Early Detection and Rapid Response Plan for the European Green Crab, *Carcinus maenas*, in Alaska

Prepared for:

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Executive Summary

The European green crab, *Carcinus maenas* (hereafter: *Carcinus* or green crab) is a highly successful global invader with a well documented history of ecological and economic impacts. Populations of *Carcinus* are present in at least 22 estuaries on the Pacific coast of North America from Morro Bay, California to Vancouver Island, British Columbia. Populations on the west coast of Vancouver Island are prolific and have been spreading north. Given an increase in water temperature associated with global climate change, an influx of *Carcinus* larvae or adults into Alaskan waters would likely persist and threaten the marine natural resources and ecosystems of Alaska.

Carcinus is an omnivorous predator that consumes or competes for food with numerous organisms including algae, crustaceans, mollusks, and fish, among others. *Carcinus* preys on and competes with many commercially important species such as Dungeness crab (*Cancer magister*) and many species of bivalve that are cultured in aquatic farms. The voracious appetite of this consumer can lead to a host of direct and indirect impacts to native communities including some threatened species such as *Polysticta stelleri* (Steller's eider; endangered) and *Numenius borealis* (Eskimo Curlew; threatened).

This Early Detection and Rapid Response Plan for *Carcinus maenas* in Alaska reviews a) the biology, impacts, and invasion history of *Carcinus*; and then b) provides a conceptual framework to facilitate the prevention and detection of invasion by this crab and to organize and implement a rapid response after an invasion is detected. The primary goal of the Early Detection and Rapid Response Plan for *Carcinus maenas* in Alaska is to prevent the establishment and spread of *Carcinus maenas* in Alaskan estuaries. The plan utilizes an adaptive approach that can be amended as necessary to deal with biological, logistical, jurisdictional, or other changes that may occur.

Our framework is organized into five specific objectives and secondary goals:
Objective 1: Vector & source population management, Goal: Decrease propagule pressure; Objective 2: Outreach & Education, Goal: Increase public understanding of the threat of *Carcinus*; Objective 3: Detection & monitoring, Goal: Increase likelihood of detecting an invasion; Objective 4: Coordination of management activities, Goal: Provide a clear procedure and framework for rapid response to invasion of *Carcinus*; Objective 5: Control & Management Options once detected, Goal: Initiate a rapid and effective response to invasion by *Carcinus*.

We also propose specific actions to enhance the likelihood of preventing, detecting, and controlling invasions of *Carcinus* to Alaska. These actions include (see full list at end of report):

- Develop a state ballast water management program to reduce likelihood of introductions;
- Develop a state program for hull maintenance of both commercial and recreational boats;
- Develop state rules for cleaning and inspection of products, sterilization of packaging materials, and quarantine during transit;
- Develop state regulations that prohibit the sale or importation of live marine bait;
- Support management of potential source populations;
- Inventory and expand signage and written materials, and establish an outreach website;
- Conduct outreach about the risks and spread of *Carcinus* to citizen scientists and professionals, including developing outreach programs for shellfish importers and exporters and researchers and educators;
- Continue monitoring in the present sampling locations and expand monitoring plan to incorporate additional sites that are suitable to *Carcinus*;
- Develop a broader volunteer base by expanding efforts to engage and recruit citizen scientists, special interest groups, and school groups;
- Monitor by trapping at least yearly during the late summer. When possible, increase trapping effort following El Niño – Southern Oscillation (ENSO) events and mild winters;
- Establish clear jurisdictional and management responsibilities in the event of invasions of *Carcinus* or other aquatic non-native species for all involved agencies and organizations;
- Establish a rapid communication system such as a phone tree or an official listserv for all agencies and organizations that have management responsibilities potentially affected by *Carcinus* and other interested parties;
- Upon detection, confirm the report through identification by trained personnel with a photo or a specimen, contact stakeholders and control team, broaden monitoring, establish a timeline for the control strategy and its assessment, and assign responsibilities;
- Upon detection, consult *Carcinus* experts, initiate management protocols and timeline;
- Establish a protocol to allow for maximum coordination between agencies to ensure the logistical and financial burden is minimized and shared evenly;
- Estimate required funding for several invasion scenarios and identify potential funding sources for each;
- Assess the progress and efficacy of the management strategy.

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Ecological impacts

The European green crab, *Carcinus maenas*, is a global invader with many well documented ecological and economic impacts. Populations of *Carcinus* can attain very high densities (e.g., Cohen et al. 1995, Thresher et al. 2003) and larger body sizes (Grosholz and Ruiz 2003) in their invaded range, which likely exacerbate their predatory, competitive, and indirect impacts to native communities. *Carcinus* is a voracious omnivorous predator and aggressive competitor. Cohen et al. (1995) found that a wide diversity of prey (158 genera, 14 phyla) can be consumed by adults and larvae of *Carcinus* including algae, hydrozoans, marine worms, mollusks, numerous crustaceans, fish and more.

Predation by *Carcinus* (and the concomitant indirect effects) is an important structuring force in soft sediment communities and in some rocky intertidal communities (Menge 1983; Leonard et al. 1998, Grosholz et al. 2000). In New England, intense predation by *Carcinus* reduced mussel densities (the dominant biota) allowing alternate species assemblages to persist (Menge 1983). It can also alter the community structure and assemblages by competing for food and space and through both direct and indirect predatory effects (Leonard et al. 1998). In the Danish Wadden Sea, *Carcinus* can prevent the establishment of cockle (*Cerastoderma edule*) beds by preying on recruits (Jensen and Jensen 1985). In central California, Grosholz et al. (2000) found *Carcinus* exerts strong top down control on at least 20 native species, especially the native clams *Nutricola* spp. and shore crab *Hemigrapsus oregonensis*. Predation by *Carcinus* may also facilitate invasions by other non-native species. In Bodega Bay, CA, predation on *Nutricola* spp. by *Carcinus* facilitated the spread of a non-native gem clam (*Gemma gemma*; Grosholz 2005). In addition to numerical impacts, *Carcinus* can also alter the tidal distribution and body size in native crabs (de Rivera et al., in revision).

Many of the species that are negatively impacted by invasions of *Carcinus* are also an important prey base for waterfowl, larger fish, and other higher-level consumers (Cohen et al. 1995, Grosholz and Ruiz 1995, Grosholz et al. 2000). Reductions of the abundances of numerically dominant prey species (i.e. bivalves) could have detrimental impacts to the numerous predators that rely on them such as migrating waterfowl, Dungeness crabs, and surfperch (Grosholz and Ruiz 1995). While Grosholz et al. (2000) did not detect a negative indirect effect of predation on migratory waterfowl, they suggest such impacts are difficult to quantify in particularly vagile species. They predicted further population increases and range expansions of green crabs could lead to a detectable deleterious effect (Grosholz et al. 2000). *Carcinus* may also impact primary production in invaded habitats through bioturbation and physical disruptions to eelgrass restoration (Davis et al. 1998).

The impacts of *Carcinus* are not limited to the direct and indirect effects of predation as they can outcompete native species for both food and shelter (McDonald et al. 2001, Jensen et al. 2002, Rossong et al. 2006). *Carcinus* outcompetes the native shore crab *Hemigrapsus oregonensis* for food (Jensen et al. 2002) and can outcompete the Dungeness crab *Cancer magister* and juvenile lobsters (*Homarus americanus)* for shelter and food and prey upon them (McDonald et al. 2001, Rossong et al. 2006, Larson et al. unpublished).

Economic impacts

The introduction of *Carcinus* has caused substantial impacts to commercial and recreational fisheries. In New England, this non-native crab has been associated with a decline in the soft-shelled clam (*Mya arenaria*) fishery (Glude 1955). *Carcinus* also preys on cultured bivalves such as quahogs in southern New England and Long Island (*Mercenaria mercenaria*; Walton & Walton 2001), Manila clams (*Venerupis philippinarum*; Cohen et al. 1995), and Pacific oysters (*Crassostrea gigas*; Grosholz, personal communications). Green crabs are also predicted to impact the Australian mariculture of the clam *Katelysia scalarina* (Walton et al. 2002). While most studies have investigated the impact of *Carcinus* on bivalve prey, green crabs can also affect commercially important mobile epifauna such as crabs and potentially fish. Since *Carcinus* is aggressive and can exclude native juvenile *Cancer magister* from both food and shelter and prey upon them (McDonald et al. 2001, Larson et al. unpublished), it may have detrimental impacts to the Dungeness crab fishery. Although the economic effects of *Carcinus* on the commercial Dungeness crab (*Cancer magister*) fishery have yet to be documented, several authors address this concern (Cohen et al. 1995, Lafferty and Kuris, 1996, Jamieson et al. 1998, McDonald et al. 2001, Larson et al. unpublished). The negative effects of *Carcinus* to juvenile lobsters (*Homarus americanus*) may also result in negative economic impacts (Rossong et al. 2006). There is also concern that juveniles of the commercially important finfish, English Sole (*Pleuronectes vetulus*), may be preyed upon by this voracious predator (Jamieson et al. 1998). Furthermore, green crabs may interfere with eelgrass (*Zostera marina*; Davis et al. 1998) and native oyster restoration (Grosholz and Kimbro 2006).

Potential *Carcinus* impacts in Alaska

Invasions of *Carcinus* in Alaska may have economic, recreational, cultural and social impacts to a wide range of stakeholders (Table 1). In particular, the introduction of *Carcinus* may put many native species at risk, including species vital to thriving commercial and recreational fisheries (*Cancer magister* (Dungeness), *Pandalus borealis* (Spot shrimp)) and aquaculture (*Crassostrea gigas* (Pacific oyster), *Mytilus trossulus* (Bay mussel), *Protothaca staminea* (Littleneck clam), *Panopea abrupt* (Geoduck clam); Table 2). Commercial fisheries are vital to the economy of Alaska (Hartman 2002). In 2006, the seafood industry employed more workers than are employed in any other industry sectors (56,606 workers) and brought in $3.4 billion to basic sector income (Northern Economics 2009). Aquatic farms are also important to the state economy. In 2007, the production value of aquatic farms in Alaska was over $600,000 (ADFG 2008). The predatory effects of *Carcinus* could negatively impact the commercial landings of some fisheries and the production of aquatic farms (depending on culture method). In addition, the competitive and predatory effects on the prey base may indirectly impact many endangered and threatened species that utilize similar food resources as *Carcinus* such as Steller's eider (*Polysticta stelleri*; endangered) and Eskimo Curlew (*Numenius borealis*; threatened) or species of cultural importance.

Table 1. List of non-governmental stakeholders that may be impacted by invasions of *Carcinus*.

Stakeholder	Interests	Potential Impacts by *Carcinus*
Recreational fishers	Clamming, fishing	Reduce catch of recreational species, indirect impacts to prey base
Commercial fishers	Fishing	Reduce catch of commercial species, indirect impacts to prey base
Ecotourism & nature enthusiasts	Natural habitats	Degrade and alter pristine habitats and communities
Aquaculture industry	Cultivation of marine species	Prey on cultured species, reduce catch
Native peoples	Preserving indigenous culture & traditions of hunting, trapping & fishing	Degrade and alter pristine habitats and biological communities, reduce catch of culturally important species
Subsistence users	Clamming, fishing, foraging	Reduces availability of desired species and indirect impacts to prey base
Habitat restoration professionals	Restoring marine habitats	Disrupts potential restoration of eelgrass transplants and may inhibit efforts to reestablish native oysters

Table 2. Commercial (C), Recreational (R) and Subsistence (S) fisheries and mariculture species (M) that may be affected by invasion of *Carcinus maenas* in Alaska.

