years. It ranked lower in the offshore domain, but was still fourth highest in abundance there. Its average rank in frequency of occurrence in trawls over the total survey area incorporating both depth regimes was fifth highest.

Maps

Distribution and abundance of *A. amurensis* on the eastern Bering Sea continental shelf over the period of 1984 through 2013 is shown in Figure 2, along with broad-scale bathymetry of the region. The maps were developed using the software ArcGIS (version 10.1) developed by Environmental Systems Research Institute, Inc. (ESRI; www.esri.com) and are based on data for the standardized time series of RACE bottom trawl surveys of 1982 through 2013. The maps display year-by-year spatial distribution as the average CPUE (kilograms per hectare) within each sampling-grid square. Due to variations in emphasis by RACE personnel on taxonomic resolution in identification of various species caught as well as varying conditions and workloads in the field, resolution has varied among and within years of the survey. Four specific years (1982, 1983, 1990, and 1992) within the 32-year targeted time series have been omitted from the map sequence to avoid possible ambiguities in taxon identification. In each of these four the total EBS catch identified as merely “sea star unidentified” (Asteroidea) was significantly large relative to that identified as *A. amurensis*. However, gradual improvements in taxonomic knowledge and training have led to more informed and consistent classification of many fish and invertebrate taxa over time, and all of the other years reported relatively insignificant amounts for the “sea star unidentified” classification.

On the maps each grid square is color-coded to represent one of five contiguous CPUE intervals that together cover the full range of densities observed during all the surveys included in these diagrams. Break-point values between intervals were set according to the Jenks Natural Breaks classification system (www.esri.com). The classes are based on natural groupings inherent in the data, with break points set where there are relatively big differences in the data values. Data are divided into classes that best group similar values and that maximize the differences between classes. The maximum CPUE for the time series was determined (516 kg/ha in 2006), and the classification system was then applied to the data in that survey year. For easy comparison of densities amongst the years, the same CPUE classes were applied to all years. The color of each grid square is that of the coded class encompassing the average CPUE value of that year's trawl sample(s) taken within the square.

Habitat Domains

The maps show that the species is common over large areas of the EBS shelf. There is little indication of large-scale variation in the distribution and abundance pattern of *A. amurensis* over the total range of years. This may be related to the resistance and resilience of the species to effects of anthropogenic and natural factors such as fishing, predation, etc. This persistence and adaptability has been observed in studies of trawling effects (Brown et al. 2005, McConnaughey et al. 2005, McConnaughey et al. 2000) and benthic feeding interactions (Feder et al. 1981, Feder and Jewett 1980) indicating *A. amurensis* is an enduring terminal species in food webs in which it participates and an opportunistic scavenger, with few natural enemies.

The maps corroborate the findings of Yeung and McConnaughey (2006) describing the significant presence of the species over most of the survey area, but finding its abundance greater

at inshore depths of 20 m to 50 m than in deeper mid-shelf water out to 100 m. From there to the shelf edge at ~200 m the species seldom occurs, except in the west-central portion of the survey area. There, in the proximity of the Pribilof Islands and an offshore salient of the 100 m isobath indicating steeper bottom between depths of 100 m and 200 m, the species seems more abundant than usual for that depth. This feature separates two areas of very low abundance on the EBS shelf, in the northwest and southeast, respectively.

In the inshore domain of bottom depths ≤ 50 m, *A. amurensis* shares the invertebrate assemblage with other prominent species showing similar habitat preferences, such as *Chionoecetes bairdi* (snow crab), *Paralithodes camtschaticus* (red king crab), and the whelk gastropods *Neptunea heros* and *Neptunea ventricosa* (Shimek 1984, Smith et al. 2011, Yeung and McConnaughey 2006). This area is part of the zone dominated by the low Arctic-Boreal complex of benthic marine fauna (Nieman 1968, Shimek 1984).

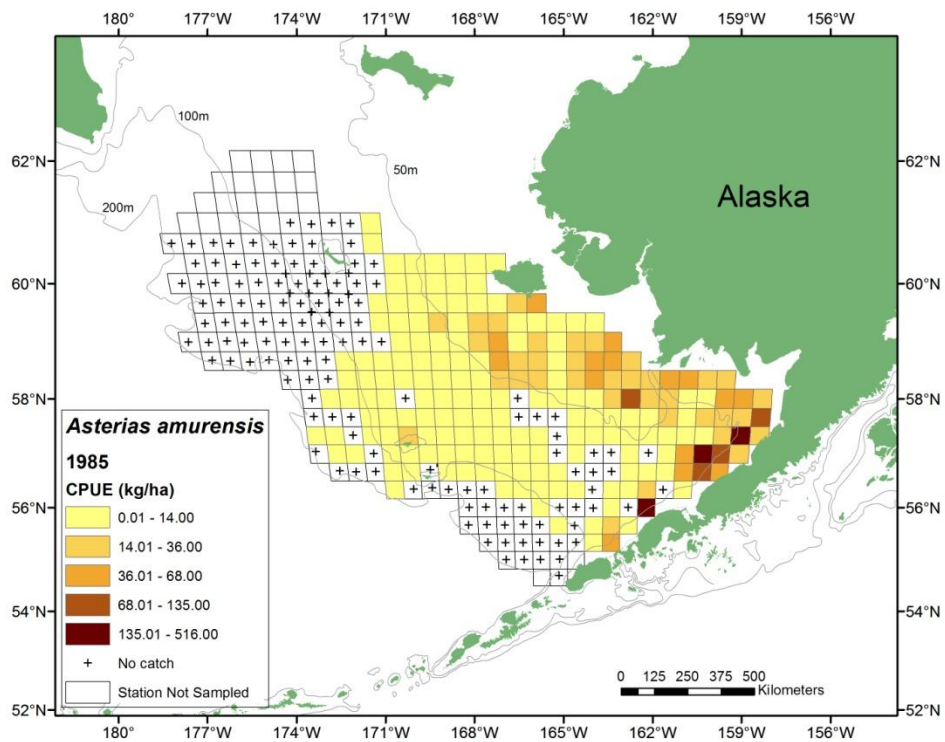
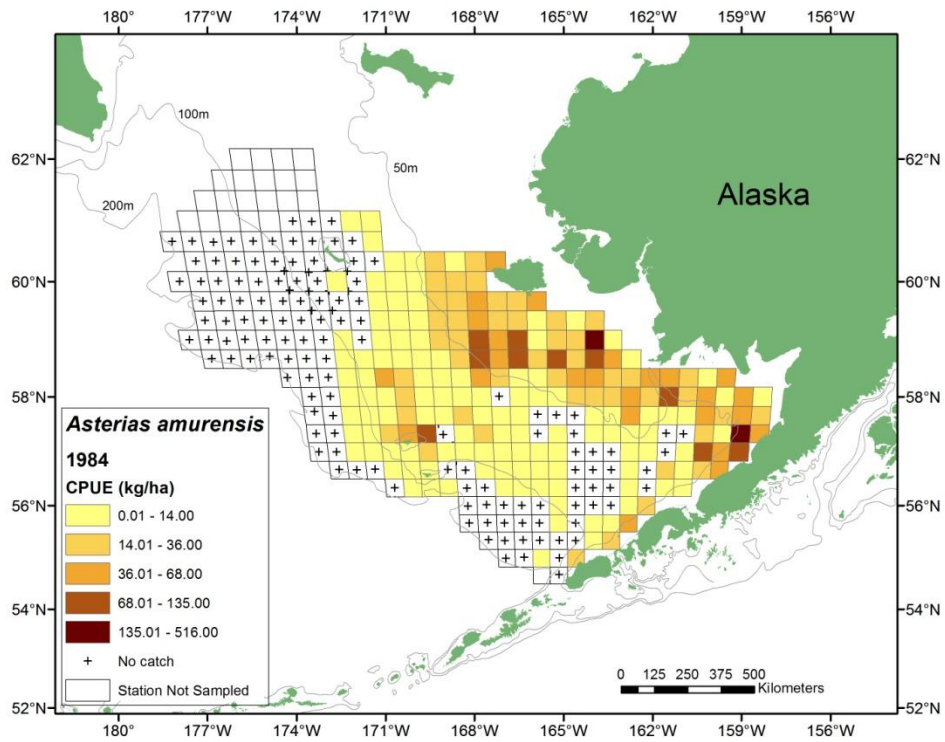


Figure 2. -- Maps showing abundance of *Asterias amurensis* in the Eastern Bering Sea (EBS) shelf region as catch per unit effort (CPUE, kg/ha) by standard RACE bottom trawl sample surveys of groundfish and invertebrates for the select years 1984 through 1989, 1991, and 1993 through 2013. The grid of 20 nmi \times 20 nmi contiguous squares represents the standard EBS shelf area covered by the survey. Each map square is colored to represent the average CPUE of the species within that square in that year's survey.

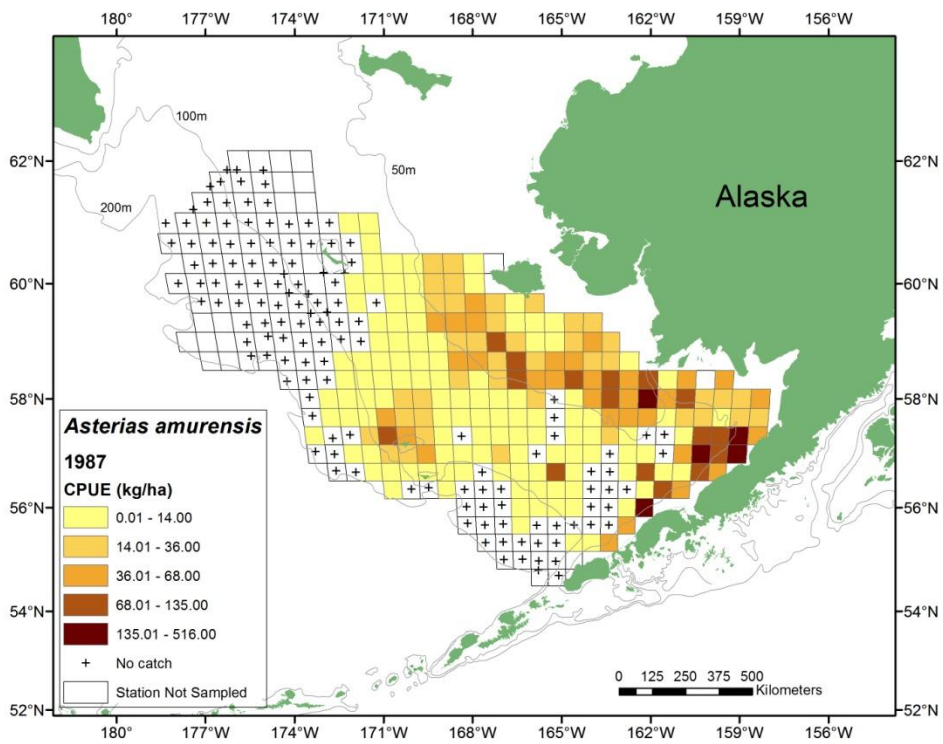
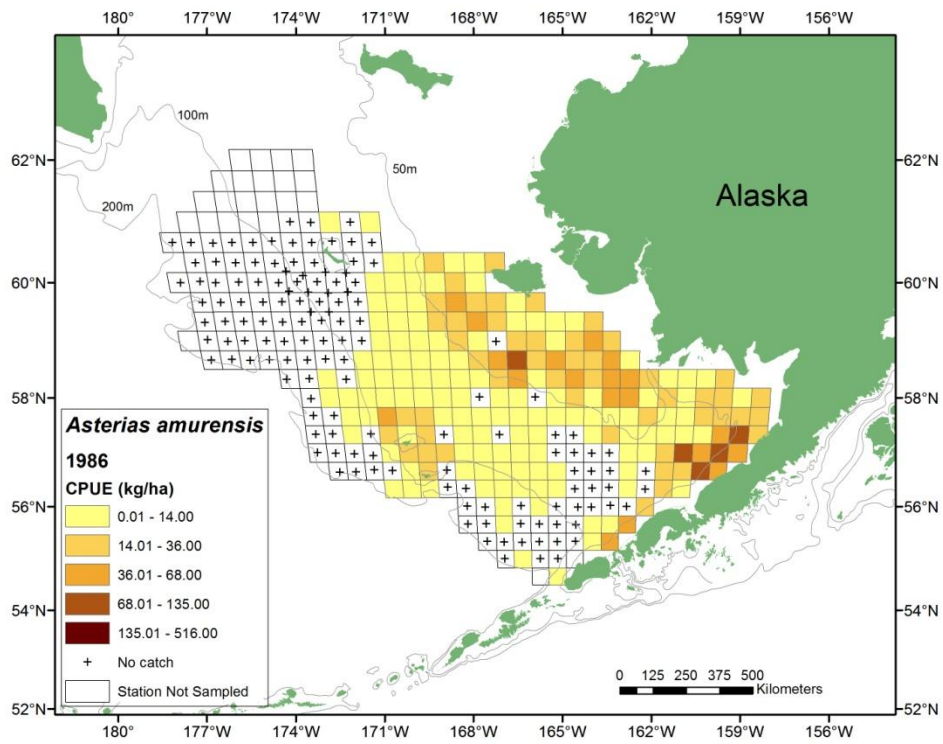