Common name	Scientific name	Fishery type	Landings (metric tons)	Estimated value (USD)[1]
Geoduck clam	*Panopea abrupt*	C, R, S, M	110.3	$423,603[2]
Razor clam	*Siliqua patula*	C, R, S, M	161.7	$195,080[2]
Pacific oyster	*Crassostrea gigas*	M	479.8	$470,955[3]
Littleneck clam	*Protothaca staminea*	C, R, S, M	28.0 (cultured)	$148,924[3]
Littleneck clam	*Protothaca staminea*	C, R, S, M	11.4 (commercial)	$36,965[4]
Butter clam	*Saxidomus giganteus*	C, R, S, M	11.4 (commercial)	$36,965[4]
Basket cockle	*Clinocardium nuttallii*	C, R, S	11.4 (commercial)	$36,965[4]
Bay mussel	*Mytilus trossulus*	M, S	0.8	$4,484[3]
Rock Scallop	*Crassedoma gigateum*	M	Data unavailable	Data unavailable
Dungeness crab	*Cancer magister*	C, R, S	2,045.7	$6,740,000[2]
Spot shrimp	*Pandalus platyceros*	C, R, S	320.0	$3,003,459[2]
Coonstripe shrimp	*Pandalus hypsinotis*	C, R, S	31.8	$166,039[2]
Pink shrimp	*Pandalus borealis*	C, R, S	609.9	$284,137[2]

[1] Values do not include landings or value of recreational and subsistence fisheries

[2] Mean landings and value of the commercial fishery between 1998 and 2002, Woodby et al. 2005

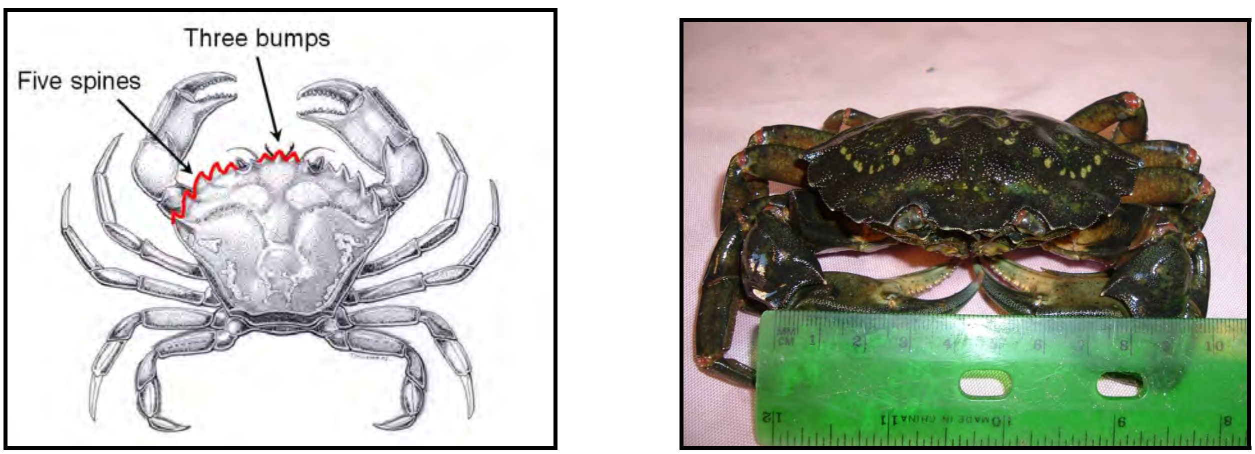
[3] Production and value of the cultured populations from 2003, Timothy and Petree 2004

[4] Mean landings and values are for the commercial fisheries for littleneck clams, butter clams, and basket cockles together between 1998 and 2002; individual values were not available.

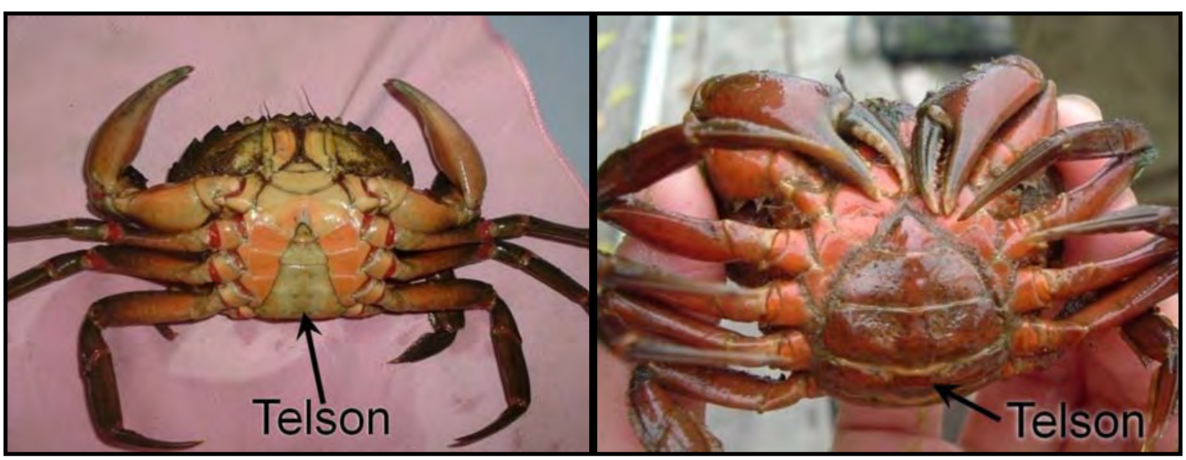
Biology of *Carcinus maenas*

Identifying characteristics

Carcinus is a small portunid shore crab with a fan shaped carapace (maximum carapace width approximately 105 mm). *Carcinus* is distinguished from native crabs by the presence of 5 spines on the anterolateral edge of the carapace on either side of the eyes and 3 blunt bumps between the eyes (Figures 1A-B, also see Appendix C for comparisons with native crab species). The coloration of the crab varies: the dorsal side can be a dark green (almost black) to lighter green in color often with a mottled appearance, while the ventral surface can vary from bright yellow-green in freshly molted individuals to dark orange to red in late intermolt crabs. The average size of green crabs varies by location. They are larger in California than they are on the east coast and they are larger still in the British Columbia: a typical crab caught in California is only 50-75 mm carapace width while ones in British Columbia are typically between 45-90 mm (de Rivera, unpublished data, Gillespie et al. 2007). The sex of green crabs can be determined by the shape of the telson; the telson of female crabs forms a wide rounded dome-like shape with a small protrusion while males have a telson that is more slender and triangular in shape (Figures 2A-B). Green crabs also harbor dimorphic claws: one claw is slender and used for cutting and fine manipulation and the other larger slightly more powerful claw is used for crushing prey.



Figures 1A-B. *Carcinus maenas*, the European green crab. Identifying characteristics include: 5 anterolateral spines and 3 blunt bumps between the eyes. Drawing courtesy of Tim Sullivan.



Figures 2A-B. Determining the sex of *Carcinus maenas* based on the shape of the telson (arrows). A. The telson of male crabs (left) is more narrow and triangular than B. the telson of female crabs (right), which is wider and dome-like in shape.

Why *Carcinus* is a successful invader

Broad environmental tolerances

Carcinus adults are eurytolerant and capable of persisting under a wide range of environmental conditions. *Carcinus* is tolerant to both variable salinity (4 to 54 psu or ppt) and water temperature (0 to 33°C; Eriksson et al. 1975). Green crabs are also highly resistant to desiccation and can live for up to 60 days out of water when covered with seaweed (Carlton, personal communications as cited in Behrens Yamada 2001). They can also withstand up to 3 months of starvation (Wallace 1973). The growth of larvae became depressed when populations were held in salinities below 25 psu (Anger et al. 1998) and water temperatures lower than 10°C and higher than 25.5°C (de Rivera et al. 2007b). Similarly, Nagaraj (1993) found *Carcinus* zoeae (larval stage) can withstand a variety of temperature (10, 15, 20, 25) and salinity combinations (20, 25, 30, 35) and only suffered greater than 50% mortality under the 10°C and 20 psu temperature and salinity combination.

Life history & dispersal

Green crabs are fecund and are capable of reproducing several times in a lifetime. Female green crabs (42 mm in carapace width) can produce up to 185,000 eggs per brood and the number of eggs in a brood is positively correlated with body size (Broekhuysen 1936 as cited in Cohen et al. 1995). In their native range, *Carcinus* first reproduce between 1-2 years of age (Behrens Yamada 2001). In their non-native range, they can reproduce at less than one year of age in Oregon and at 2-3 years of age in Maine (Behrens Yamada 2001, Berrill 1982).

The growth rate of *Carcinus* varies considerably due to several factors that affect molting (temperature, salinity, food availability, intraspecific interactions, and age; Behrens Yamada 2001). Water temperature, in particular, is an important factor in determining the persistence and abundance of *Carcinus*. *Carcinus* cannot molt when water temperatures decrease below 10°C in winter and cannot feed in temperatures below 7°C (Ropes 1968). Furthermore, recruitment is increased after years with mild winters (Berrill 1982, Beukema 1991, Behrens Yamada et al. 2006, Behrens Yamada and Gillespie 2008). Green crabs also exhibit a high growth rate and larger size on both the Pacific and Atlantic coasts of North America than in their native range (Grosholz & Ruiz 1996, Behrens Yamada 2001, Grosholz and Ruiz 2003).

The larvae of *Carcinus* are planktotrophic and spend one to two months in the water column depending on water temperature (Dawirs 1985, de Rivera et al. 2007b). Thus, green crabs have the potential to be dispersed many kilometers through ocean currents. Crab larvae (zoea) have moderate pigmentation, relatively long dorsal and rostral spines and lack lateral spines (see

Rice & Tsukimora 2007). After developing and feeding in the plankton, the megalopae larvae then metamorphose and settle out typically in sheltered habitats in the high intertidal such as eelgrass (*Zostera* spp.), cordgrass (*Spartina* spp., if it invades Alaska), filamentous green algae, mussel, or gravel beds (reviewed by Behrens Yamada 2001). Peak larval settlement occurs throughout the summer in their native range and in Maine but appears to occur in spring in Oregon (Behrens Yamada 2001).

Diet and feeding rate

Green crabs are voracious consumers that can prey on over 158 genera, including marsh vegetation, algae, crustaceans, marine worms, mollusks, fish and more (Cohen et al. 1995). *Carcinus* exhibits a variety of characteristics that may allow them to exploit a diversity of prey types including: dimorphic claws, a higher mechanical advantage of the claw lever system, higher propal heights (a proxy for claw strength) than some native Pacific coast crabs (Behrens Yamada 2001, Davidson, unpublished), and the ability to learn new opening techniques with novel prey (Cunningham and Hughes 1984). The dimorphic claws of *Carcinus* may allow *Carcinus* to exploit hard shelled prey at a greater rate than ecologically similar native crab *Cancer magister*; thus the per capita impacts of *Carcinus* to hard shelled prey may be greater than from native crabs (Behrens Yamada et al., in preparation).

The feeding rates accompanied by the high densities of *Carcinus* in invaded ranges can drastically affect the abundances of estuarine species. Juvenile *Carcinus* can feed at a rate of 6 juvenile cockles in the Danish Wadden Sea (4 mm; *Cerastoderma edule*) per day; this feeding rate could prevent the establishment of cockle beds (Jensen and Jensen 1985). Mascaró and Seed (2000) found individual *Carcinus* (40-55 mm) in North Wales can feed on mussels (*Mytilus edulis*), oysters (*Ostrea edulis* and *Crassostrea gigas*), and cockles (*C. edule*) at a rate of 19.4, 1.8, 3, and 7.1 bivalves per day, respectively. In central California, green crabs in field enclosures were responsible for 78%, 56%, and 92% declines of the mean abundances of the small bivalves *Nutricola confusa* and *N. tantilla*, and the cumacean *Cumella vulgaris*, respectively (Grosholz and Ruiz 1995). *Carcinus* also preyed upon species that ecologically similar co-occurring native crabs do not consume (Grosholz and Ruiz 1995). Through a series of field enclosures, Larson et al. (unpublished) determined *Carcinus* fed at a rate of 111 *Nutricola* spp., 1.2 *H. oregonensis*, or 1 juvenile *C. magister* per day. They predict that a population of 12,794 adults of *Carcinus* could consume over 922,794 *Nutricola* spp., 12,922 *H. oregonensis*, or 12,794 juvenile *C. magister* per day. The high feeding rate of *Carcinus* on a diversity of prey taxa warns of the potential predatory effects *Carcinus* may have on native biota in Alaska.

Habitat distribution

Green crabs are found in a variety of estuarine and nearshore habitats. *Carcinus* can be found along rocky shores on the Atlantic coast, in sheltered mud- and sandflats, in vegetation (saltmarshes, eelgrass, macroalgae; Moksnes 2002), within crab burrows in marsh banks (Crothers 1967), under rocks and woody debris (Davidson, personal observation), and in mussel beds (*Mytilus edulis*; Moksnes 2002). *Carcinus* can inhabit areas of variable wave energy, but is found in the highest densities in wave sheltered shores (Crothers 1970) and estuaries (Behrens Yamada 2001). In its native range (Wales, UK), the vertical distribution of *Carcinus* primarily ranges from the intertidal to 5.5 m in depth (Crothers 1967), but in invaded estuaries of the PCNA, they are primarily found between the middle intertidal to shallow subtidal (McDonald et al. 2006, de Rivera et al., unpublished data).

While green crabs can live in a variety of habitats, their local and regional distribution often appears to be limited by the interaction with native crabs. Hunt and Behrens Yamada (2003) found the red rock crab (*Cancer productus*) excludes *Carcinus* from the lower estuary of an Oregon bay. In addition, McDonald et al. (2006) found green crabs primarily inhabited the mid littoral zone despite the higher metabolic costs of living there versus the sublittoral. They suggest interspecific interactions with *Cancer magister* may be responsible for the zonation patterns of *Carcinus*. In central California, the distribution of green crabs also appears to be limited by native cancrid crabs (Jensen et al. 2007). Green crabs were primarily found in areas devoid of *Cancer* spp. and those green crabs that were found adjacent to populations of *Cancer* spp. exhibited high levels of limb loss and damage. The latitudinal range and intertidal zonation of *Carcinus* are also limited by interactions with native blue crabs (*Callinectes sapidus*) on the Atlantic coast of North America (de Rivera et al. 2005a) and are hypothesized to be limited by sharks and perhaps other vertebrates (de Rivera and Ruiz unpublished).

Distribution and spread

Global distribution and projected potential distribution

Carcinus is native to the northeast Atlantic from Mauritania (20.90° latitude) to Scandinavia (71.03° latitude; Figure 3; de Rivera et al. 2007a). It is a global invader with established populations in many regions of the world including both coasts of North America, Japan, Australia, South Africa, and Argentina (summarized by de Rivera et al. 2007a). The ecological niche model developed by de Rivera et al. (2007a) through Genetic Algorithm for Rule-set Production (GARP) predicts that

Carcinus has the potential to spread and persist in many other temperate regions of the world beyond their current distributions.

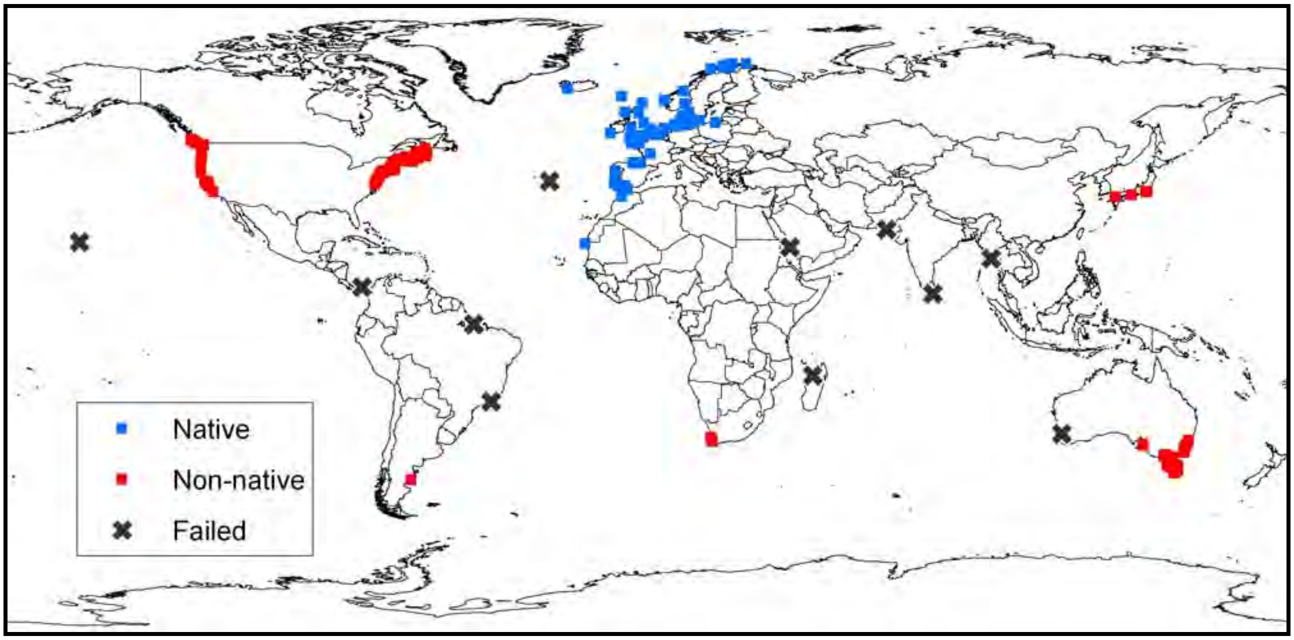


Figure 3. Global distribution of native (blue) and non-native (red) populations of *Carcinus maenas.* Crosses denote the locations of failed invasions. Modified from de Rivera et al. (2007a).

Invasion history and distribution on the Pacific coast of North America

Carcinus maenas was first recorded on the Pacific Coast of North America (PCNA) in Drakes Estero (70 km above San Francisco Bay) in May 1989 (Cohen et al. 1995). In 1989 or 1990, the crab was also found in San Francisco Bay and by 1991, could be found in very high densities (100's per trap; Cohen et al. 1995). The introduced crab has since spread along the west coast, invading at least 22 estuaries from Morro Bay to British Columbia (Figure 4). While many vectors are capable of spreading *Carcinus* within the region, the wide distribution and timing of green crab invasions suggest that planktonic dispersal on ocean currents is likely the primary vector for the spread of *Carcinus* along the Pacific coast of North America (Behrens Yamada and Hunt 2000).

Persistent, prolific populations in Vancouver Island, British Columbia, when coupled with favorable ocean currents, have the potential to act as a major source of future invasions of *Carcinus* to Alaska. Large populations of *Carcinus* thrive in at least 21 different sites along the west coast of Vancouver Island, British Columbia (Gillespie et al. 2007). We expect *Carcinus* will continue to spread past their current northernmost range in Quatsino Sound where it was found in high densities in 2007 (Gillespie unpublished).

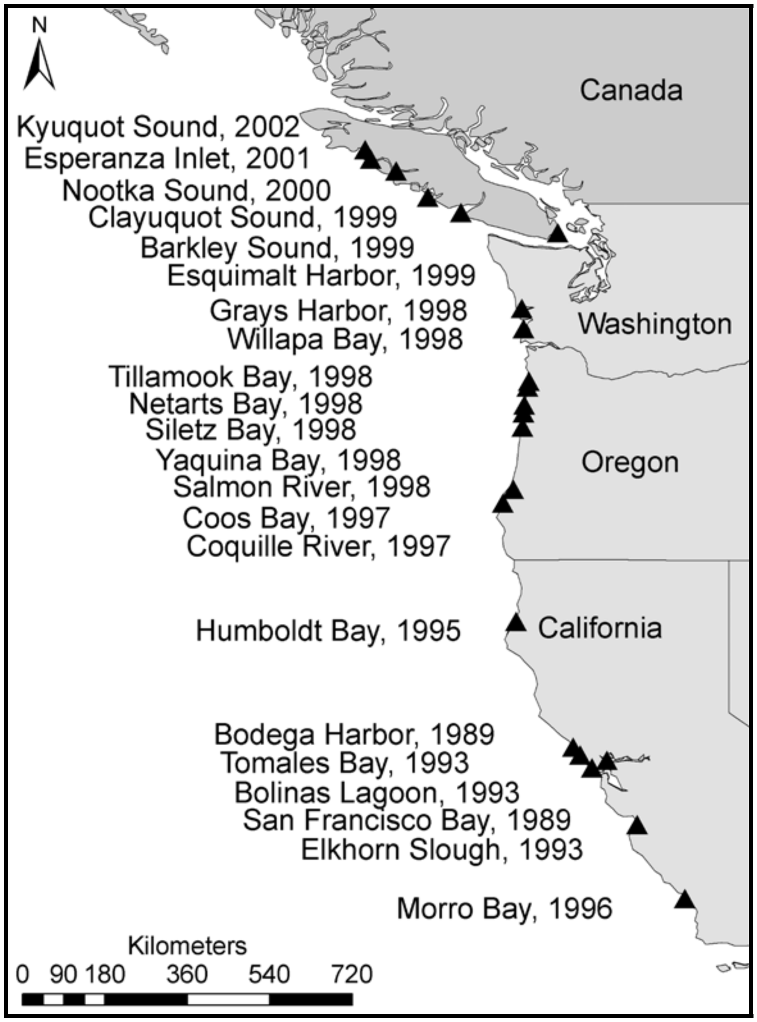


Figure 4. Distribution of non-native populations of *Carcinus maenas* on the Pacific coast of North America with date of discovery listed. Data provided by de Rivera et al. (2007a).

Vectors

Several anthropogenic and natural vectors may facilitate the spread of *Carcinus*. Green crabs can be spread anthropogenically through ballast water, ship fouling or the vessel infrastructure (sea chests, seawater pipes), the fouled hulls of exploratory drilling platforms, fouled marine equipment, the live seafood trade and live bait, from educators and researchers, or from private releases to establish a fishery (reviewed by Cohen and Carlton 2003). The initial introduction of *Carcinus* to the Atlantic coast of North America is thought to have been through hull fouling on sailing ships or possibly dry and wet ballast (Cohen et al. 1995, Cohen and Carlton 2003). Populations of *Carcinus* introduced to the PCNA originated from populations in the Atlantic coast of North America (Geller et al. 1997) and are thought to have been introduced through discarded seaweeds used in packing bait worms and/or Atlantic seafood, ballast water harboring *Carcinus* larvae, or from a ship's seawater pipe system (Cohen et al. 1995, Behrens Yamada and Hunt 2000).

Natural vectors are thought to be largely responsible for intraregional spread in the PCNA and other recipient regions. The larval stages of green crabs are pelagic and can spread naturally by ocean currents. Strong El Niño Southern Oscillation (ENSO) events appear to have facilitated the colonization and persistence of *Carcinus* in Oregon, Washington and British Columbia (Behrens Yamada and Hunt 2000, Behrens Yamada 2001, Behrens Yamada and Gillespie 2008; see Objective 3). *Carcinus* also could presumably spread naturally by migrating along the shores (Hunter and Naylor 1993) since it is found on the open coast on both sides of the Atlantic. Populations along the PCNA, however, appear restricted to estuaries (Grosholz and Ruiz 1996) and likely do not spread between bays through benthic migration.