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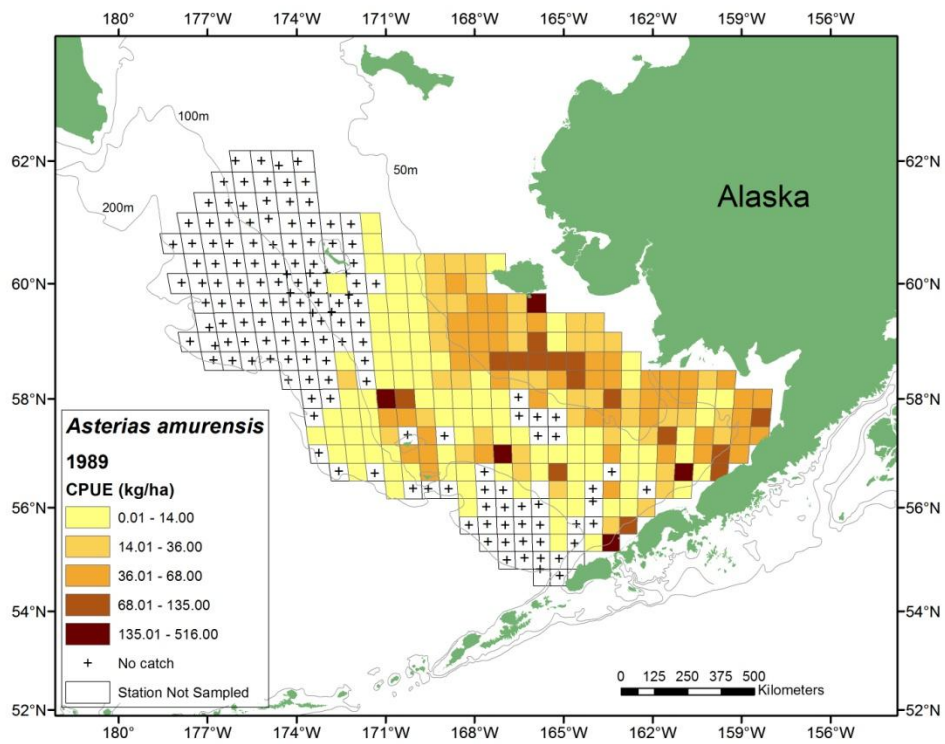
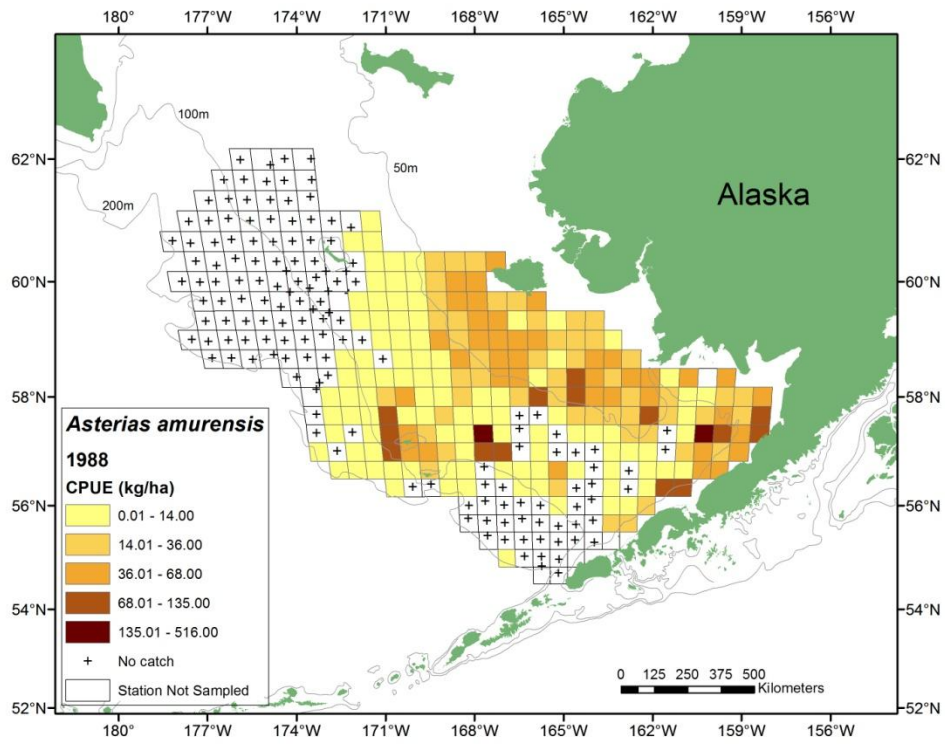


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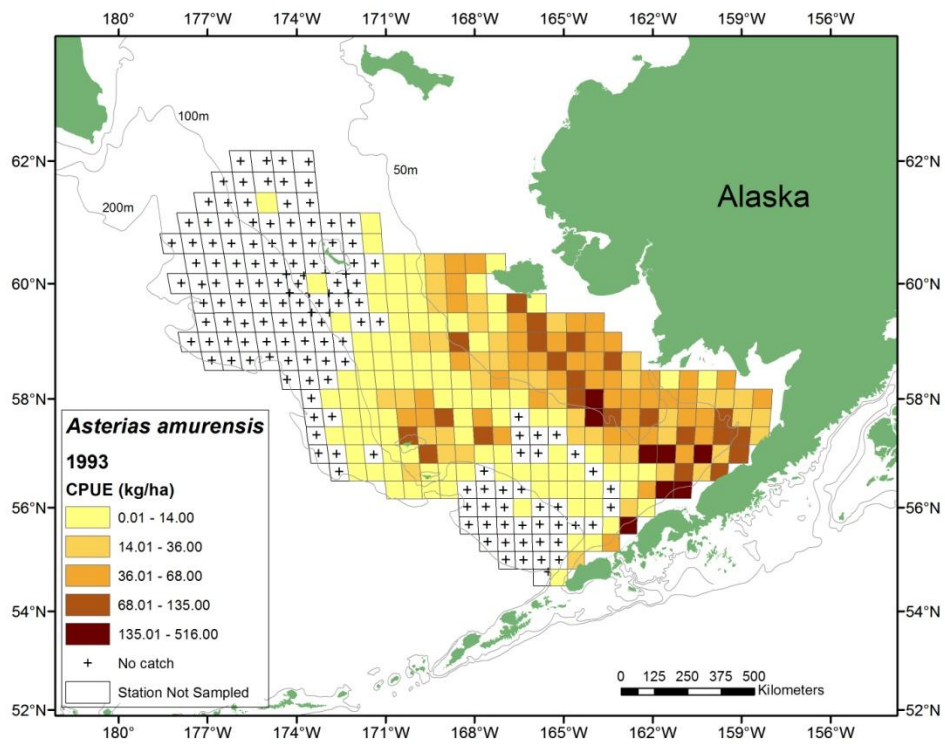
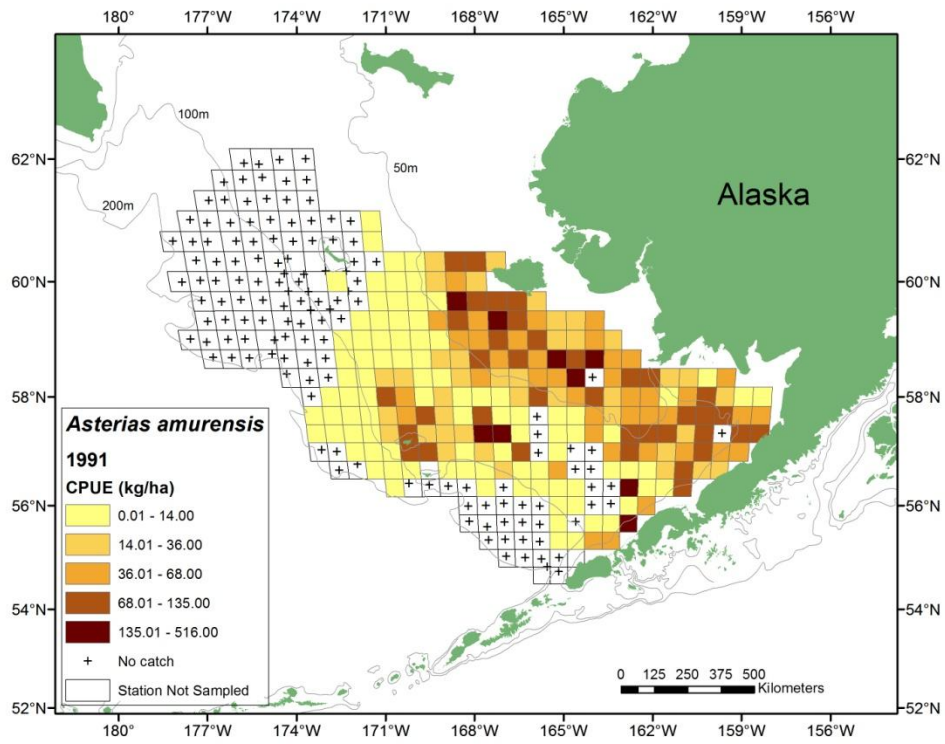


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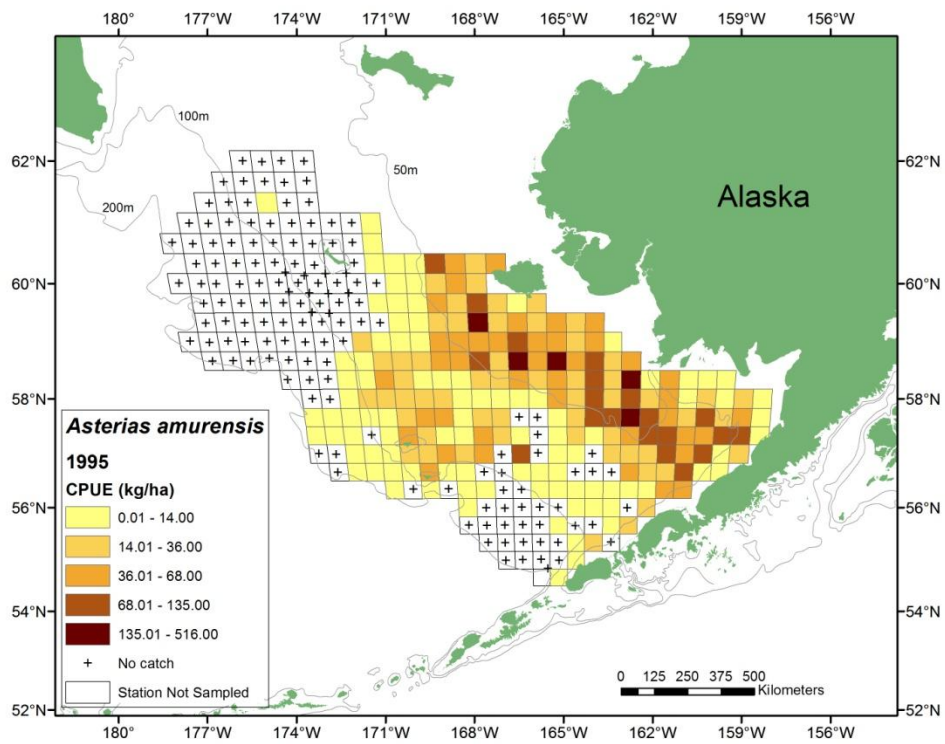
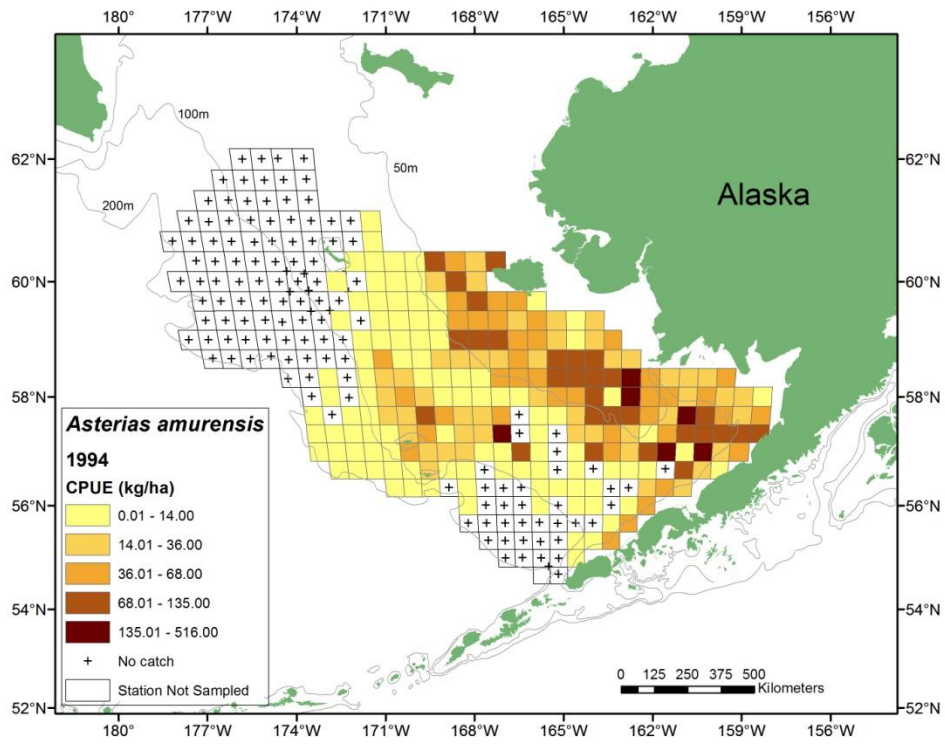