Potential spread to Alaska

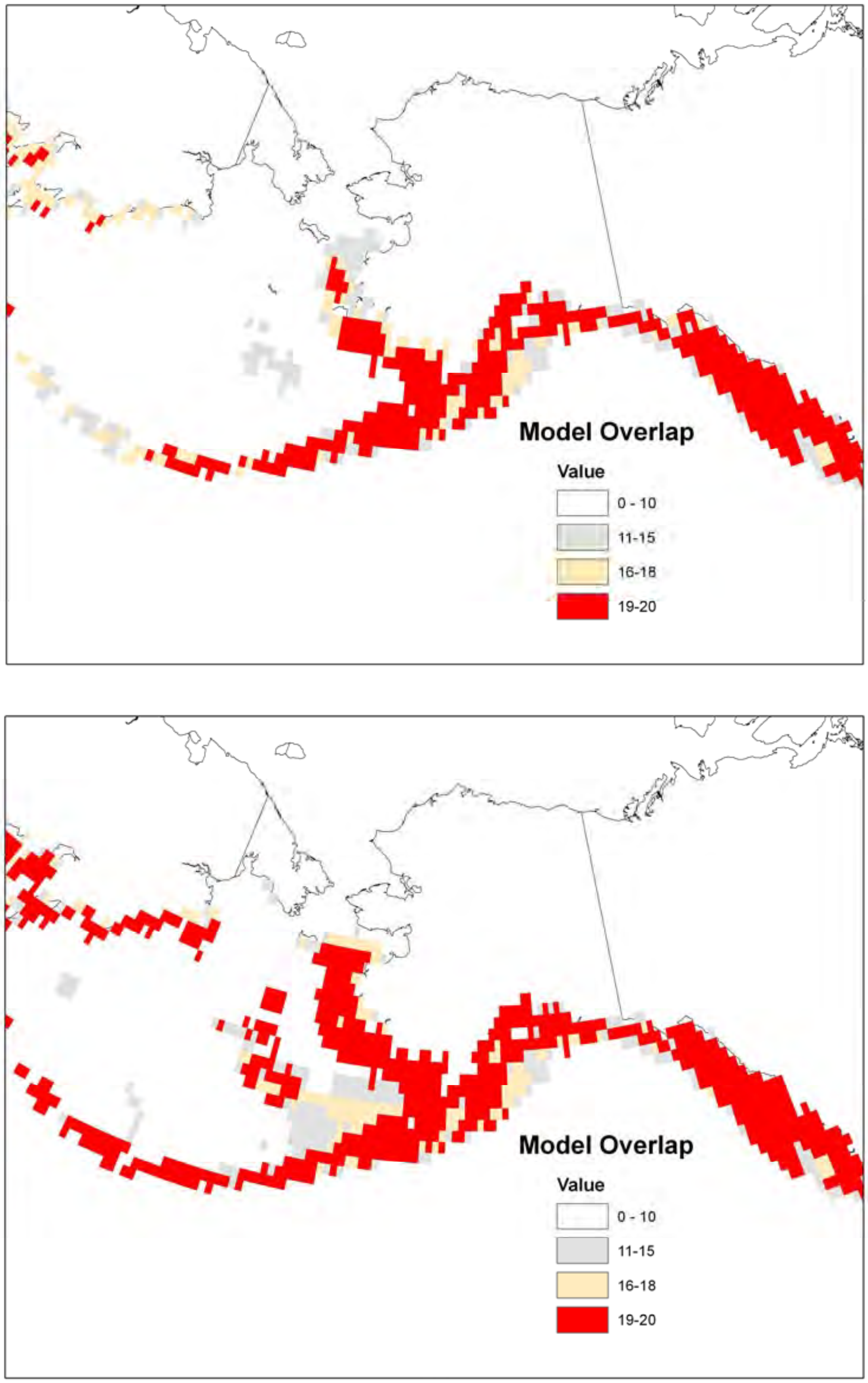
Potential for introduction

Small ephemeral and seasonal recruitment events could introduce populations of *Carcinus* to Alaska. In Oregon and Washington estuaries, water temperatures are not consistently conducive to larval development of *Carcinus* but populations of green crabs persist (Behrens Yamada and Hunt 2000, Behrens Yamada et al. 2005, Behrens Yamada and Kosro, submitted). Behrens Yamada and Hunt (2000) suggest that populations from California may be seeding Oregon and Washington estuaries. Some of these estuaries, which may be unable to harbor self-sustaining populations, have water temperatures that are highly variable; thus, while self or outside recruitment may not occur every year, it can occur when ocean conditions appear favorable (Behrens Yamada and Kosro, submitted). Behrens Yamada and Kosro (submitted) found the mean catch per unit effort (CPUE) of 0-age class *Carcinus* in 6 Oregon and Washington estuaries was positively correlated with several ocean conditions including warmer winter water temperatures, higher Pacific Decadal Oscillation Indices, later spring transitions, and weak southward moving shelf currents during March and April. Thus, vigilant monitoring of ocean conditions may reveal potential strong recruitment years. The relatively long life of green crabs on the PCNA (6 years) may allow populations to persist in areas, even if recruitment is low (with only one good recruitment event every 5 years or so; Behrens Yamada et al. 2005). Since green crab feeding (and presumably growth) can continue at temperatures as low as 7°C (Ropes 1968), populations introduced sporadically through favorable ocean currents could persist in Alaska and have negative effects for many years. Large persistent populations of *Carcinus* thrive in several bays of the west coast of Vancouver Island, BC (Gillespie et al. 2007, Behrens Yamada and

Gillespie 2008). These prolific populations could be a major source for future invasion of green crabs in Alaska. For additional discussion of anthropogenic vectors of *Carcinus* in Alaska see Vector management.

Potential for establishment

Ecological niche models and habitat suitability models reveal *Carcinus* has the potential to survive in many areas in Alaska. Using GARP, de Rivera et al. (2007a) found environmental conditions are suitable for green crabs from Southeast Alaska to Adak Island (Latitude: 51.784°) and as far north as Cape Romanzof (latitude: 61.780°; Figures 5A-B), suggesting green crab populations could persist throughout this range. Habitat suitability models developed by Harney (2007, 2008) predict wave protected areas with at least one additional habitat characteristic (eelgrass, saltmarsh, or sand/mudflat) are suitable areas for green crabs in Alaska. Although many areas appear to be susceptible to invasion, sites that exhibit all four critical green crab habitat characteristics may be particularly prone to invasion. These characteristics include: 1) protected or semi-protected wave exposures, 2) sand- and mudflats in the low intertidal, 3) eelgrass in the low intertidal/shallow subtidal, and 4) saltmarsh vegetation in the supratidal zone (Harney 2008). In British Columbia and parts of Southeast Alaska, 615 hotspot areas exhibit these 4 habitat characteristics and are predicted to be especially prone to invasion (Harney 2008), although a more comprehensive analysis of Southeast Alaska should be undertaken once shoreline data becomes available (Jodi Harney, personal communications). Furthermore, proximity to ports or aquaculture may also increase the vector strength and the potential for introduction to these hotspots that are more likely to support *Carcinus* populations.



Figures 5A-B. Projections of the potential range of *Carcinus* **A.** during the current climate regime and **B.** when incorporating the projected effects of global climate change (2°C increase in mean surface water temperatures over the next 100 years). Reproduced from de Rivera et al. (2007a)

While adults could persist, their larvae might be unable to develop in cold waters (de Rivera et al. 2007b). Additional models based on water surface temperatures and larval development times predict green crab larvae would be able to develop in just the 3 of 12 Alaska sites examined: Ketchikan, Sitka, and Seward (de Rivera et al. 2007b). However, with the advent of a predicted 2°C water temperature rise over the next 100 years (IPCC 2007), de Rivera et al. (2007b) predicted green crab larvae could develop in 9 out of 12 of the Alaskan sites examined north and west to Sand Point, on the Alaska Peninsula: Ketchikan, Sitka, Yakutat, Cordova, Valdez, Seward, Seldovia, Kodiak and Sand Point (Not predicted at Juneau, Unalaska and Adak Island). Moreover, present temperatures in some embayments, particularly shallow enclosed embayments, may be substantially warmer than the mean sea surface temperatures of the adjacent open coast. For example, de Rivera et al. (2007b) report that the water temperature near the entrance of Kachemak Bay had been measured one day in July around 10°C, while the water temperature from three sites further into the bay averaged 18.9°C that same day. If back bays are warmer and larvae are retained long enough to speed development of first and last larval stages as well as eggs, then there is potential for successful reproduction and larval development in areas we would otherwise think would be out of the temperature range for larval development. Cohen et al. (1995) suggested that the warmer enclosed shallow habitats within San Francisco Bay (tidal sloughs and lagoons) may have acted as an incubator for *Carcinus*. Thus, warmer enclosed habitats within Alaskan estuaries may also promote the establishment of *Carcinus*. Finally, populations that persist might quickly adapt to local conditions once introduced.

Early detection and rapid response plan

Goal of *Carcinus* management in Alaska

The goal of *Carcinus* management in Alaska is to prevent the establishment and spread of *Carcinus maenas* in Alaskan estuaries. The plan utilizes an adaptive approach that can be amended as needed to deal with biological, logistical, jurisdictional, or other changes that may occur. We propose several specific objectives and secondary goals to accomplish this goal:

Objective 1: Vector & source population management

Goal: Decrease propagule pressure

Objective 2: Outreach & education

Goal: Increase public understanding of the threat of Carcinus

Objective 3: Detection & monitoring

Goal: Increase likelihood of detecting an invasion

Objective 4: Coordination of management activities

Goal: Provide a clear procedure and framework for rapid response to invasion of Carcinus

Objective 5: Control & management options, given detection

Goal: Initiate a rapid and effective response to invasion by Carcinus

Early detection

Objective 1: Vector & source population management

Vector management

Populations of *Carcinus* can be spread to and throughout recipient regions by multiple anthropogenic vectors, as discussed above in Vectors. Primary vectors include ballast water, hull fouling, the live seafood trade, live bait, and from educators and researchers. The diversity of vectors requires different vector management strategies to be employed to prevent the spread and establishment of *Carcinus*.

Ballast water

The National Invasive Species Act of 1996 (NISA) requires open ballast water exchange at least 200 nautical miles offshore for all ships entering US waters. Vessels may also retain the ballast water in port or use an approved treatment method. Ballast water treatment can be an effective option if open water exchange is too dangerous or costly. Some options include heating ballast water, chemical treatments, deoxygenating the water, UV light, or pumping the ballast water in port and treating it onshore. While ballast water management will help prevent invasions from outside the US into Alaska, the introduction of *Carcinus* through ballast water is possible if ballast water were collected at infected ports within the US, such as San Francisco Bay or Coos Bay. In addition, some vessels (i.e. oil tankers) are currently exempt from ballast water exchange requirements and thus remain a potential and likely significant vector for the introduction of non-native species (See 2008 Vessel General Permit with the EPA at http://cfpub.epa.gov/npdes/home.cfm?program_id=350). McGee et al. (2006) examined patterns of vessel arrival in Alaska during 2003-2004 and found the largest percentage of arrivals were passenger vessels (23.5%) followed in descending order by ferries (23.1%), large commercial fishing vessels (11.8%), tankers (8.9%), tugs (8.4%), general cargo vessels (7.4%), and container vessels (7.1%). While tankers and other shipping vessels constitute a relatively low number of arriving ships, their voluminous ballast tanks (Hines et al. 2000) suggest these vessels are a significant vector for non-native species. Furthermore, vessels that remain close to the Canadian shore (within the EEZ) as they travel to and from Alaska are not required to exchange or treat their ballast water (See 33 CFR 151.2037a for details)

The State of Alaska has laws to prevent the discharge of ballast water that is contaminated with chemicals or sewage organisms, but the current legislation does not prevent the discharge of biological organisms into Alaskan waters. Therefore, the state laws should be amended to minimize the discharge of biological organisms into Alaskan waters to help reduce the likelihood of invasions by non-native species. State ballast water regulations are not unprecedented. The other Pacific coast states (California, Oregon, and Washington) have requirements beyond the federal regulations for vessels that enter their ports or travel through their waters. In those states, vessels from Alaska (or anywhere above 50° latitude) have to exchange or treat their ballast water or retain it in the vessel. California's regulations, which are among the most stringent in the world, require within-State exchange and have a zero discharge standard to take effect in 2020 (California Title 2, Division 3, Chapter 1, Article 4.6 section 2284 and 4.7 section 2295). Alaska, with its extensive coastline and amount of intra-state vessel movements, should evaluate implementing similar requirements.

Specific actions to take include establishing legislation that will:

- Determine what waters, seasons and times are high-risk for the intake of ballast water containing green crab larvae, and work with other Pacific coast states, Canada and the shipping industry to limit the intake of ballast water in those high-risk times and areas;
- Develop a state ballast water management program to reduce likelihood of introductions;
- Support removal of the tanker exemption from federal ballast water management guidelines;
- Support new requirements for in-state exchange.

<u>Hull fouling and vessel infrastructure</u>

Carcinus and other non-native species may also be introduced to a new area by hitchhiking amongst fouling on a ship hull or in the vessel infrastructure (such as a sea chest or seawater pipes). The initial introduction of *Carcinus* to the Atlantic coast of North America in the 19th century was thought to be from hull fouling on wooden sailing ships (Cohen et al. 1995). While modern anti-fouling paints and fouling release coatings reduce the accumulation of fouling, fouling organisms are still capable of settling on protected hulls especially as the treatments age and degrade. In addition, the complex structure of the vessel infrastructure provides a variety of microhabitats for small macrofauna, including crabs, to dwell (Coutts and Dodgshun 2007). Thus, while this vector may not be as strong (relative to current vectors) as it was in the 19th century, it is still viable for transplanting populations of *Carcinus* as well as other non-native species as transit times have significantly decreased. Periodic inspections of vessel hulls and infrastructure would reveal the relative strength of this vector for transplanting *Carcinus* to Alaska. Alaskan stakeholders should review the Australian regulations for management of the hulls of yachts arriving from foreign ports and California's recent recommendations for commercial vessel fouling (see Takata et al. 2006).

Specific actions to take to reduce threat from hull fouling include:

- Developing a state program for hull maintenance of both commercial and recreational boats;
- Work with U.S. Customs and Border Protection authorities to incorporate screening for green crab to their existing operations at ports of entry;
- Requiring drydocking and hull cleaning every 3-5 years for commercial ships and cruise ships with multi-ocean positioning.

<u>Aquaculture and seafood products</u>

The transportation of aquaculture and seafood products is also a potential source of *Carcinus* to Alaska. In Coos Bay, Oregon, Carlton (1989, as cited in Cohen et al. 1995) observed a large adult specimen of *Carcinus* in a lobster tank at a local restaurant 7 years before populations were found in Coos Bay. Regulations that reduce international and national movement of live seafood and aquaculture products would help prevent the movement of *Carcinus*. Educating and establishing working partnerships with local shellfish growers as well as those growers exporting products would also facilitate efforts to prevent the spread of *Carcinus* in Alaska.

Tailoring the Grosholz and Ruiz (2002) suggestions to Alaska, specific actions to take to prevent the intrastate movement or introduction of *Carcinus* with seafood products include:

- Developing state rules for cleaning and inspecting products and sterilizing packaging materials at the processing facility before export;
- Developing state rules to quarantine products during transit to avoid contamination;
- Work with U.S. Customs and Border Protection authorities to further develop a state program for inspecting seafood products to ensure the live product is free of *Carcinus* and other non-native species;
- Supporting development of national regulations for inspection of products and sterilization of living packaging materials (e.g., seaweeds) before export and quarantine during transit;
- Developing outreach programs for shellfish importers and exporters about the threat and mechanisms of spread of *Carcinus* and how to reduce spread.

<u>Live bait</u>

The initial introduction of *Carcinus* to the Pacific coast of North America may have been from the seaweed used with shipments of bait worms (Cohen et al. 1995). The release of live bait products and the packing material may also be a source of *Carcinus* in Alaska. On the Atlantic coast of North America, *Carcinus* is sold as live bait in many bait shops and is, according to informally interviewed fishermen, a potential cause of rare adult green crabs found beyond the southernmost established populations (de Rivera, unpublished).

Revision of current regulations to preventing the sale or importation of live bait in marine areas could be highly effective in preventing accidental introduction of *Carcinus*. Inspection of bait shops in Alaska would also help prevent *Carcinus* from being sold or inadvertently transported. At a minimum, regulations requiring that live bait be disposed of on land could be effective.

> The specific recommended action is to develop state regulations that prohibit the sale or importation of live marine bait.

<u>Researchers and educators</u>

Carcinus may also be imported to Alaska for use by researchers or educators and intentionally or unintentionally released. Thus, informing researchers and educators of the risk involved with releasing unwanted lab or research specimens is important. In addition, regulations restricting the importation of invasive species would help but not fully prevent the purchase and importation of non-native species since many non-native species are easily obtained through online businesses; citizens may be unaware of the regulations.

> The specific recommended action is to develop outreach programs for researchers and educators about the threat of *Carcinus* and other non-native species and the risks of releasing live specimens.

Managing source populations

While many anthropogenic vectors can be managed, natural vectors are more difficult or impossible to manage. *Carcinus,* which has spread to nearly every major estuary from Morro Bay, California to Vancouver Island, British Columbia (Figure 4), is widely thought to have spread throughout the PCNA primarily by strong northward moving ocean currents (e.g., Behrens Yamada and Hunt 2000). Therefore, any effort to prevent *Carcinus* from invading Alaska requires management of the source populations of *Carcinus* propagules. For Alaska, the primary natural source of invasion is likely the dense and expanding populations of *Carcinus* on Vancouver Island, British Columbia. The high catch per unit effort (CPUE) of *Carcinus* off Vancouver Island (1.72 and 22 crabs per trap CPUE in 2006 and 2007, respectively) far exceeds the CPUE in Oregon and Washington estuaries (Behrens Yamada and Gillespie 2008; Behrens Yamada, personal communications); these populations may be a source of billions of larvae. Investing effort and money in reducing populations of *Carcinus* at the source would serve to reduce the likelihood of future *Carcinus* invasions of Alaska and would help control the spread and impact of *Carcinus* in Canada. Thus, international efforts to manage or eradicate *Carcinus* would be beneficial for both countries and is greatly encouraged. The Pacific Coast Collaborative and the West Coast Governor's Agreement on Ocean Health provide initiatives that set the stage for interstate and province collaborations for the control of invasive species. We introduce several methods of *Carcinus* control under *Objective 5: Control and Management Options.* Controlling source populations would also help reduce anthropogenic spread by any of the coast-wide vectors previously discussed.

Specific actions to reduce propagule pressure include:

- Support management of potential source populations;
- Work collaboratively with Canada to control or eradicate high density populations off Vancouver Island.

Objective 2: Outreach & education

Established educational outreach

Education and outreach are effective means of preventing the establishment and spread of non-native species. The primary education and outreach tools include: 1) public presentations, 2) informational websites and videos, 3) citizen science, 4) printed materials (pamphlets, booklets, information sheets/cards), and 5) signage. In Alaska, extensive outreach and education programs and websites on non-native species have been established by many governmental agencies and non-governmental organizations such as: Alaska Department of Fish and Game, Alaska Invasive Species Working Group, Alaska Association of Conservation Districts, University of Alaska Fairbanks Cooperative Extension Service, federal land management agencies and the Smithsonian Environmental Research Center. Summaries and contact information for many of these groups can be found at: (http://www.invasivespeciesinfo.gov/unitedstates/ak.shtml, *accessed 5-April-2009* and http://www.alaskainvasives.org *accessed 23-June-2009*). Other organizations work actively with citizen scientists such as school groups or conservation volunteers to help monitor for non-native species, including *Carcinus*, such as Kachemak Bay Research Reserve (KBRR) and Prince William Sound Regional Citizens' Advisory Council (PWSRCAC). Written outreach materials such as pamphlets, booklets, informational sheets/cards, and scientific reports are also effective means to educate the public about the threat of non-native species. Many governmental organizations actively produce and distribute these materials on non-native species (including *Carcinus*): Alaska Department of Fish and Game, University of Alaska Fairbanks Cooperative Extension Service, PWSRCAC, and KBRR. National Oceanic and Atmospheric Administration (NOAA) funded, through the NMFS, Alaska Region, an interagency produced poster "Look Out for Invasive European Green Crab" and distributed it to harbormasters, Customs and Border Patrol agents and natural resource agencies and organizations throughout Alaska (Available for download at http://www.uaf.edu/ces/aiswg/pdf-documents/LOOK_OUT_FOR_European_green_crab.pdf). KBRR has produced a card "Stop Aquatic Invasives Species European Green Crabs" which has also been widely distributed. In addition, signage at boat launches, marinas, and recreational sites would be effective in educating boaters about some non-native species.

Further outreach

The dissemination of information to the general public is critical to producing an educated, aware, and vigilant populous. Expanding present efforts to inform the public about *Carcinus* and other non-native species at these and other public access points is encouraged. Specific actions to take with current citizen scientist groups and educational programs include:

- Ensure that written material and signage are up to date and distributed or posted clearly;
- Inventory existing outreach materials to identify areas where additional outreach is needed;
- Expand present efforts to inform the public about *Carcinus* and other non-native species at boat ramps, parks, and other public access points.
- Incorporate public service seminars and expansion of present efforts to inform the public about *Carcinus*;
- Continue to cultivate working partnerships and collaborations between local, state, federal agencies, industries, native corporations, non-governmental institutions, universities, and conservation groups to enhance monitoring efforts and outreach.

Several additional actions will enhance education and outreach of the potential impacts of *Carcinus* in Alaska.

1) *Establish a website for citizens to report new invaders*

To complement the phone number the Alaska Department of Fish and Game maintains for citizens to report suspected invaders (1-877-INVASIV; 1-877-468-2748), and to increase reporting, establish a website that a) allows the public to submit online reports or sightings of suspected non-native species and b) educates the public about the threat of *Carcinus* and other invaders. The website would help disseminate all outreach materials designed to help with prevention and detection of *Carcinus* and other invaders. Including a webpage that lists contact information for the organizations conducting monitoring across Alaska might also help increase the volunteer pool. The Oregon Invasive Species Online Hotline is one example of a reporting tool for the general public; since its establishment in April 2008 there have been over 300 reports of non-native plants and animals submitted (http://oregoninvasiveshotline.org/, *accessed: 5-April, 2009*; Figure 6).

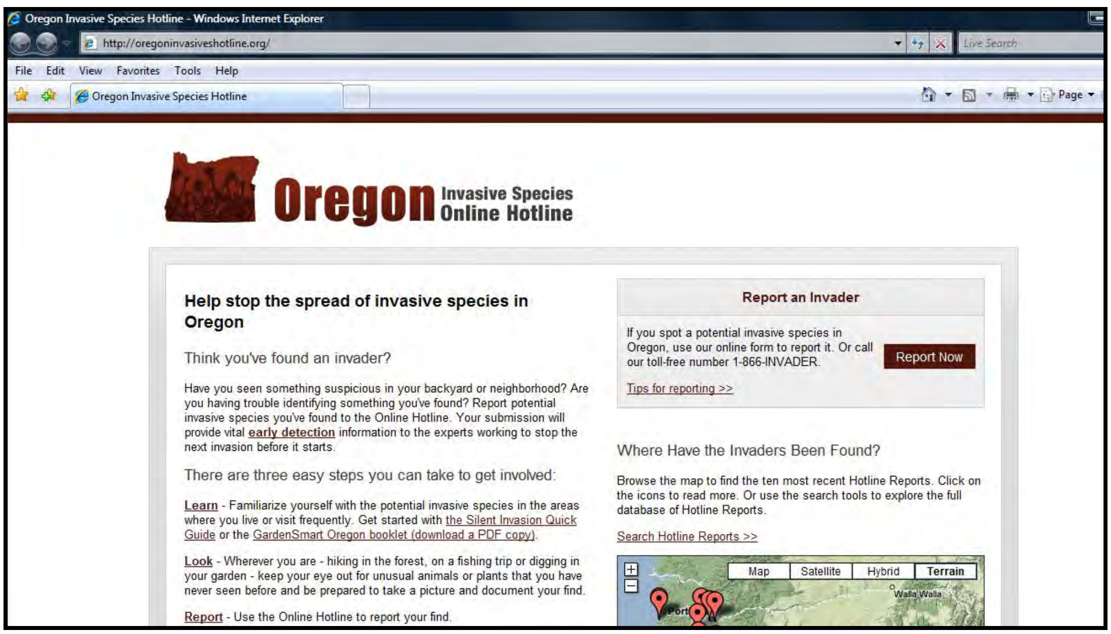


Figure 6. Screen shot of the Oregon Invasive Species Online Hotline reporting system, http://oregoninvasiveshotline.org/, *accessed: 5-April-2009*.

2) Enhance dissemination of information through the creation and distribution of printed material and other materials

The creation and distribution of additional printed material including pamphlets, informational sheets/cards, and booklets may help better inform the public. First, an inventory should be undertaken to identify gaps in the current outreach materials. Ideally, allowing open access to materials and the distribution of outreach materials online would help reduce the redundancy of materials and save effort and costs. For *Carcinus*, the creation of a comprehensive native and non-native crab guide would be an invaluable resource to distribute. Similar guides produced by the Oregon Department of Fish and Wildlife were highly successful and only cost $1/laminated sheet to produce (Figure 7, Scott Groth, personal communications). Finally, it is essential to include on all printed material both the web addresses for additional online information about non-native species and instructions on how to volunteer. Training the public would also be enhanced by acquiring more preserved specimens or specimen displays that can be distributed or observed during public presentations.