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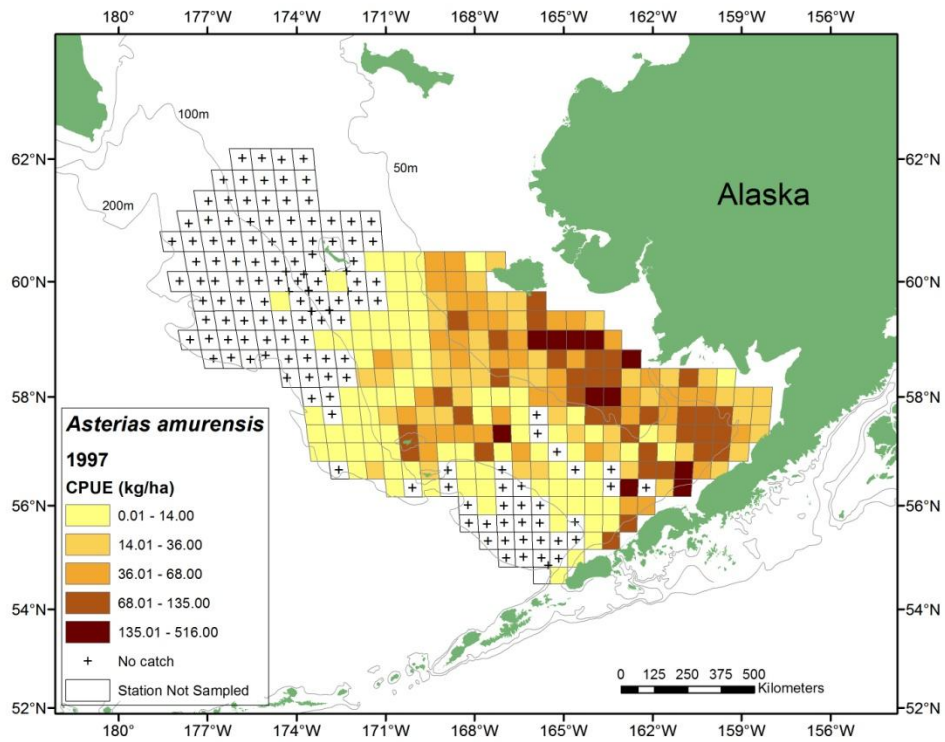
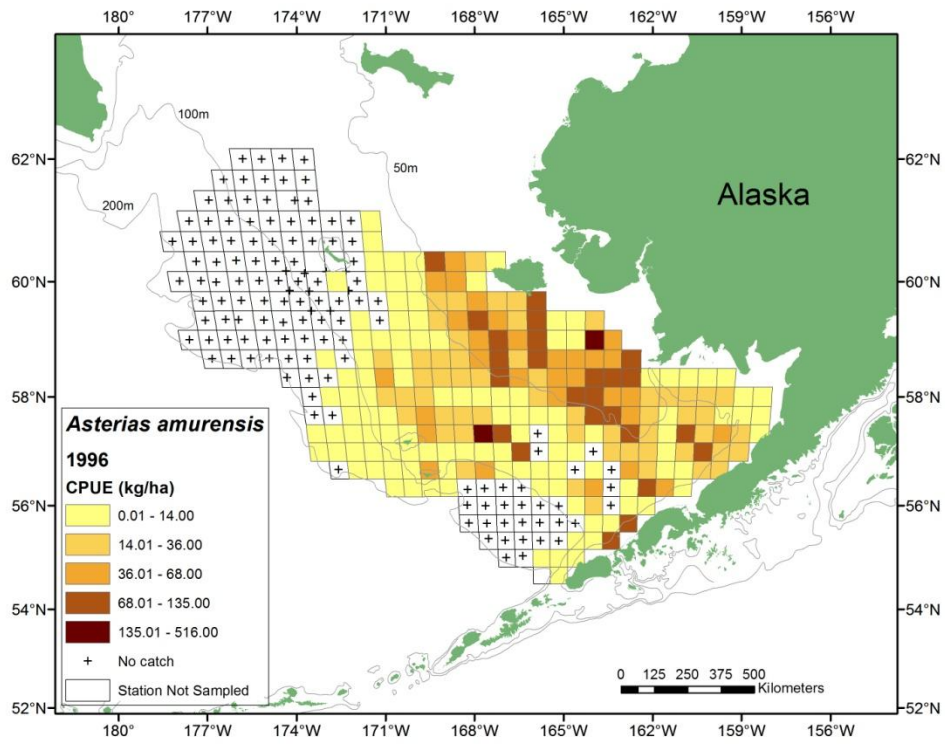


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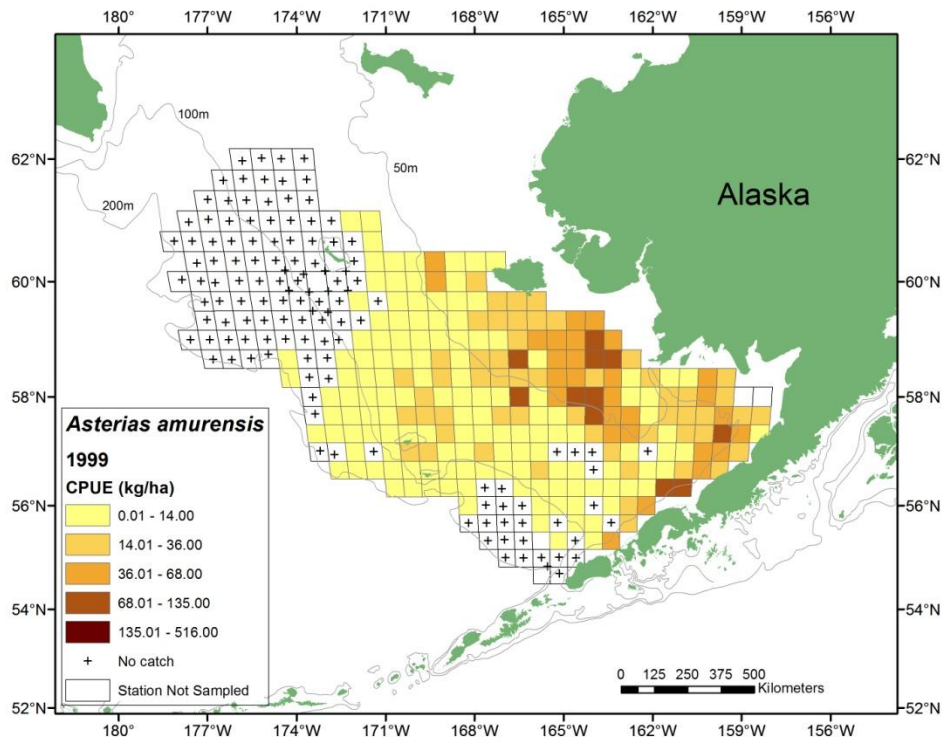
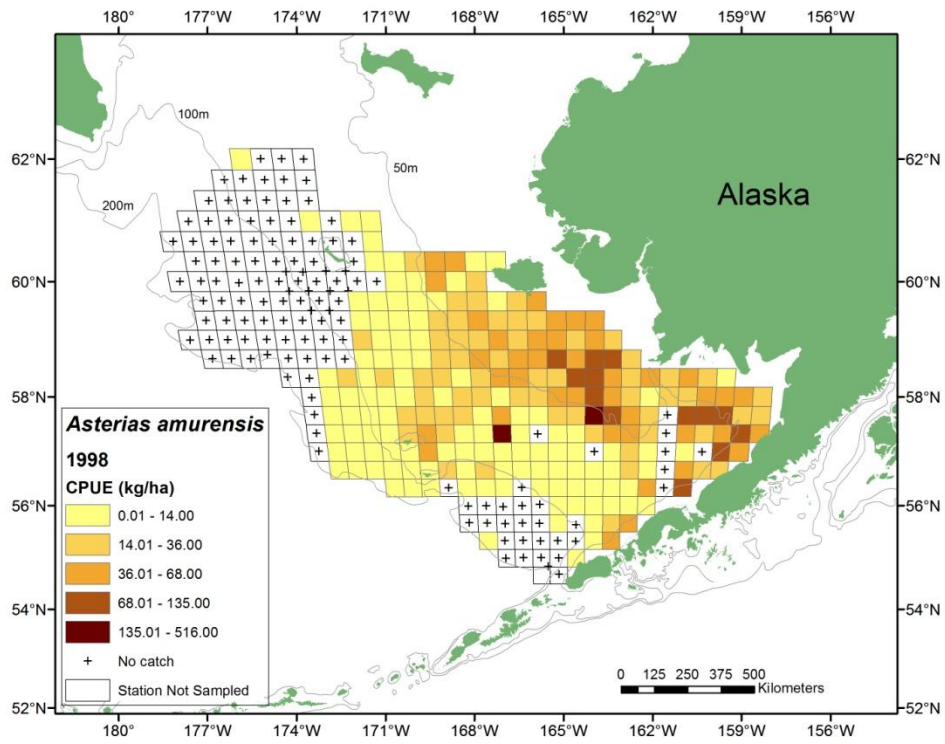


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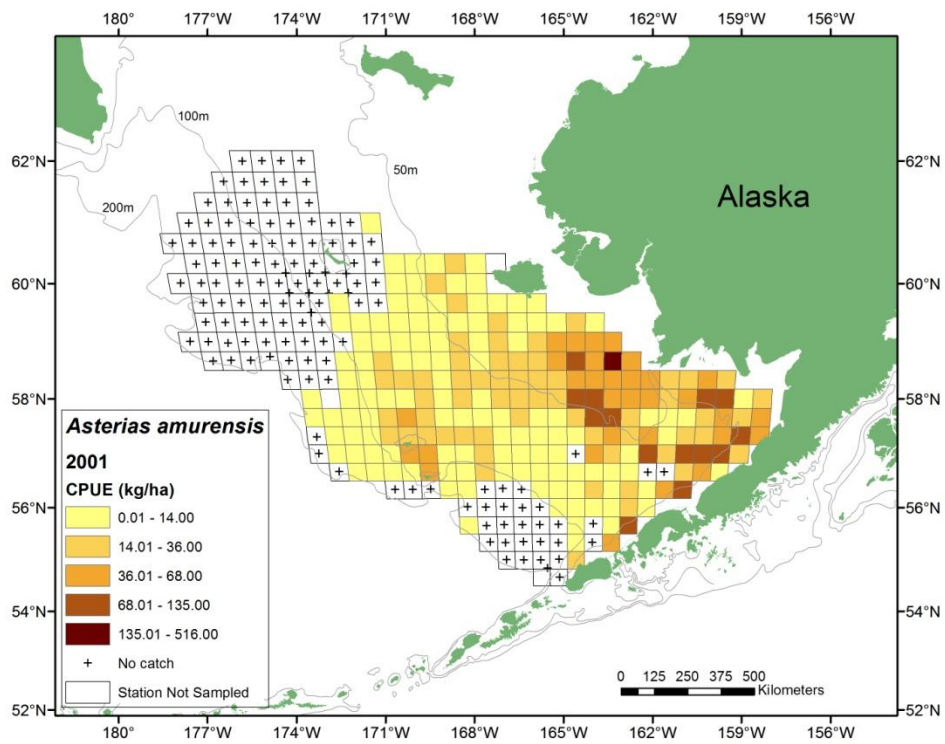
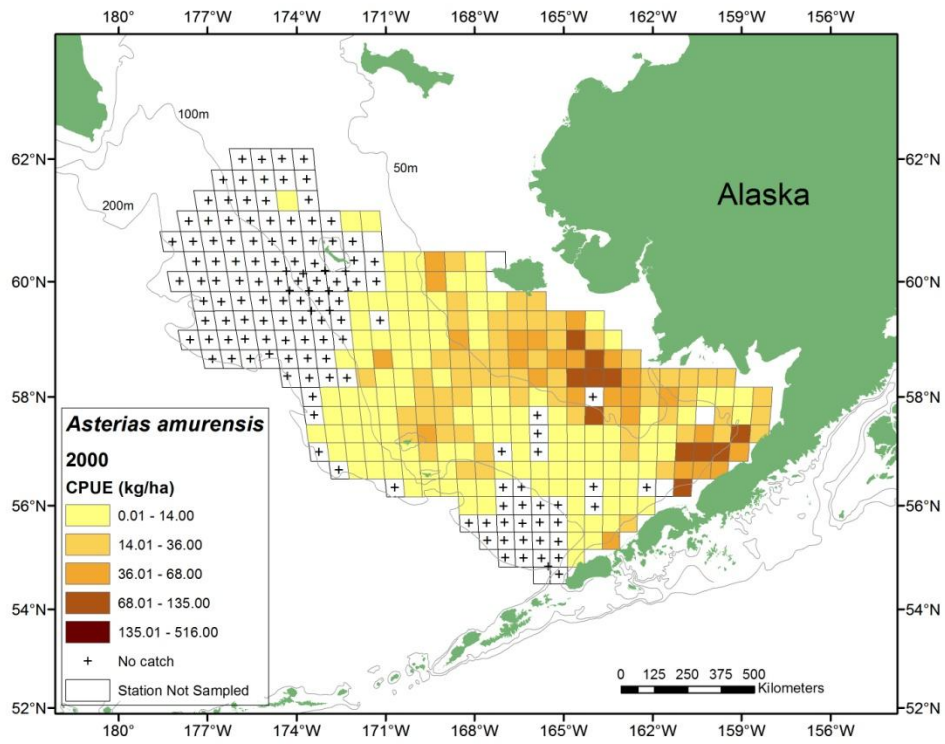