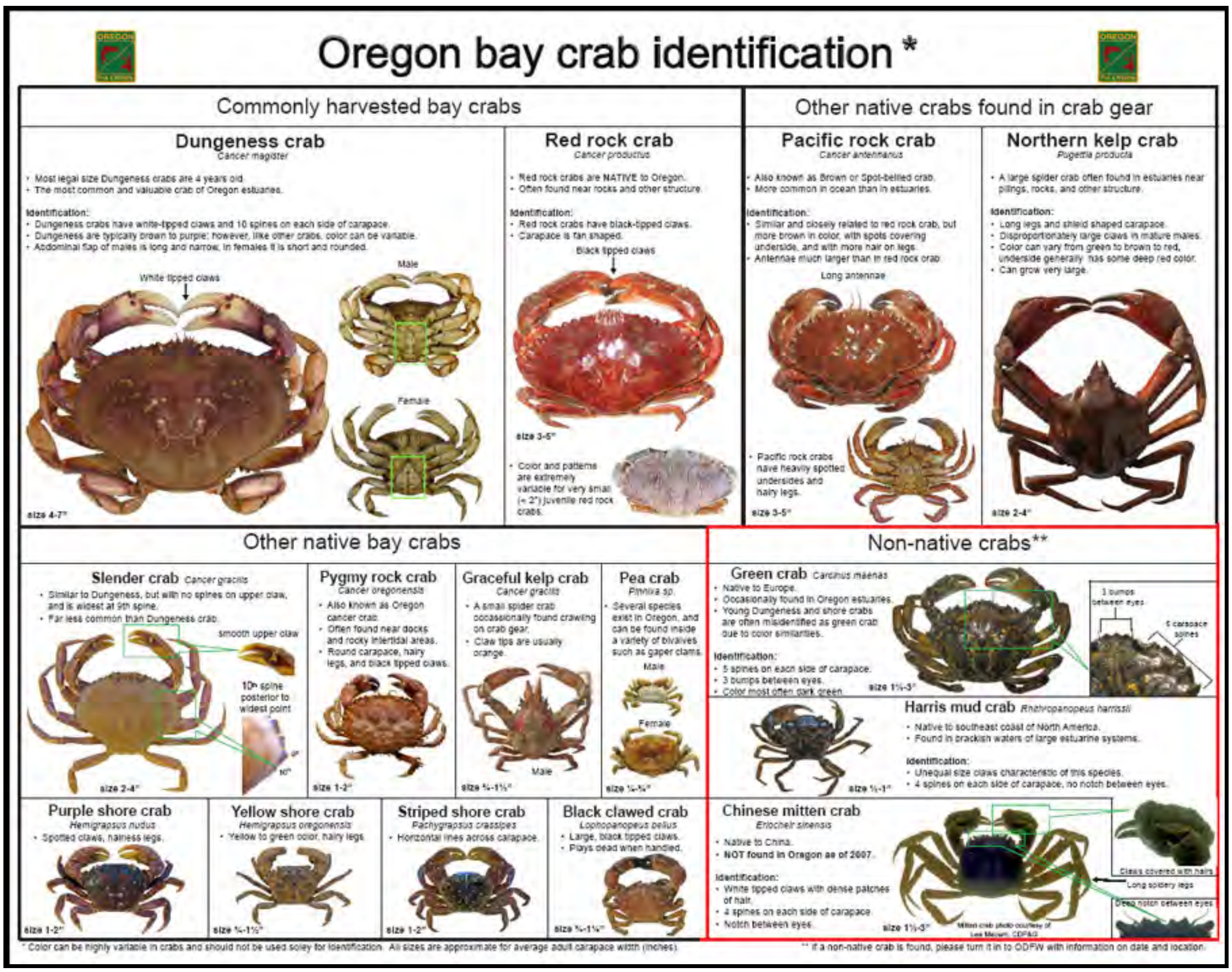


Figure 7. Oregon bay crab Identification guide, produced by Scott Groth of the Oregon Department of Fish and Wildlife (2007; reproduced with permission). A similar guide produced for Alaska would greatly aid the ability of the public to detect invasions of *Carcinus*.

3) *Conduct outreach to citizen scientists and professionals*

Several of the *Carcinus* invasions were first detected by recreational and commercial fishers. In 1989, a fisherman found a single male green crab specimen in a gill net in Drakes Estero (70 km north of San Francisco; Cohen et al. 1995). In August 1991, a recreational crabber in San Francisco Bay, CA found an unusual crab (*Carcinus*) unlike any of the native crabs he encountered in his traps (Cohen et al. 1995). Similarly, in 1997, an oyster grower discovered the first specimen of *Carcinus* in Oregon (Coos Bay; Behrens Yamada, personal communications); the subsequent year, he discovered thousands of small *Carcinus* sheltering in oyster shells (Behrens Yamada et al. 2005). Such important discoveries by citizens emphasize the importance outreach and education can play in the early detection of invasion by *Carcinus*.

Outreach should target special interest groups and stakeholders (Table 1), including beach combers and shell collectors, amateur naturalists, eco-tourists and environmental resource specialists, birders, recreational foragers, fishers and clammers, that frequent habitats where *Carcinus* or their molts are likely to be found. Commercial fishers and mariculture professionals, particularly, should be targeted for outreach due to their knowledge of marine species, extensive time spent in the waters, and the likelihood that their industries will be negatively impacted by *Carcinus*. Outreach can include presenting at meetings, club events, or special events (such as fairs or sportsmen/fishing expos), distributing printed materials, or meeting with the leaders of special interest groups.

Concerned citizens should also continue to be recruited for current or future monitoring programs. Monitoring programs should utilize standardized methodologies (discussed in *Objective 3: Detection & Monitoring*) to ensure consistent and quantifiable sampling effort and for additional scientific purposes. Educated and informed citizens, perhaps recruited from the above special interest groups, would continue to offer a critical service. In addition, many community college and university programs offer or require internship and research credits for their students; thus, networking with professors, instructors, and academic/program advisors may aid in recruiting additional volunteers for monitoring programs. Education and awareness can start early; education and coastal monitoring programs are currently in place with K-12 groups in Kachemak Bay, AK and may serve as an example of the successful implementation of outreach materials to increase vigilance (Appendix C).

Objective 3: Detection & monitoring

Detection & monitoring protocol

To monitor and detect invasions by *Carcinus,* scan shorelines for molts and trap following protocols consistent with those used in the National Estuarine Research Reserve System, including KBRR (KBRR 2008, Appendix C) and the National Marine Sanctuary Program (de Rivera et al. 2005b). Consult with personnel in Alaska and British Columbia that are currently conducting monitoring efforts trapping from shore (KBRR and Heather Woody of Sitka Tribes), by float planes (Gary Freitag of Sea Grant Marine Advisory) and small motorized boats (Graham Gillespie of Fisheries and Oceans Canada) for site/habitat specific field knowledge (Appendix A). Use a combination of baited collapsible Fukui box traps and modified minnow traps, which effectively catch *Carcinus* (Larson et al. unpublished) and are easy to deploy and transport. These characteristics make Fukui box traps and modified minnow traps the ideal tools to sample green crabs in areas with limited wave energy (i.e. mudflats) or when there is limited storage space for equipment (i.e. when sampling from a small boat, float plane, or kayak). Deployment of both types of these traps is recommended since each trap is more effective at catching different sizes of green crabs. The larger box traps are effective for adult green crabs (especially males) while minnow traps, modified with expanded openings, are more effective at catching young-of-the-year and small adult crabs (30-55 mm in carapace width, light green coloration), especially females (Larson and de Rivera, unpublished).

Collapsible Fukui box traps (60 x 45 x 20 cm, with two 40 cm openings and 12 mm mesh; Figure 8A) are strongly recommended and are available for order online through Fukui North America: http://www.fukuina.com/fishtraps/square_multi_species_marine_trap.htm.

Fukui traps cost around $50 including shipping, but require orders of at least 100. Flimsy, inexpensive versions are available from Memphis Net and Twine: http://www.memphisnet.net/product/2847/traps_fish_collapsible for around $27-$30 depending on how many are ordered; these will need to be replaced more frequently as they deteriorate more quickly than the Fukui traps. Minnow traps (vinyl-coated or galvanized steel or plastic tapered cylinders, 42 cm long, 23 cm diameter, with openings on either side and ~10 mm mesh; Figure 8B) are available locally in most sporting stores for around $9 and should be modified to have an opening on one side large enough for smaller adult green crabs (5.0 ± 0.5 cm diameter opening).

Figures 8A-B. Baited folding Fukui box traps (left) and modified minnow traps (right). A commercial bait container can be observed inside the minnow trap (white capsule, right).

These traps should be deployed at low tides, slightly submerged in habitats with structure or types of habitats known to harbor green crabs (e.g. deep channels, adjacent to saltmarshes, eelgrass beds (*Zostera marina*), rocky riprap). KBRR (2008) recommends deploying traps at 1.0 ft below MLLW if traps are deployed from shore. Fukui and minnow traps should be alternately deployed at least 20-30 m apart. At least 5 of each trap type should be deployed per site, with the spacing modified to fit the extent of the site. Traps can be tethered to a pole or structure and, in areas with strong currents, anchored with rocks or rebar to avoid loss and movement in currents. Traps should lay flat against the substrate and be anchored well enough to allow benthic epifauna to enter. Deploying traps from boats may be a more feasible method if the surrounding areas are dominated by mucky unconsolidated sediment or otherwise inaccessible. This can be accomplished by attaching weighted traps individually to buoys or along a line using long line (halibut) clips. Fresh or frozen fish or in commercial bait containers or perforated plastic tubs can be used as bait. Commercial bait containers are small perforated capsules (15 x 8 cm, with 5 mm holes; Figure 8B) that allow the odors of the bait to diffuse yet restrict access to the bait by the trapped species. Oily fish such as herring or sardines appear to be preferred bait. Traps should be retrieved after 24 hours, but can remain deployed for up to 3 days. All captured green crabs should be sealed in containers, frozen, and preserved; identification should also be confirmed by an expert. Subsequent to confirmation, the crab may be disposed of on dry land after trapping.

The mortality of bycatch has been low using these methods and can be minimized by following a few precautions. Fastening a zip tie to each opening will reduce the aperture size in Fukui traps and thereby reduce incidental mortality of mammals, birds, and larger fish. The mortality of small bycatch species (such as crustaceans and small fish) in traps placed in the intertidal may be reduced by placing both types of traps in water filled depressions and by checking them as soon as the tide retreats the day following deployment.

A variety of other traps are used by various researchers to capture green crabs including pitfall traps and traps/structures that crabs would enter for refuge (habitat traps, piles of bags filled with oyster shells), and other types of baited box traps. Pitfall traps are 5-gallon buckets that are buried flush with the sediment and filled with water; they are passive traps designed to collect crabs as they walk across the surface. Pitfall traps, however, must be constantly maintained and monitored as they can rapidly fill with sediment and otherwise continuously catch benthic epifauna. The aggregation of epifauna in these buckets can promote predation by motile predators such as large fish or even raccoons. We also suggest marking pitfall traps to reduce the chance that a person may unwittingly step into one and hurt themselves. Habitat traps are unbaited traps that attract crabs due to the shelter and habitat aspects offered by the traps. For example, this can include any form of trap that provides shelter such as a Fukui or another box trap filled with algae and eelgrass or pipe traps (bounded lengths of PVC piping with one closed end). If an area of high water flow or energy must be sampled, use a more robust and weighted box trap to prevent damage or loss of the Fukui or minnow traps. Sturdy box traps constructed of PVC piping and hardware cloth appear to be robust to high flow areas and the powerful claws of cancrid crabs that can damage Fukui traps. However, areas with large numbers of cancrid crabs also appear less likely to harbor populations of *Carcinus* (Hunt and Behrens Yamada 2003).

Additional techniques to detect green crabs include beach seines, trawls, snorkel surveys (Grosholz et al. 2000) and by shoreline surveys for crab molts and individuals. Beach seines are particularly effective in detecting young-of-the-year green crabs (Larson et al., unpublished), but their use also has a variety of difficulties such as high levels of bycatch, long processing times, and the inability to be used in areas with lots of structure such as submerged aquatic vegetation and woody and rocky debris. Boat trawls were not an effective method of detecting *Carcinus* in Bodega Bay (Larson et al., unpublished) since *Carcinus* is not typically found in deep waters. Snorkel surveys can be used quantitatively (along a transect) or qualitatively to detect green crabs, but are less efficient than trapping. The efficacy of these methods varies and is further evaluated in *Objective 5*: *Control & management options once detected*.

Shoreline (walking) surveys for molts and individuals of *Carcinus*, however, are a relatively minimal cost-effective method of detecting populations of *Carcinus*. The high tide mark, where flotsam and jetsam accumulate, and shallow water should be examined for *Carcinus* molts. Crab molts are identified by the same number of spines but are often bleached in appearance. Quick qualitative shoreline surveys in other regions have been successful in detecting adult and juvenile

Carcinus and other non-native species, even in areas where live ones have not yet been trapped (Davidson 2008, Davidson unpublished, Davidson and de Rivera unpublished). Heterogeneous intertidal habitats such as rocks, woody debris, and algae can harbor individuals of *Carcinus*. Rock turning, in particular, can be effective when the habitat is composed of muddy sand to sandy mud, with smaller rocks that are shallowly embedded (de Rivera and Larson, per obs). Monitors should be attentive while in the field; many meters of shoreline can be examined for molts and individuals of *Carcinus* and other non-native species (including invasive cordgrasses, *Spartina* spp.) while traveling to the trapping locations.

Where to monitor?

Based on the wide physiological tolerances, documented habitat use, and survey data of *Carcinus*, monitoring for green crabs should focus on the low-intertidal to shallow subtidal zones of wave sheltered bays and estuaries. However, if large densities of cancrid crabs are present, then *Carcinus* may be found in high intertidal to mid intertidal zones. Green crabs should be sampled in areas with physical structure such as cobble/rock beds, shell beds, woody debris, and amongst vegetation (algae, eelgrass, saltmarsh plants) or in depressions or tidal channels. In Bodega Bay, CA, exposed areas and areas with colder, more saline water with large populations of cancrid crabs do not appear to harbor large populations of *Carcinus* (Grosholz and Ruiz 1996; de Rivera and Larson, unpublished). Similarly, surveys by Hunt and Behrens Yamada (2003) revealed that the highest densities of *Carcinus* are found in the middle areas of the estuary between river miles 2 to 7.4, which do not harbor large populations of *Cancer productus*. Behrens Yamada and Gillespie (2008) predict green crabs may be found in the highest densities in estuaries with low salinity.

Effort

The CPUE of green crabs, a proxy for density, varies greatly among estuaries on the west coast (Table 3). Central California and British Columbia harbor green crab densities that appear much larger than in Oregon and Washington. One of the premier challenges of ecology and conservation biology is determining an adequate number of samples or effort necessary to detect rare species; the analog of this problem in invasive ecology is detecting a rare invader. Determining the number of samples necessary to detect a rare species can often be aided through a statistical power analysis, but without having accurate estimates of the variance of the present population, such an analysis is not possible. However, examining the effort required to detect these relatively small populations of *Carcinus* in some embayments may allow us to determine a baseline estimate of the effort required to detect a small population of *Carcinus* in other estuaries. In addition, studies by de Rivera and Larson (unpublished) will reveal how CPUE of *Carcinus* changes with population size once population levels are verified (through removal) in Bodega Bay, CA. Populations of *Carcinus* in Oregon, Washington, and Humboldt Bay, California have been consistently low in the years following their initial large scale invasion in 1997/8. The CPUE in these embayments was less than 1 per 100 traps (per 24 hours) in Gray's Harbor, Washington and Humboldt Bay, California. During the survey of Humboldt Bay, Grosholz (unpublished) deployed 144 traps and only caught a single green crab. Thus, it would appear deploying around 100-150 traps in a location may provide a minimal effort to detect low populations of *Carcinus*. If the number of traps available is limited, traps may be redeployed over the course of several days. Ideally, of course, deploying more traps would be preferred if logistically and economically feasible. Many of these estimates were based on traps deployed at preferred or likely locations to find green crabs given their habitat preferences and environmental constraints and during the spring and summer.

Trapping effort should be focused on these preferred habitats, as well as hotspots for other potential vectors such as aquaculture facilities, and during the late summer and at least once a year, because the population is unlikely to recruit in large numbers at multiple times a year. By late summer, crabs should be large enough to be retained in baited traps.

Table 3. Catch per unit effort (CPUE; *Carcinus* per 100 traps deployed) in select embayments of California (CA), Oregon (OR), Washington (WA), and British Columbia (BC). Sources: Behrens Yamada and Gillespie 2008, de Rivera and Grosholz unpublished, Gillespie et al. 2007, Grosholz 2004, 2006. Empty cells indicate data is unavailable. Data unavailable for 1996.

Embayment	Region	Latitude	Longitude	1994	1995	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Kyuquot Sound	BC	50.074	-127.133								P			P	53
Esperanza Inlet	BC	49.871	-126.757							P	P	P		5	46
Nootka Sound	BC	49.641	-126.616						P						3[a]
Clayoquot Sound	BC	49.119	-125.848						P						20
Barkley Sound	BC	48.826	-125.137					P						P	172
Esquimalt	BC	48.455	-123.465					P							
Grays Harbor	WA	46.972	-123.804		0[a]		28	3	3	1	<1			2	2
Willapa Bay	WA	46.373	-123.950		0[a]		35	43	4	3	4	3	3	25	8
Tillamook Bay	OR	45.543	-123.903		0[a]	P[b]	128	P	P	2[a]	3	9	8	11	28
Netarts Bay	OR	45.423	-123.946			P	139			6[a]	0	25	31	49	57
Yaquina Bay	OR	44.624	-124.052	0[a]	0[a]	P	192	69	63	57	15	6	3	13	23
Alsea Bay	OR	44.432	-124.066				P				P	P			
Winchester Bay	OR	43.680	-124.195				P								
Coos Bay	OR	43.441	-124.224	0[a]		<1	65	38	P	63[a]	5	7	13	4	8
Coquille River	OR	43.124	-124.409				P							5[a]	
Humboldt Bay	CA	40.831	-124.085	0[a]							<1		0		
Bodega Harbor	CA	38.316	-123.038	P	225[a]		7350[a]	1360[a]		344[a]	602	277[a]	91	146[a]	394
Tomales Bay	CA	38.156	-122.890	1650[a]	1717[a]							482	542	367[a]	93
Drakes Estero	CA	38.044	-122.946	367[a]	0[a]										
Bolinas Harbor	CA	37.909	-122.685	684[a]	345[a]										
San Francisco	CA	37.890	-122.482	P	94						44	39	148		
Elkhorn Slough	CA	36.812	-121.736	6	16		51	43			234	1709	302		156

[a.] Indicates fewer than 50 traps were deployed

[b.] P indicates the Presence of *Carcinus* from public reports

Trapping summary

- Monitor by trapping at least yearly during the late summer in sheltered bays and estuaries that contain some structure. When possible, increase trapping effort following ENSO events and particularly mild winters;
- Deploy traps along transects, alternately placing at least five Fukui and five Minnow traps, baited with herring or anchovies, at intervals of about 20 m;
- Focus trapping on the low intertidal to shallow subtidal zones of wave sheltered bays and estuaries; traps should be at least partially submerged at low tide. However, if large densities of cancrid crabs are present, then sample in the mid to high intertidal as well or instead;
- Place traps in/near physical structure such as cobble/rock beds, shell beds, woody debris, and amongst vegetation (algae, eelgrass, saltmarsh plants) or in depressions or tidal channels. Placement of traps in these preferred habitats will also help reduce desiccation of trapped animals during low tide;
- Opportunistically scan for *Carcinus* carapaces along the shoreline where flotsam has accumulated.

Other detection tools

<u>Habitat suitability models</u>

The habitat suitability models created by Harney (2007, 2008) corroborate our recommendations. The model developed by Harney (2007) suggests that the presence of sand- and mudflat as well as one other habitat characteristic can predict green crab habitat. These habitat models are an important tool for broad identification of invadable habitats in Alaska but can miss some of the fine scale habitat characteristics (undetectable by aerial photography and satellite imagery) that may provide important habitat for green crabs.

<u>Aerial photography and satellite imagery</u>

Aerial photography and satellite imagery provide low cost methods of characterizing the broad scale habitat characteristics in otherwise logistically or physical inaccessible areas. Combined with ground-truthing, these techniques could be very informative at revealing the potential invasibility of regions of Alaska. In addition, obtaining environmental parameters such as temperature and salinity, and analyzing and visualizing the patterns within a Geographic

Information System (GIS) would provide helpful predictive models of suitable green crab habitat. For example, a study that examined how CPUE in different areas of estuaries could be predicted by the presence of broad scale habitat characteristics would be very helpful. These analyses could be readily conducted through the GIS Spatial Analyst function by utilizing the appropriate suite of spatial interpolation tools and statistics. Such analyses would be very helpful for predicting which estuaries are more susceptible for invasion and need to be developed. Aerial photographs used by Harney (2008) for the habitat suitability model could be used to further develop and test areas to be ground-truthed.

<u>Expert involvement</u>

Utilizing expert advice can also provide additional important information on where and when to sample for *Carcinus*. Experts can provide additional training of the proper identification of *Carcinus* and the preferred habitats and may provide invaluable assistance in troubleshooting logistical issues. It is important to provide a training workshop for volunteers and researchers that includes instruction by experienced green crab trappers or other trained personnel. A preliminary list of *Carcinus* experts in North America can be found in Appendix B.

<u>Detection of *Carcinus* larvae using molecular techniques</u>

Darling and Tepolt (2008) developed a highly sensitive technique for detecting *Carcinus* larvae in water samples, including samples from ballast water. By using polymerase chain reaction (PCR) and examining the restriction fragment length polymorphisms (RFLP), their technique can detect a single larva of *Carcinus* in ballast water samples containing over 1 gram of non-target biomass species including several other brachyuran larvae. This technique has a tremendous potential for detecting cryptic invasions of areas that are inaccessible to trapping or as a safeguard to ensure ballast water is free of *Carcinus* larvae. The cost of this method is also inexpensive in terms of material costs (around $5) and processing time (2 hours per sample, but dozens of samples can be processed simultaneously; J. Darling, personal communications). Not only could this technique be used to simply screen for *Carcinus* larvae, but could also test for compliance with ballast water exchange regulations. However, the cost of providing the necessary equipment and expertise might require a substantial initial investment.

Existing monitoring framework

Several organizations are currently monitoring for *Carcinus* at numerous sites within 14 general locations throughout Alaska (Figure 9, Table 4, Appendix A). Some locations are composed of multiple sampling sites. Sites are being monitored by volunteers and employees of PWSRCAC, KBRR, Alaska Sea Grant, Glacier Bay National Park and Preserve, Sitka Tribe and the US Forest Service; Southeast Alaska monitoring is being coordinated by the National Marine Fisheries Service, Alaska Region. Expanding the monitoring to the following areas will ensure a more comprehensive coverage of the possible locations for invasion: Petersburg, Yakutat and estuaries near Juneau in Southeast Alaska.

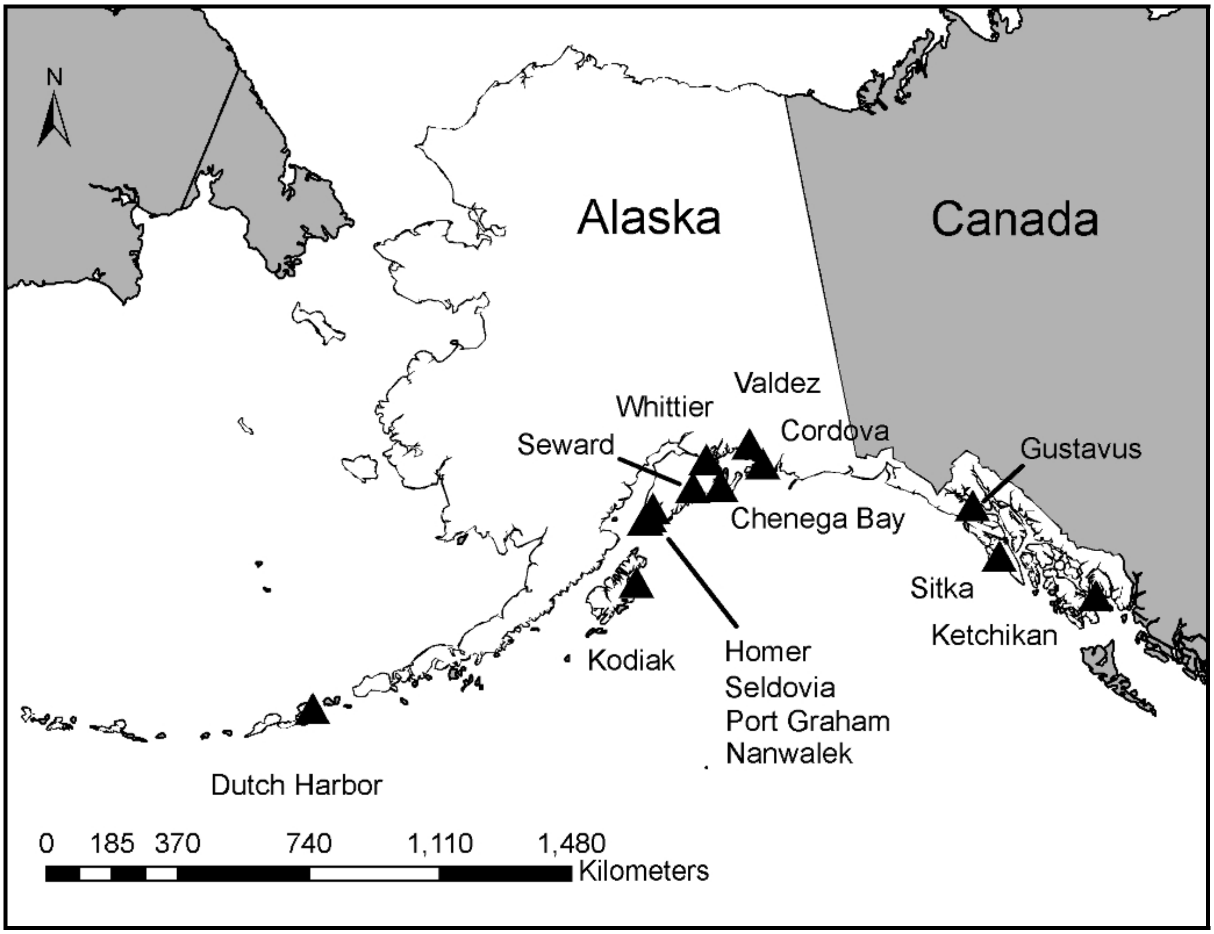


Figure 9. General locations of *Carcinus* monitoring programs in Alaska.