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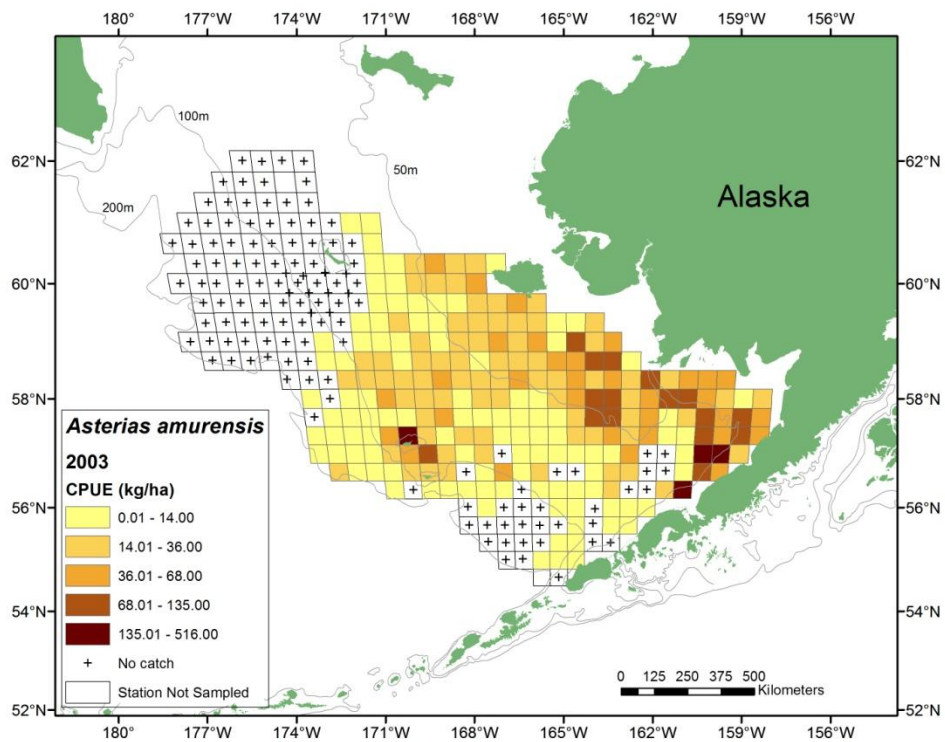
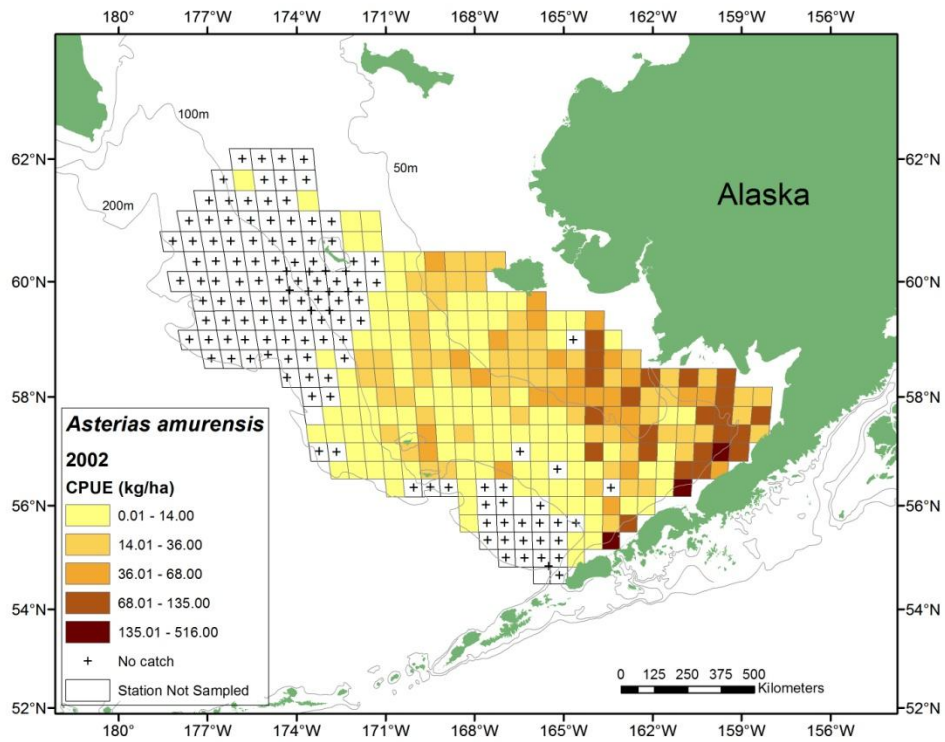


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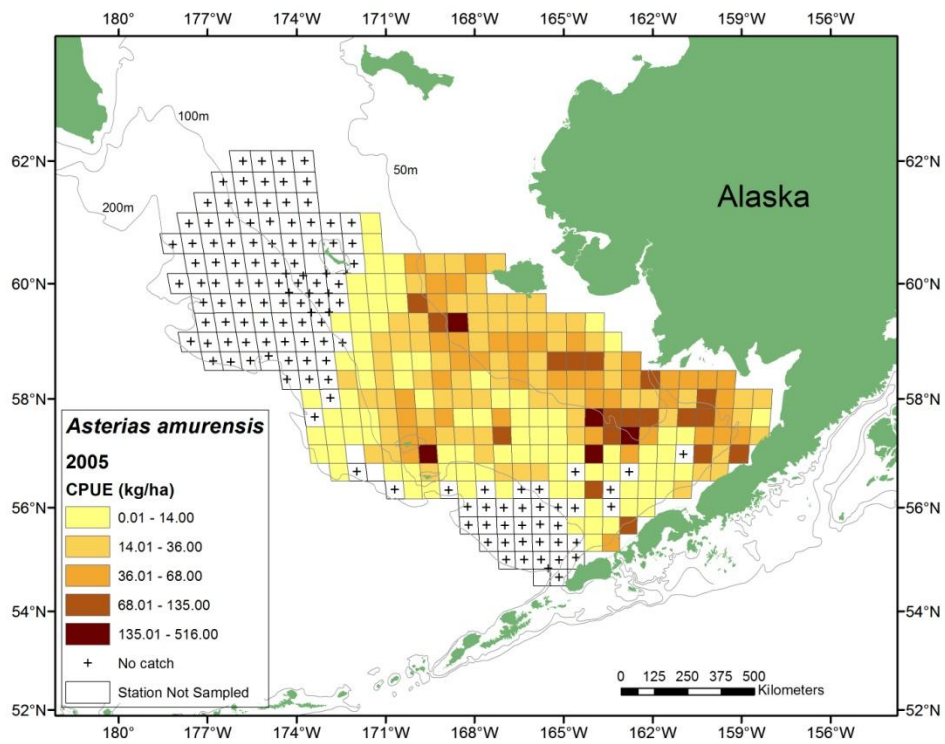
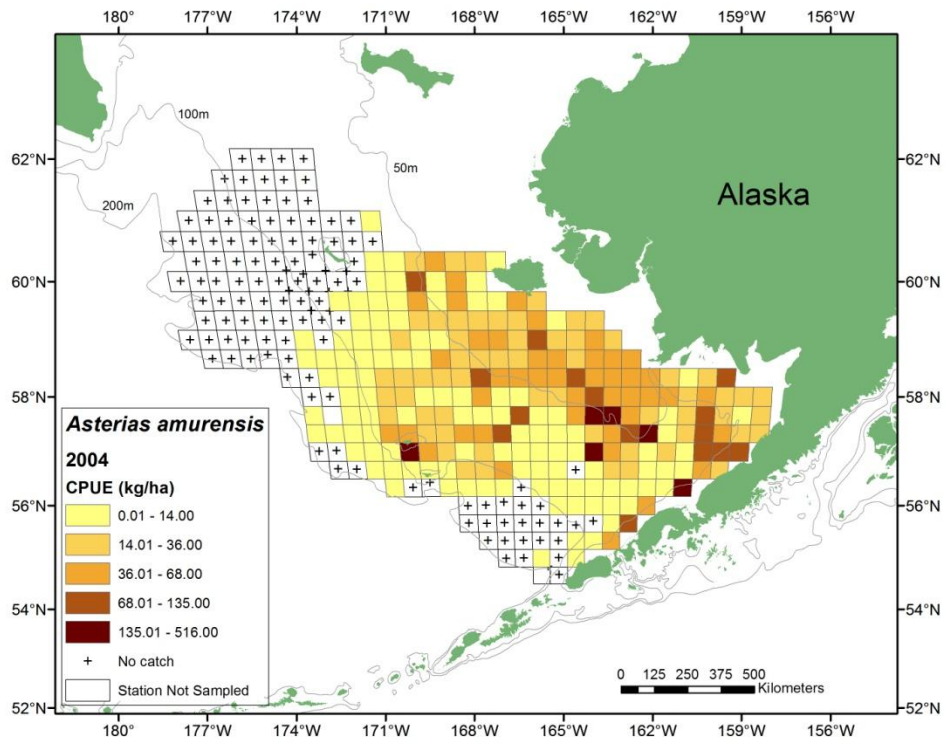


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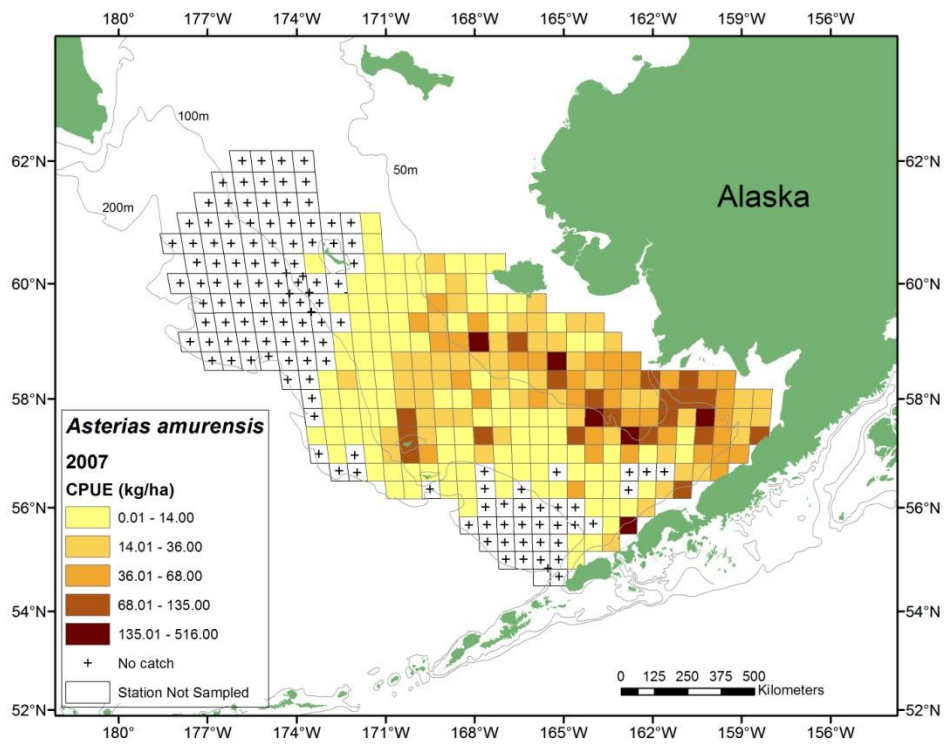
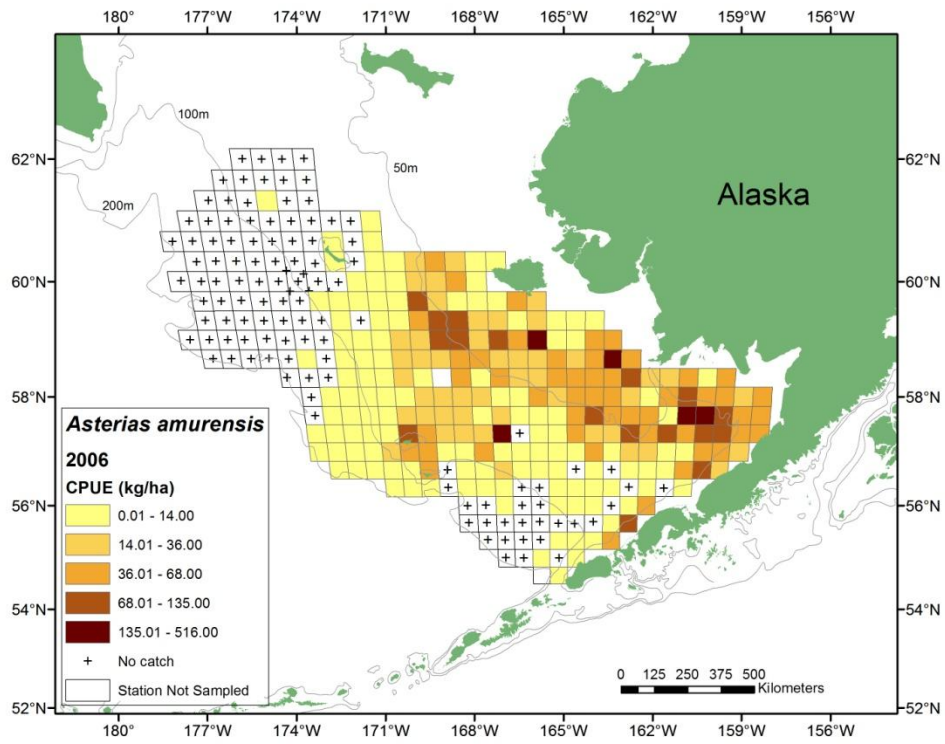


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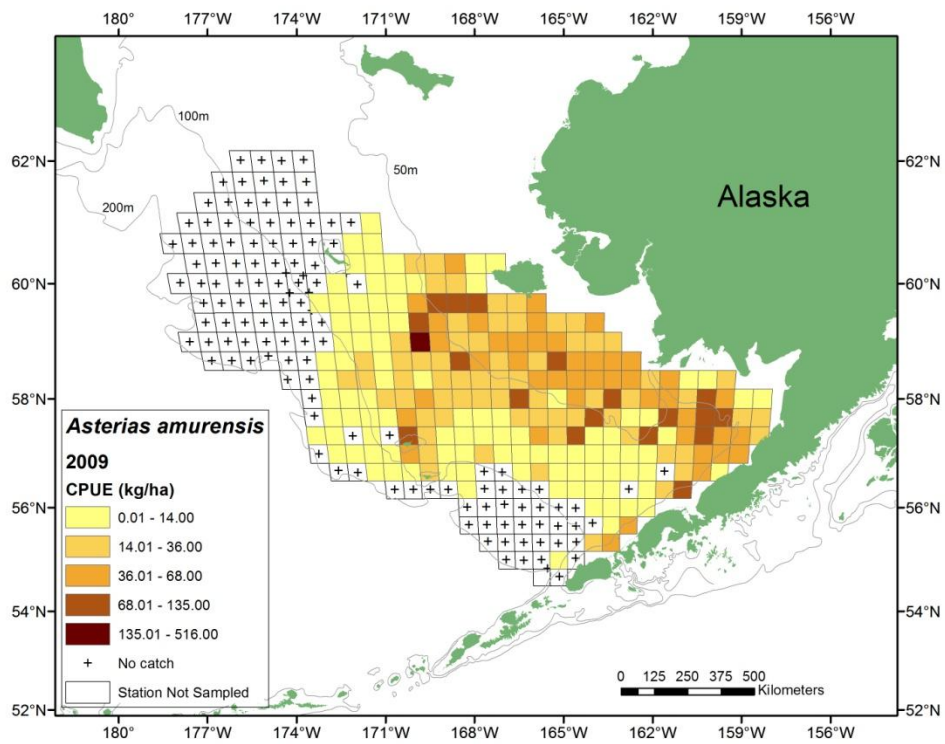
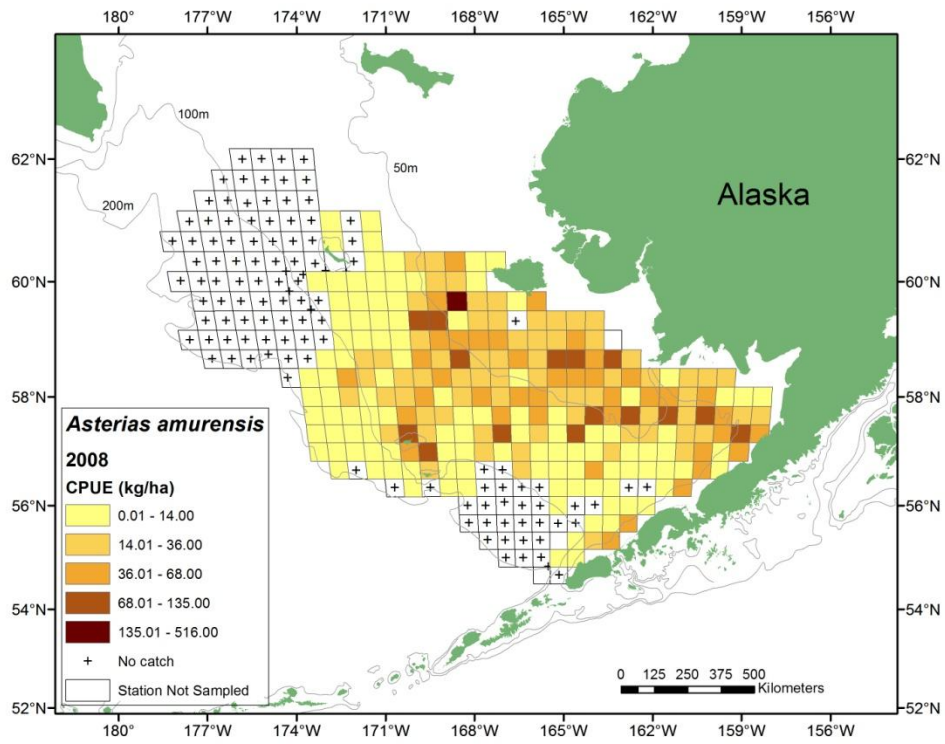


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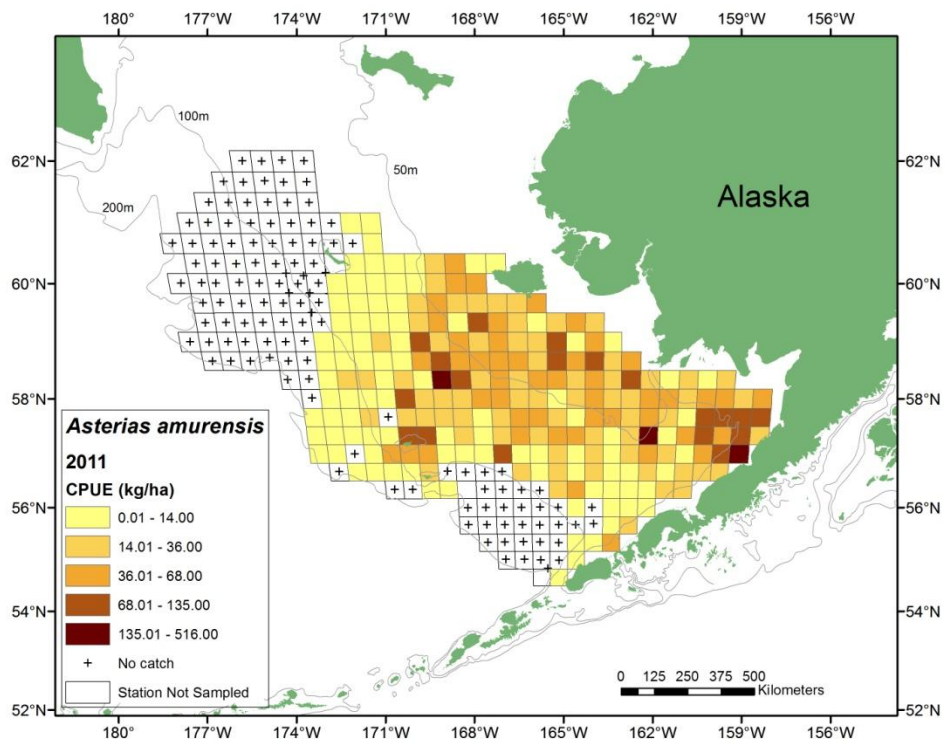
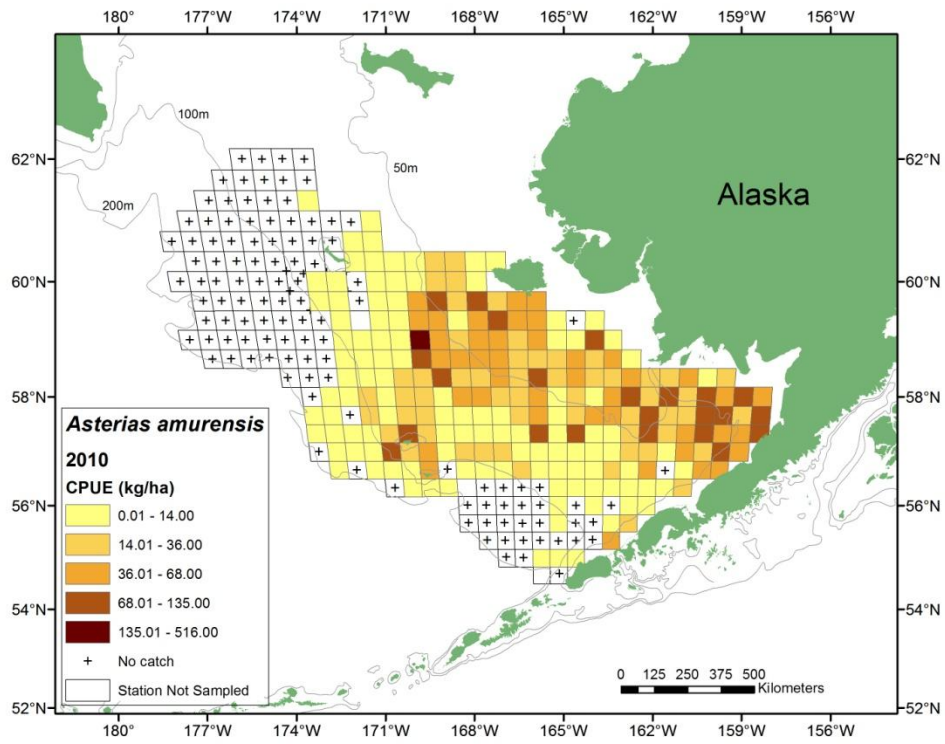


Figure 2. -- Cont.

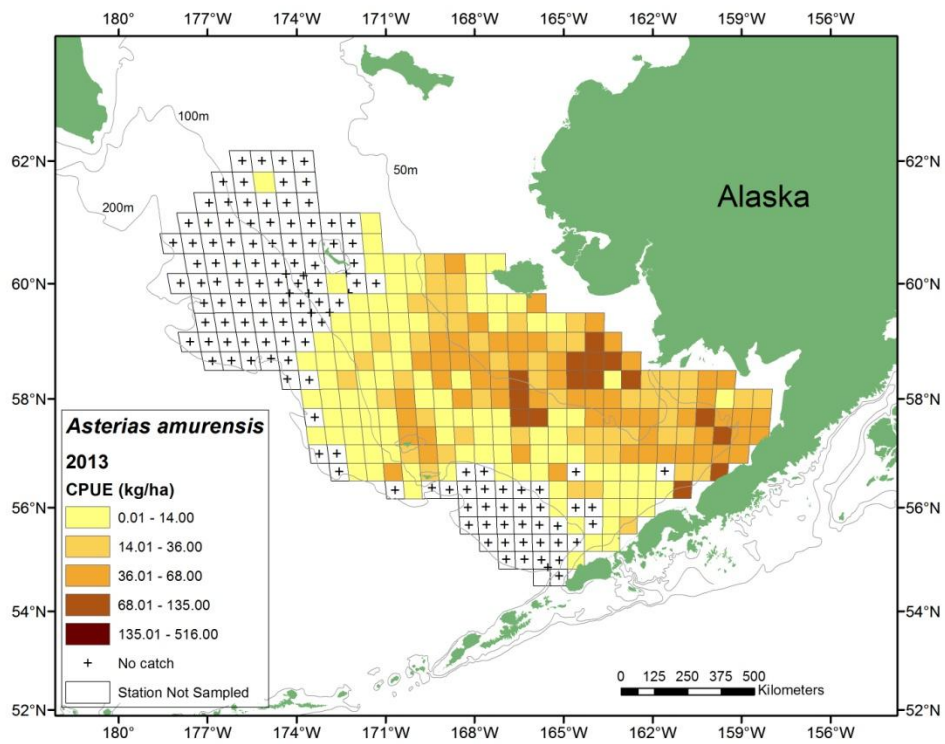
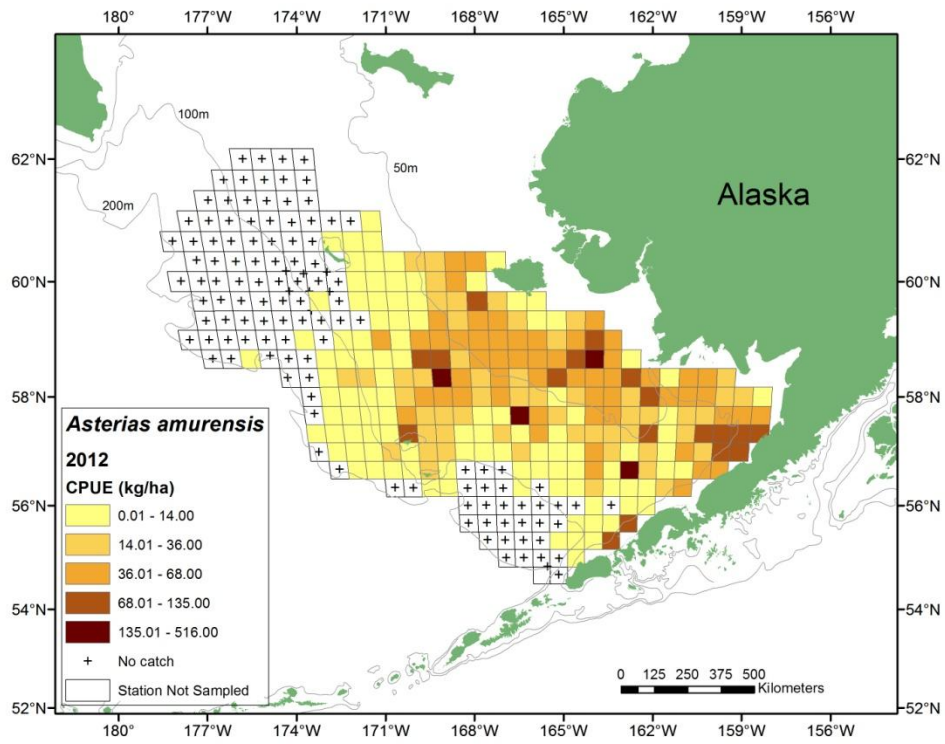


Figure 2. -- Cont.

Other Distribution Characteristics

In addition to depth, other physical variables could influence the distribution of *A. amurensis*. Overall, the abundance of the species does not show as obvious a correlation with features of a map of bottom water temperatures (based on measurements at trawl sites taken during the annual RACE surveys no earlier in the respective years than the 23rd of May nor later than the 6th of October) averaged over the 1982-2013 period (Fig. 3). Conversely, a map of the average grain diameters (by weight) of individual bottom sediment samples taken on the EBS shelf (Fig. 4) does display a possible relationship of abundance of the species with bottom sediment texture. These sediment samples were taken over a period of decades by multiple oceanographic surveys (Smith and McConnaughey 1999). For comparison with the average grain diameters indicated on the map, Table 1 gives the grain-diameter limits of recognized sediment classes (e.g., sand, silt) as defined by Wentworth (1922). Over the southeastern EBS shelf, the areas of high *A. amurensis* concentration seem to coincide with those where the average grain size is that of fine sand, or coarser classes. Of course, due to a basic oceanographic mechanism, when sediment enters shallow coastal waters as a result of runoff or weathering, the finer classes, such as mud (silt and/or even finer clay), are more readily kept suspended by random water movement from waves and currents than are coarse grains such as sand or gravel. The latter readily settle on the bottom near shore while the finer material ultimately reaches calmer, deeper water where it in turn settles to form the seabed. This produces the classic graded shelf (Johnson 1983, Sharma et al. 1972, Smith and McConnaughey 1999). Thus the two physical variables of depth and sediment grain size to which abundance of the species seems to relate, are themselves related by physical processes, making it hard to infer which might have a direct effect on the

species. For a crawling predator like *A. amurensis*, bottom type might affect motility and hunting.

The distribution of the species is noticeably attenuated in the northwest corner of the survey area on most of the yearly maps. This may be influenced by one or a combination of the observed environmental variables, as in this area the depth increases toward >100 m, bottom sediment is generally finer, and the bottom temperature decreases toward <1°C. Indeed, Lee et al. (2004), observing the larval development and hatching of fertilized eggs of *A. amurensis* from the coast of Jangmok, South Korea, under controlled temperatures, calculated that the theoretical lower limit of temperature at which such development could occur (i.e., the lower limit of the inverse of time required for development as regressed on temperature) was 0.97° C.

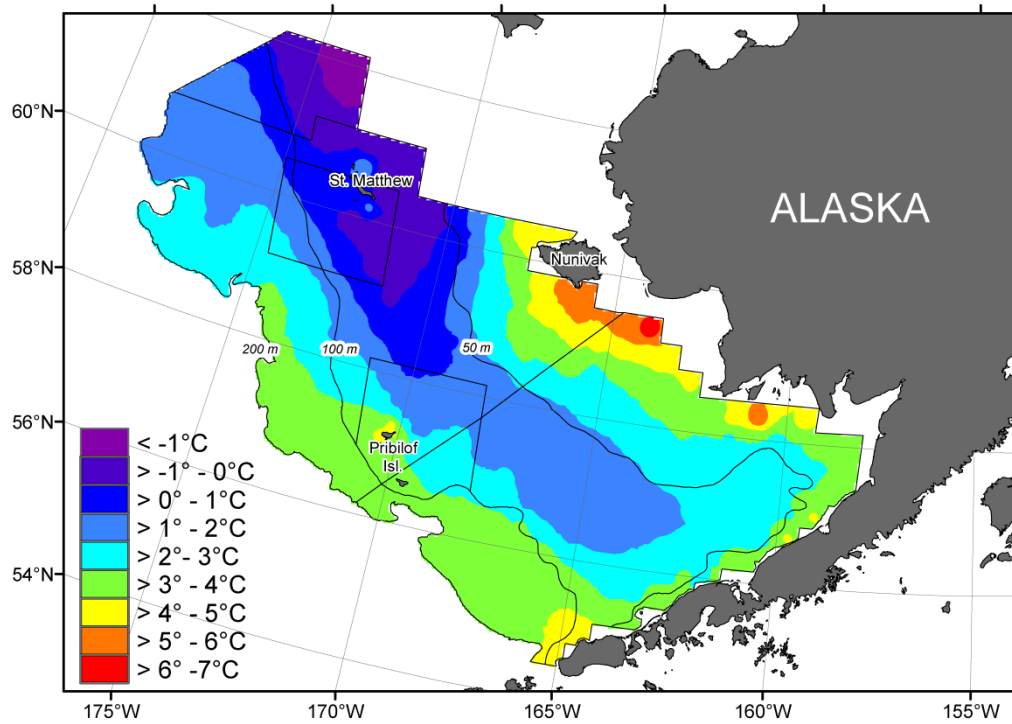


Figure 3. -- Mean bottom temperature recorded at individual trawl stations of the RACE annual EBS summer bottom trawl survey, averaged over the existing readings from 1982 to 2013 and then smoothed over the survey area. Readings were taken during daylight hours while trawling, no earlier in the year than the 23 of May nor later than the 6th of October.

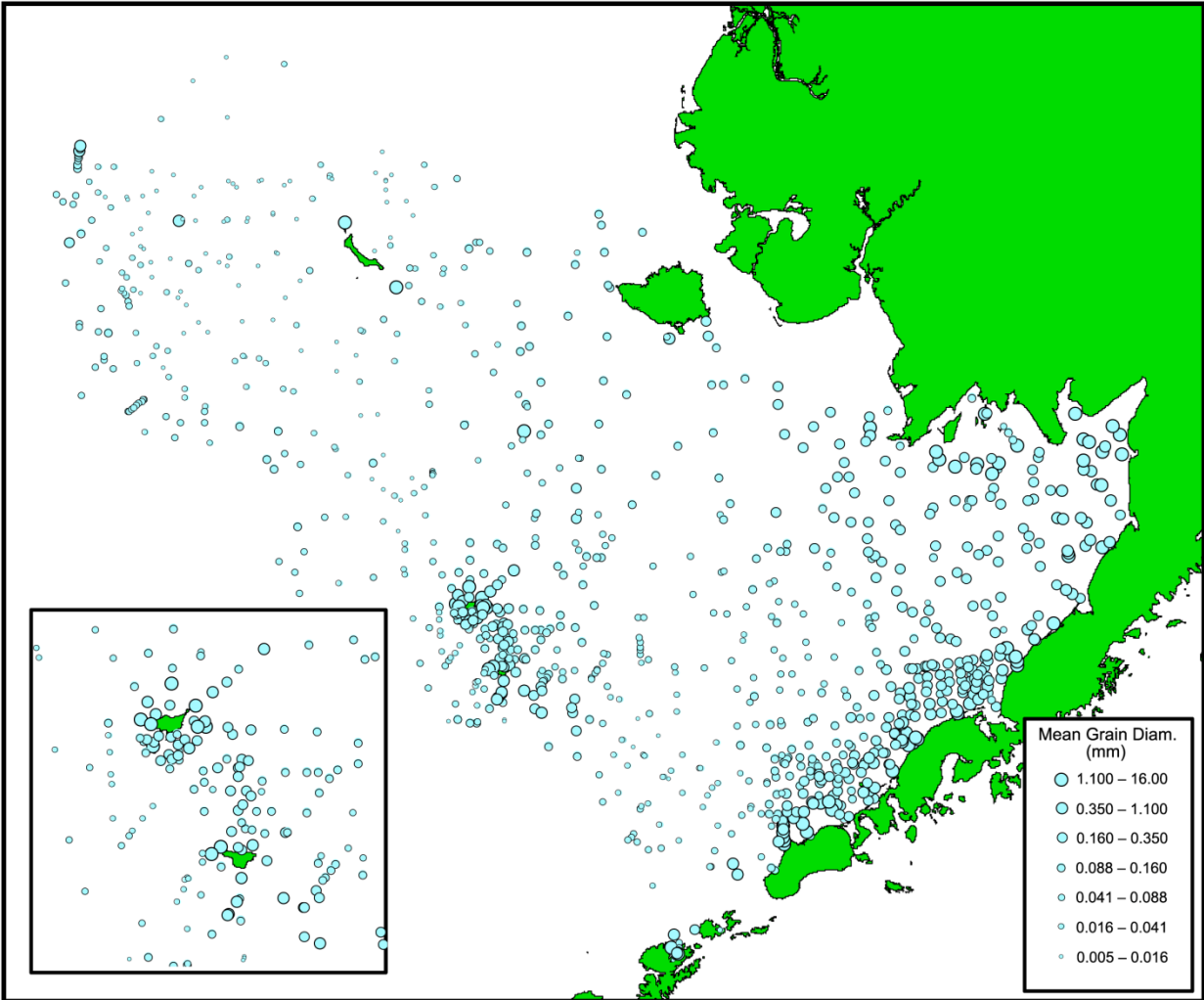


Figure 4. -- Mean grain diameter (by weight) of bottom sediment at 994 sample locations on the eastern Bering Sea continental shelf, shown according to seven divisions of the range of sample values (mm). Inset is larger-scale view of St. George and St. Paul Pribilof Islands and vicinity. Adapted from Smith and McConnaughey (1999).

Table 1. -- Scale by Wentworth (1922) classifying sediment particles according to diameter (mm).

Major grade	Diameter limits (mm)		Wentworth size class
	Lower	Upper	
gravel	256	>256	boulder
	64	<256	cobble
	4	<64	pebble
	2	<4	granule
sand	1	<2	very coarse sand
	0.5	<1	coarse sand
	0.25	<0.5	medium sand
	0.125	<0.25	fine sand
	0.0625	<0.125	very fine sand
mud	0.0313	<0.0625	coarse silt
	0.0156	>0.0313	medium silt
	0.0078	<0.0156	fine silt
	0.0039	<0.0078	very fine silt
	>0	<0.0039	clay

LIFE HISTORY AND ECOLOGY

Sources of Information

There have been relatively few biological studies focusing on *A. amurensis* in the northeastern Pacific. However, some investigations have been made in the EBS and the adjacent Chukchi Sea of ecological relationships including the species among an array of benthic invertebrates, such as studies of predator/prey interactions and the inadvertent effects of commercial fishing targeting other organisms (Brown et al. 2005, Feder and Hoberg 1981,

Feder and Jewett 1981, Feder and Jewett 1980, Feder et al. 2005, Fukuyama and Oliver 1985, Jewett and Feder 1981, Kaimmer et al. 1976, McConnaughey et al. 2005, McConnaughey et al. 2000). In addition, life history characteristics have been examined in *A. amurensis* populations outside the region. Because these characteristics are likely to exhibit similarities among regional populations within the species, the available findings from such pertinent studies are included in this summary.

Reproduction

Some species of asteroids regularly reproduce by fission, softening the mutable connective tissue occurring at the fission plane. The most common method of fission is division of the disc into two halves, each half then regenerating missing parts of the disc and arms. Most asteroid reproduction, however, is sexual (Ruppert et al. 2004), and *A. amurensis* is dioecious. In various studies of populations in Japanese waters including Tokyo, Sendai, and Mutsu bays, the ratio of males to females among individuals mature enough to allow identification of sex varied from roughly 0.94:1 to 1.24:1 (Hatanaka and Kosaka 1959, Ino et al. 1955, Kim 1968).

Spawning Physiology and Chronology

Individuals of *A. amurensis* possess 10 gonads, 2 per arm and situated on opposite sides of the radial axis. Gonads of both sexes grow from the base of the arms, gradually extending to the arm tips at spawning. With the approach of maturity, sexes become easy to distinguish. Ovaries become orange, testes become yellow-gray. In Sendai Bay, Japan, the minimum size, represented by the distance from the center of the disc to the arm tip, among females deemed mature by histological examination of the gonads was 55 mm, and among mature males 56 mm (Hatanaka and Kosaka 1959). A similar study of the population in Mutsu Bay, Japan, reported

the size at which individuals first appeared with gonads developed to a state where spawning was imminent was 50-55 mm in both sexes (Kim 1968), whereas in Tokyo Bay this population characteristic was estimated to be 46 mm for females, 47 mm for males (Ino et al. 1955).

In asteroids, gonads each have an individual gonopore located on the aboral surface, in the interradius near the base of the respective arm. Fertilization is external, with female and male both discharging gametes into the water from the gonopores. In most cases, asteroid zygotes and later developmental (larval) stages are planktonic (Ruppert et al. 2004).

Asteroids have an annual reproductive cycle (Novikova 1978). However, in females of some species, gametogenesis (i.e., the development of oocytes from oogonium to definitive cell) requires 2 years. Examples of species known to require a similar period for oocyte development are *Odontaster validus* (Pearse 1965) and *Leptasterias hexactis* (Chia 1968). Research has indicated that the length of this period for *Asterias amurensis* in Mutsu Bay, northern Honshu, Japan, is about 9 months (Kim 1968). The annual timing of actual spawning, coordinated between the sexes, has been established for various regional populations in Japan (Hatanaka and Kosaka 1959, Ino et al. 1955, Kim 1968, Novikova 1978), South Korea (Paik et al. 2005), and Tasmania, Australia (Byrne et al. 1997b). Spawning is sequential, as histological examination of specimens from the Sendai Bay population indicated that a single female will release some eggs while others which are still developing will mature and be released later in the same spawning season (Hatanaka and Kosaka 1959). Table 2 presents the annual timing of peak spawning in each of the areas, along with the associated water temperatures.

Table 2. -- Annual spawning periods and coincident water temperatures observed for some *Asterias amurensis* populations in coastal waters of northeast Asia and in a non-native population in Tasmania, Australia.

Location	Spawning Season	Sea Temperature	Thermometer Location	Source
Peter the Great Bay, Sea of Japan	1st season: late June – early July	1st season: 17° C	Surface	Novikova 1978
	2nd season: September (first half)	2 nd season: 23° C		
Coastal Hokkaido Island, Japan	July	11° C	—	Ino et al. 1955
Mutsu Bay, Japan	March - April	5°-10° C	Surface	Kim 1968
Sendai Bay, Japan	February	9.8° - 12.3° C	Bottom	Hatanaka and Kosaka 1959
Tokyo Bay, Japan	February (latter third)	11° C	—	Ino et al. 1955
Tongyeong, South Korea	April	—	—	Paik et al. 2005
Derwent River Estuary, Tasmania, Australia	July - October	—	—	Byrne et al. 1997b

Within the non-indigenous population of *A. amurensis* inhabiting the Derwent River estuary of southeastern Tasmania and experiencing the austral seasons, spawning is 6 months out-of-phase compared to the cycles in populations at similar degrees of latitude, but in the northern hemisphere, in Japan. In the former population in the southern hemisphere, peak of spawning is from July to October (Byrne et al. 1997b), whereas for the population in Mutsu Bay, Japan, it is in March – April. Diel photoperiod regimes experienced by the southern and northern

populations are similar when this 6-month seasonal difference is considered. This phase-shift argues for photoperiodic regulation of gametogenesis. Indeed, such regulation has been artificially reproduced in a laboratory experiment. Spawning periodicity in another species of Asteroiidae, *Pisaster ochraceous*, was established and maintained for samples of both sexes 6 months out-of-phase from that of the field population by controlling light exposure (Byrne et al. 1997b). A similar pattern of increases and decreases in sea temperatures associated with the various stages of gametogenesis indicates modulation by temperature as well.

Fecundity

Female *A. amurensis* have been reported to produce 10-20 million mature eggs per year (Luntz 1998). In Sendai Bay, Japan, depending on size (and thus likely on age) mature females had ovaries containing 0.4 to 15.5 million eggs. The typical 1-year-old female measuring 8.5-9.1 cm in arm length produced approximately 0.4-2.8 million eggs and the 2-year-old ones of 11-14 cm arm length produced 5.3-15.5 million eggs. These estimates were based on histological examination (Hatanaka and Kosaka 1959). The exact number of eggs actually spawned and fertilized is unknown, but Rupert et al. (2004) report that in some species of asteroids a single female may shed 2.5 million eggs per year.

Development

As it does in many species of asteroids, larval development in *Asterias amurensis* proceeds through two stages: 1) Free-swimming, bilaterally symmetrical bipinnaria hatch from the eggs, and are pelagic and planktotrophic. They later develop into 2) brachiolaria, which although initially bilaterally symmetrical, settle on and attach to substrate where they begin

metamorphosis to the pentamerous, radially symmetric morphology of the juvenile/adult (Ruppert et al. 2004).

In waters off Tongyeong, South Korea, eggs of *A. amurensis* have been observed to hatch 22 hours after fertilization in April (Paik et al. 2005). By day 2, the larvae have a complete alimentary canal and begin feeding on plankton. They are called bipinnaria at this stage. By day 32, early brachiolaria-stage larvae have developed three pairs of brachiolar arms. Settlement-form brachiolaria develop as early as 6 weeks after fertilization. With the pelagic stage of brachiolaria estimated to extend 40-50 days, settlements in this area seem to occur during June-July (Paik et al. 2005). In this process, brachiolaria attach to substrate via an anchored stalk. Subsequently, after completion of metamorphosis the juvenile detaches from the remainder of the brachiolaria and becomes motile, crawling by means of tube feet on the underside of the arms and disc (Ruppert et al. 2004). Early juveniles appear during August-September (Paik et al. 2005).

Like the other species of the family Asteroiidae, *A. amurensis* have four rows of suckered tube feet under each arm (Lambert 1981, Gale 1987), two rows on either side of the long axis and extending from mouth to arm tip. Tube feet are able to adhere to surfaces by chemical and/or muscle-actuated hydrodynamic vacuum forces (Ruppert et al. 2004) and are used in both crawling and in capturing prey.

Trophic Interactions

Prey

Asterias amurensis is a generalist carnivore eating a wide variety of live prey, as well as opportunistically scavenging carrion. Most often species of *Asterias*, as well as other genera of the family Asteroiidae, feed on less motile prey often ensconced in refuges such as shells or tubes,

including bivalves, barnacles, and some polychaetes (Ruppert et al. 2004). *Asterias amurensis* in particular has the potential to consume considerable quantities of bivalves such as *Nuculana fossa* and *Spisula polynyma* in the eastern Bering Sea (Feder and Jewett 1981), and thus to affect the production of useful crabs and fishes competing for the same resources. In feeding studies of specimens from the various age-groups of the species in Sendai Bay, Japan, the local population was estimated capable of consuming 8.25 million kg of clams per year. Since the area's bottom fish require up to 10 million kg of food annually, in the case that such food resources are limiting then competition by the sea star would have an important bearing on production by the commercially exploited bottom fish species (Hatanaka and Kosaka 1959).

Like all species in the order Forcipulatida, *Asterias amurensis* can digest food extra-orally (Ruppert et al. 2004). Individuals use arms and tube feet (with suckers) to exert a constant tension to pull open shells of prey, or they may find a natural breach in the gape. They then evert the stomach through the mouth and into the shell (Ruppert et al. 2004). Asteroids have a mutability characteristic which allows individuals to effect a mechanical stiffening of the dermis which does not result from muscle contraction (Motokawa 2011, Ruppert et al. 2004). *Asterias amurensis* likely employs this increased rigidity as an anchor against which to pull the two halves of a bivalve shell apart in opposite directions. At any gap, the sea star can excrete digestive enzymes onto the soft parts of the prey. The bivalve's adductor muscles tire or are digested, allowing further opening of the shell until the stomach of the predator can be extruded inside. There it can be used to engulf and retract solid food, or transport digested food into the body along ciliated grooves in the lining. Japanese species of *Asterias* can consume a bivalve in 2.5 to 8 hours (Ruppert et al. 2004).

Table 3 lists prey taxa of the *A. amurensis* population in Norton Sound, based upon laboratory examination of stomach contents and oral surfaces among diver-collected specimens, or by field (diving) observations monitoring prey to which oral surfaces of individuals had attached (Fukuyama and Oliver 1985). Prey identified in Norton Sound included bivalves, polychaetes, gastropods, tunicates, crustaceans, and echinoderms (Table 3). The latter included *A. amurensis*, indicating the possibility of cannibalism. Of course in stomach-content analysis it is not always possible to distinguish prey captured alive from that eaten *post mortem*. In the diving observations, four *A. amurensis* individuals were scavenging on unknown carrion.

Table 3. -- Prey of *Asterias amurensis* from Norton Sound, identified to the lowest discernible taxon as seen in laboratory and/or diving operations (Fukuyama and Oliver 1985). Specimens were dissected and stomach and mouth contents analyzed in the laboratory. In the field divers recorded taxa to which the oral surfaces of *A. amurensis* had attached.

Phylum or Class	Observation Method	
	Laboratory	Field (diving)
Bivalvia	<i>Yoldia hyperborea</i> <i>Mya truncata</i> <i>Macoma calcarea</i>	<i>Yoldia hyperborean</i> <i>Tellina lutea</i> <i>Spisula</i> sp.
Polychaeta	<i>Myriochele oculata</i> <i>Glycinde</i> sp. tube worm unidentified	<i>Pectinaria</i> sp. tube worm unidentified
Echinodermata	<i>Strongylocentrotus</i> sp. Ophiuroidea unidentified	<i>Asterias amurensis</i> sand dollar unidentified
Gastropoda	unidentified	unidentified
Tunicata	<i>Pelonaia</i> sp.	unidentified
Crustacea	ostracod unidentified cumacean unidentified <i>Dulichia</i> sp.	
unidentified (carrion)		unidentified

The largest bivalve species/individuals appeared less vulnerable to predation by *A. amurensis* in Norton Sound, as these animals often live deeper than the top 10 cm of sediment to which the sea star generally limits digging for prey. In laboratory tanks having bottoms lined with a layer of sediment the predator dug no deeper than 5 cm to reach previously released buried prey (Fukuyama and Oliver 1985). Examples of deep-burrowing bivalves included large *Mya truncata* and *Macoma calcarea*. In both field experiments and in laboratory tanks, large *Yoldia hyperborea* reacted to touch by an arm of the predator by using the bivalve foot to rapidly burrow under the sediment. Large *Serripes groenlandicus* reacted to the same stimulus by using convulsive movement of the foot to leap 3-15 cm, with one subject leaping 9 times after a single contact (Fukuyama and Oliver 1985). *Mya truncata* and *Macoma calcarea* did not respond to contact with *A. amurensis*.

Taxa reportedly consumed by *A. amurensis* specimens from the southeastern Bering Sea (Table 4) have included bivalves, polychaetes, bryozoans, sponges, Echinoidea, barnacles, shrimp, crabs, jellyfish, and fish (Feder and Jewett 1981, Feder and Jewett 1980).

Table 4. -- Prey taxa observed in mouths and/or stomachs among *Asterias amurensis* specimens taken by trawl net in the southeastern Bering Sea. Taxonomic identifications were made to the lowest discernible level (Feder and Jewett 1981, Feder and Jewett 1980).

Phylum or Class	Sub-taxon
Bivalvia	<i>Spisula polynyma</i>
	Cardiidae unidentified
	unidentified
Polychaeta	unidentified
Bryozoa	unidentified
Porifera	unidentified
Echinoidea	<i>Strongylocentrotus droebachiensis</i>
	<i>Echinarachnius parma</i>
	sand dollar unidentified
Cirripedia	Balanidae
Malacostraca	<i>Pandalus goniurus</i>
	<i>Crangon dalli</i>
	<i>Pagurus ochotensis</i>
	<i>Oregonia gracilis</i>
	<i>Chionoecetes</i> sp.
	mysid shrimp unidentified
Schyphozoa	unidentified
Vertebrata	fish unidentified

In the northwest Pacific part of its range, *A. amurensis* from Miyazu Bay, Kyoto Prefecture, Japan, have been observed in tank experiments to feed on live *Fulvia mutica*, a native cockle of the family Cardiidae (Uchino et al. 1990).

The species is an opportunistic scavenger as well as a predator. In addition to bivalves, the stomach contents of *A. amurensis* specimens from Sendai Bay, Japan, included small crabs, small shrimps, and the less frequent presence of sand lance and anchovy (Hatanaka and Kosaka 1959). As crustaceans and fish are usually relatively motile taxa, the appearance of such species in stomach contents of specimens from the EBS and the northwestern Pacific indicates feeding on carrion or such sources of crustacean remains as automotized limbs or exoskeleton molts (Feder and Jewett 1981, Feder and Jewett 1980, Fukuyama and Oliver 1985, Ross et al. 2002).

Mortality

Predators

Paralithodes camtschatica have been reported to eat sea stars (Asteroidea) in shallow waters in the vicinity of Kodiak Island in the western Gulf of Alaska (Feder et al. 1979) and in Bristol Bay of the EBS (Tarverdieva 1976). *Chionoecetes opilio* have also been reported to consume small amounts of sea stars in Bristol Bay (Tarverdieva 1976), and *Gadus macrocephalus* have been reported to eat sea stars in waters near Kodiak Island (Jewett 1978). In all these cases, the actual species of Asteroidea consumed is unknown, as is the viability of the organisms when ingested (i.e., whether alive or as carrion). In a laboratory experiment, trumpet shells of the genus *Charonia* collected from inshore areas of Mosulpo and Seogwipo, South Korea, were observed to feed on living *A. amurensis* (Kang and Kim 2004). Nevertheless, *A. amurensis* has few predators in either its native or invaded ranges. It generally occupies a terminal position in food webs in which it occurs (Feder and Jewett 1980).

Pathogens and Parasites

Asterias amurensis, like numerous other predators in the benthic food chain, is apparently vulnerable to infestation of food sources by agents of paralytic shellfish poison. Such toxins have been reported in tissues of specimens collected in the estuary of the Nikoh River, Kure Bay, Japan (Asakawa et al. 1997). Apparently the sea stars acquire the toxin from prey such as bivalves which have become contaminated during infestations of toxic dinoflagellates such as *Alexandrium tamarense*.

The ciliate *Orchitophyra stellarum* can cause male infertility in *A. amurensis* (Byrne et al. 1997a). This parasite infests testes, where it can cause phagocytosis of sperm. It has been suggested as an agent of biological control of *A. amurensis* in areas where the species poses a threat to native populations of shellfish or in aquaculture (see Anthropogenic Considerations below).

Defenses

Like many asteroids, *Asterias* species can automotize an arm in response to a disturbance (Lawrence 1992, Ruppert et al. 2004). Regeneration of an arm can also occur. Arm loss in asteroids is primarily in response to damage from biotic or abiotic sources. Such loss may affect feeding, locomotion, digestion, nutrient storage, and reproductive output (Lawrence 1992). In *A. vulgaris*, complete regeneration will occur from as little as one arm and one-fifth of the disc, if the remaining disc portion includes the madreporite (Ruppert et al. 2004). Rate of regeneration depends on availability of nutrients—arm regeneration is secondary in importance to production in existing structures when the nutrient supply is limited (Lawrence 1992).

Other Interaction with Trophic Web

Asteroids have few predators, and with their ubiquitous presence in the benthos may constitute a major carbon sink, only supplying further secondary production via a relatively low mortality rate. However, an additional effect may be the resource provided by spawning asteroids like *A. amurensis*. In its annual reproductive cycle the species produces considerable quantities of gametes (see section above, “Reproduction”), which as such or as embryos are potential food for other planktivores. Development of gonads in the Tokyo Bay population reaches 20-30% of body weight in a typical adult (Hatanaka and Kosaka 1959), of which a large amount is subsequently released during spawning. In addition, metamorphosing larvae each develop and then abandon a non-viable anchoring stalk on becoming juveniles. Such contributions could constitute a major seasonal pulse of secondary production in each biocenosis inhabited by the species (Feder and Hoberg 1981, Feder and Jewett 1980, Feder et al. 2005, Hatanaka and Kosaka 1959).

Anthropogenic Interactions

Fishing Effects

On the EBS shelf, the large scale of commercial trawling could potentially affect any of the benthic epifauna considerably, including the *A. amurensis* population (McConnaughey et al. 2005, McConnaughey et al. 2000). Bottom trawling seems likely to injure or kill a portion of individuals in the trawl path, as well as to physically alter the bottom structure. In Bristol Bay, adults have been observed by a remotely operated vehicle equipped with video camera, towed along transects over two categories of bottom: one which had recently been trawled by a commercial fishing vessel, and another which had not been trawled (Brown et al. 2005). There appeared to be a significant difference between the two areas, with fewer individuals counted, on

average, per unit of bottom area in the previously-trawled area. However, in the trawled area the species appeared to cluster around fish-processing waste from the trawl, making counting of individuals difficult. In addition, McConnaughey et al. (2000) conducted a study in Bristol Bay pairing the sample trawl catch of benthic invertebrates at each of a number of sites in an area historically un-trawled by commercial fishing, with that at a respective nearby site on the other side of a line marking the border with a heavily trawled area. In the samples *A. amurensis* was more abundant, as measured by weight-CPUE, in the heavily-fished area than in the unfished area ($P = 0.025$). However, in assessing this result caution dictates that we use the Bonferoni-corrected multi-comparison criterion of $P \leq 0.006$ which the investigators used when judging the data's significance at the $\alpha = 0.10$ level. Their study included data from numerous taxa, and this paper is one in a series of synopses each likely referring to their results regarding a different taxon (e.g., Smith et al. 2011). Nevertheless, it seems reasonable that potential damage to *A. amurensis* populations by trawling could be somewhat mitigated by the accompanying opportunity for the species to scavenge on discards from the vessels involved (Brown et al. 2005). Alternatively, the sea star might have access to burrowing prey species exposed by displacement of bottom sediment during fishing.

Another possible effect on benthic invertebrates of large-scale commercial trawling in the Bering Sea is change in the size distribution within the population of a species. In the project investigating effects on abundance, McConnaughey et al. (2005) also compared the mean size (by weight) of *A. amurensis* caught in trawl samples in a previously heavily-trawled area with that of individuals of the species in samples from a historically un-trawled area. Of course, trawl net samples themselves may be biased in reflecting the actual size distribution of the species, as selection of certain sizes by the mesh size and configuration of the sampling net are to be

expected. Nevertheless, statistically significant differences in sea star size distributions between the catches from the two areas would have indicated some kind of effect of fishing on size to be likely. In the event, the difference in means was not significant for *A. amurensis* ($P = 0.419$).

Ecological Portents

Asterias amurensis is a highly adaptable predator with low vulnerability to other predators. As such, it is potentially an invasive species which could threaten the ecological balance in areas where it was introduced, and this has in fact occurred on the coasts of the southern Australian mainland and southeastern Tasmania, Australia (Byrne 1996, Byrne et al. 1997b, Luntz 1998, Zeidler 1992). In some cases, exotic species have been introduced to new marine areas due to transport, either by hull fouling or in ballast water, and subsequent inadvertent release by ships transiting from foreign ports. In Australian waters the input of ballast water has been estimated at ~58 million tons per year (Zeidler 1992). *Asterias amurensis* was likely introduced there by such means from Japan, where it is common (Zeidler 1992), and probably arrived in the early 1980s. It now exists as a non-native species in the new locations and is the most damaging marine pest in Australia. Native species such as clams have been devastated in the areas it has colonized (Luntz 1998).

In a manipulative experiment in estuarine waters of southeastern Tasmania, Australia, densities of *Fulvia tenuicostata* juveniles after settling were reduced approximately 15 fold (from 580 m^{-2} to 35 m^{-2}) in the presence of sea stars at ambient densities, relative to treatment excluding access by sea stars (Ross et al. 2002). This supports the hypothesis that predation by *A. amurensis* is responsible for the recent decline of large bivalves in its current area of distribution in Tasmania.

In addition, effective escape responses of potential bivalve prey confronted by *A. amurensis* appear comparatively undeveloped in species newly exposed to the predator. Hutson et al. (2005) observed ineffective or neutral responses by scallops *Pecten fumatis* and *Chlamys asperrima* from Port Phillip Bay, southeastern Australia, when subjects were touched by tube feet of *A. amurensis*. This contrasted with responses of individuals of these scallop species when similarly touched by a native sea star predator, *Coscinasterias muricata*. In the latter case, subject scallops exhibited quicker, more directed “clapping”, a sudden closure of the valves jetting water from the shell and causing the bivalve to “swim” or “jump” away from the sea star. Thus prey species appear to be more vulnerable to predation by invasive, non-native sea stars such as *A. amurensis*.

The Tasmanian population of the sea star has probably derived from ones in central Japan (Ward and Andrew 1995). Allozyme comparisons at 22 loci have shown the former population to be more closely related genetically to populations in Suruga and Tokyo bays than to those of Vladivostok, northern Japan (Yoichi, Nemoro, and Mutsu bays), or southern Japan (Ariake Sea). Average heterozygosity per locus of the Tasmanian population was 30-40% less than that of the various native northwestern Pacific populations, suggesting colonization was accompanied by a selection “bottleneck”. Nevertheless, genetically the Tasmanian population differed significantly from those of central Japan. This may be due to founder effects, or may indicate that the true source of Tasmanian introduction has not yet been identified (Ward and Andrew 1995).

Controlling Colonization

Much of the threat posed by the species invading new areas is the potential introduction of planktonic larvae carried in ballast water dumped in ports by foreign vessels (Dunstan and

Bax 2008). This calls for ballast water management by local authorities, such as requiring ballast water exchange before arrival in port by inbound vessels. The exchange is usually mandated to constitute throughput of ballast equal to three times the tank volume. It is to be done in offshore areas where any ejected larvae from foreign coastal waters are unlikely to encounter environmental factors allowing them to survive, and currents are unlikely to transport them directly into local coastal waters (Dunstan and Bax 2008). The procedure has been calculated to exchange at least 95% of previously-loaded ballast water for open-ocean water between ports.

Oxygen deprivation induced by sparging with nitrogen has been considered as a means of sanitizing ballast water to prevent the spread of harmful exotic species, but costs of such operations have not yet appeared practical (Mountfort et al. 1999). A method has been developed using DNA sequencing to detect very dilute occurrences of planktonic larvae of *A. amurensis* in ballast water samples (Deagle et al. 2003). This may be used to help assess the risk, associated with the proposed dumping of a vessel's ballast water, of establishing the species in an area it previously did not inhabit (Deagle et al. 2003).

Countries with seaports are seeking biosecurity through individual government action, international conferences and agreements, etc., to protect local ecosystems from disruption and damage caused by such invasions. Possible methods include quarantine, testing of potential vectors such as ballast-water, voluntary cleaning guidelines, and mandated cleaning practices (Dunstan and Bax 2008, Hewitt and Campbell 2007).

Potential Biological Controls

The ciliate *Orchitophrya stellarum* (see section Pathogens and Parasites) causes male infertility in infected *A. amurensis*. The parasite is specific to species of Asteriidae and is

endemic to the North Atlantic, but was discovered in British Columbia in 1988, infesting the purple sea star, *Pisaster ochraceus* (Lambert & RBCM 2000). The parasite causes regression of the germinal epithelium of the testes, as well as phagocytosis of sperm (Byrne et al. 1997a). In *P. ochraceus* infection also caused increased mortality, an unusual symptom of the disease in the North Atlantic (Leighton et al. 1991). *Asterias amurensis* is an additional new host to the parasite, due to spreading of the ciliate to the Pacific, including infiltration of Japanese waters where infection of males of the species was first noticed in 1990 and where studies have been made of its effects on *A. amurensis* in Ise, Tokyo, and Otuchi bays (Byrne et al. 1997a). Infection in the species is highly contagious, with populations in Japanese waters observed suffering 38-100% occurrence in males. Phagocytosis is effected by the parasite itself, but also more extensively by the host's own immune system attacking its sperm cells in the infected testes. Thus infertility is caused largely by phagocytic response of the host's cells, each cell engulfing numerous sperm (Byrne et al. 1997a, Byrne 1996). In addition to a major reduction in viable sperm, the ciliate disease is associated in some Japanese waters with a marked decrease in the ratio of males to females, indicating possible ciliate-caused male mortality. Indeed some observed populations were all or almost all females. Infestation rates in the Atlantic Ocean are generally much lower (0-1 %; Byrne et al. 1997a). The comparatively greater contagiousness of the disease and the greater debilitation it generates in *A. amurensis* and *P. ochraceus* are probably because these species are relatively new hosts to the parasite (Byrne et al. 1997a, Leighton et al. 1991).

These facts suggest the possibility of using *Orchitophrya stellarum* as a biological control agent for *A. amurensis* (Byrne et al. 1997a, Goggin and Bouland 1997). However, the efficacy of using the ciliate to regulate sea star populations is uncertain. Contagious spread and the ability of

the ciliate to parasitize other genera of asteroids caution against its use for biological control of *A. amurensis* in Japan and of recently established populations in Australia (Byrne et al. 1997a, Byrne 1996).

In the study (cited in the “Predators” section) investigating prey of the trumpet shell *Charonia* (Kang and Kim 2004), snail subjects were each placed in a respective tank with individuals of a prey species, and the amount by weight of the prey consumed over a constant period of time was recorded over several predator/prey replications. Listed in descending order of preference the prey consumed by *Charonia* sp. were *Asterina pectinifera*, *Asterias amurensis*, *Stichopus japonicus* (a sea cucumber), and the sea urchins *Hemicentrotus pulcherrimus* and *Anthocardis crassispina*. The fact that none of two species of bivalves (*Venerupis philippinarum* and *Anadara broughtonii*) and none of an abalone (*Haliotis discus hannai*) were consumed suggests the possible utility of *Charonia* sp. as an agent of biological control of *A. amurensis*, at least in aquaculture, to protect certain shellfish species (Kang and Kim 2004). However, caution dictates that such use of a predator capable of preying on multiple species would have to be preceded by much detailed study.

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