Table 4. General locations and organizations currently conducting *Carcinus* monitoring in Alaska. GBNPP = Glacier Bay National Park and Preserve, USFS = United States Forest Service, PWSRCAC = Prince William Sound Regional Citizens' Advisory Council, KBRR = Kachemak Bay Research Reserve. Monitoring in Seward to begin in 2009.

Locations	Latitude [a]	Longitude [a]	Organization	Number of Traps	Frequency (per year)	Total Effort
Dutch Harbor	53.918	-166.53	PWSRCAC	24	2	48
Ketchikan[b]	55.345	-131.7	Ak Sea Grant, USFS	2-5	4	20
Sitka[b]	57.044	-135.31	USFS, Sitka Tribe	7	1	7
Kodiak	57.789	-152.43	PWSRCAC	24	3	72
Gustavus	58.452	-135.89	GBNPP	8	4	32
Homer	59.633	-151.51	KBRR	11	5	55
Seldovia	59.436	-151.71	KBRR	11	5	55
Port Graham	59.356	-151.87	KBRR	11	5	55
Nanwalek	59.351	-151.92	KBRR	11	5	55
Chenega Bay	60.076	-148.02	PWSRCAC	8	3	24
Seward	60.105	-149.43	PWSRCAC, KBRR	TBA	TBA	TBA
Cordova	60.541	-145.76	PWSRCAC	12	3	36
Whittier[b]	60.78	-148.65	PWSRCAC	8	4	32
Valdez	61.071	-146.33	PWSRCAC	16	4	64

[a] Latitude and Longitude are approximations

[b] Locations are composed of multiple sampling sites

Monitoring action items

- Continue monitoring in present sampling locations;
- Expand monitoring plan to incorporate additional sites that are suitable to *Carcinus*, as predicted by habitat suitability models (based on thermal regimes and aerial photography) and vector strength (aquaculture and harbors);
- Formalize management and monitoring areas among agencies and organizations (Kachemak Bay Estuarine Research Reserve in Homer coordinating Kachemak Bay; Prince William Sound Regional Citizen's Advisory Council in Anchorage coordinating South Central and Western Alaska; National Marine Fisheries Service, Alaska Region in Juneau coordinating Southeast Alaska);
- Develop a broader volunteer base by expanding efforts to engage and recruit citizen scientists, special interest groups, and school groups;

- Monitor by trapping at least yearly during the late summer. When possible, increase trapping effort following ENSO events and particularly mild winters;
- Whenever possible complement trapping by opportunistically scanning for **molted** *Carcinus* carapaces along the shoreline where flotsam has accumulated;
- Explore other sampling methods including habitat traps, seining and pitfall traps;
- Determine utility of detecting *Carcinus* larvae in coastal waters and in ballast waters using molecular techniques as an alternative means of early detection.

Rapid response

Objective 4: Coordination of management activities

A rapid response is critical to efforts to control or eradicate an invasion by *Carcinus*. We have provided a framework to facilitate the early detection and rapid response for *Carcinus* in Alaska (Figure 10). Coordinating and determining effective management activities (Objective 4) are tightly linked to Objective 5: Control and management options once detected. Each is integral to the other. While the goal of detecting and managing *Carcinus* in Alaska should be implemented by a partnership among governmental agencies, non-profit organizations, industry, native peoples, and the public, one agency or a statewide invasive species council should play the lead role in informing and organizing management activities. The Alaska Department of Fish and Game has agreed to lead and organize efforts to prevent the invasion of *Carcinus* in Alaska.

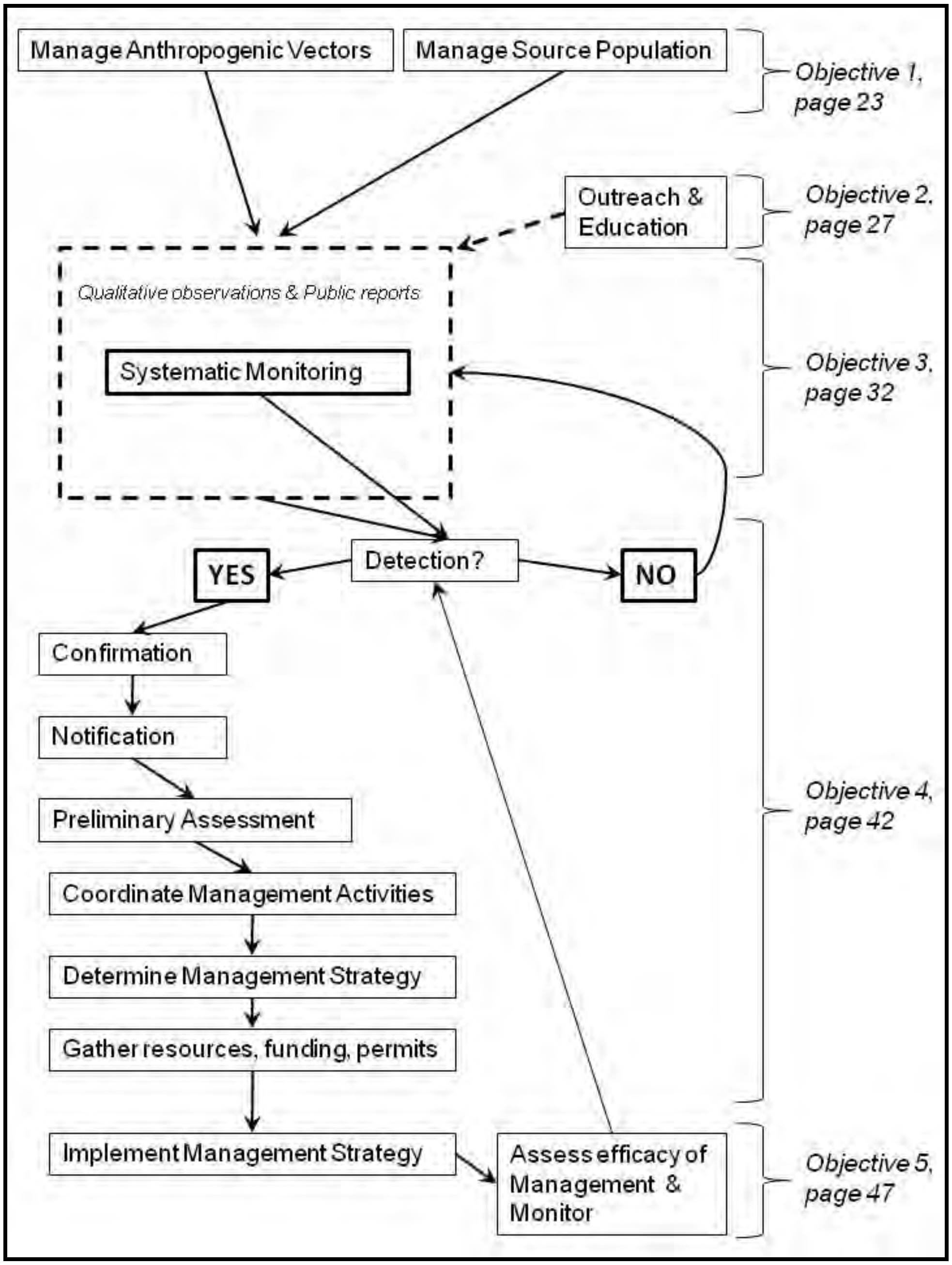


Figure 10. Early detection and rapid response framework to aid the prevention, detection, and management of *Carcinus* in Alaska. It is essential to secure emergency funding *a priori* to respond to invasions immediately, as has been accomplished in Oregon and Idaho. Objective 1: Managing anthropogenic vectors and source populations will decrease the propagule pressure of invaders. Objective 2: Outreach and education can create an informed populous, thus increasing our ability to detect invasions. Objective 3: Monitoring and detection efforts are enhanced by an informed populous (symbolized by the larger dashed box) as well as systematic monitoring. Objective 4: the coordination of management activities, responsibilities, and resources will be essential to the successful implementation of the management strategy. Objective 5: Rapidly implementing the management strategy and post-management assessment and long-term monitoring are critical to ensuring populations of green crabs are eradicated or contained.

1) Confirmation of report

Once green crabs are detected, it is essential to act rapidly to determine the extent and magnitude of the invasion. The sighting or report must be confirmed with a local biologist. While an informed and vigilant public can be very effective in detecting invasions, many of the reports of potential invaders are due to confusion with native species. This first line of interaction with the public will help ensure resources are not misspent trying to manage a spurious invasion. Secondary confirmation of *Carcinus* by a recognized expert is highly encouraged. Invasions, even those by more conspicuous species such as *Carcinus*, can be easily confused with rare native species even by trained biologists.

2) Notification

If an invasion of *Carcinus* is confirmed, it is important to notify the proper agencies and resource managers. To facilitate this, it is important to establish a rapid communication system such as a phone tree or an official listserv for all agencies and organizations that have management responsibilities potentially affected by *Carcinus* and other interested parties. The Alaska Invasive Species Working Group listserv could accommodate this need: aisc-l@lists.uaf.edu. Agencies that have resource management responsibilities that might be impacted by the invasion of *Carcinus* are listed in Table 5.

Table 5. Governmental agencies with resource management responsibilities that might be affected by invasions of *Carcinus*.

Agency	Responsibilities
Alaska Department of Fish and Game	Review application for aquaculture permits and transportation of seed stock; certification for hatcheries and seed distribution facilities;
Alaska Department of Environmental Conservation	Transportation and use of Quarantine aquatic items; Conserve, improve, & protect natural resources & environment; Issue orders, regulations, permits, quarantines, and embargoes relating to eradication of pests; Review application for aquaculture permits
Alaska Department of Natural Resources	Develop, conserve, & enhance natural resources; distributes leases for aquatic farms,
Local and tribal agencies	On-site control measures.
US Coast Guard	Regulate ballast water discharge, port inspections
US Customs	Importation of live animals, seafood packaging
EPA	CWA
Fisheries and Ocean Canada	Coordination and consult for successful survey methods and information
National Park Service	Preservation of natural ecosystems and communities
NOAA	Sustainable fisheries, implementing Endangered Species Act, marine coastal ecosystem health
US Department of Agriculture	Port surveys, protect health and value of American agriculture and natural resources
US Fish and Wildlife Service	Habitat conservation and restoration, aquatic invasive species management and education, implementing Endangered Species Act, refuge management, injurious wildlife inspections
US Army Corp of Engineers	Authorizes leases for aquatic farms; Wetland fill permitting (section 404 permits of CWA)

3) Preliminary assessment of the invasion of *Carcinus*

A preliminary assessment of the magnitude and extent of the invasion by *Carcinus* is essential to determining which management and control options will be feasible. Upon confirmation of invasion by *Carcinus*, agencies should immediately expand the monitoring effort in the detected sites and additional monitoring sites. Expanded monitoring for *Carcinus* also provides opportunities to detect other non-native species (such as *Spartina* spp.). Ideally, through the outreach measures discussed previously, agencies with an extensive and coordinated volunteer base would greatly facilitate measures to determine the extent of the *Carcinus* invasion.

4) Coordinate management activities

Coordination between agencies will also be important for preventing the establishment of *Carcinus*, once detected. Coordination through the **Alaska Department of Fish and Game** the Alaska Invasive Species Working Group (or Alaska Invasive Species Council, pending future legislation) will function to implement, monitor and assess the management of *Carcinus*. To facilitate and expedite removal of *Carcinus* should they be found, currently, a scientific collection/education resource permit is required from the Alaska Department of Fish and Game. Development of a broad-spectrum collection permit through the Commercial Fisheries Division that will cover anyone who might collect and report a suspected green crab should be completed.

Determine management strategy

Based on the results of the preliminary assessment of the invasion of *Carcinus*, possible management strategies should be carefully considered with input from the interested agencies and if applicable, the public. We review several control and management options in *Objective 5: Control & management options once detected*. A general timeline should be developed for the management strategy detailing project milestones, assessing the techniques and status, and determining if the strategy must be adapted. For example, the frequency, location, and trap type used for physical removal might need to be adjusted for the management to succeed under changing biological, environmental, logistical, or legal constraints and challenges.

Assignment of responsibilities

The involved parties should decide which agency or organization will be assigned responsibility for management. Management responsibilities should be determined according to the location of the invasion and/or by distributing different aspects of responsibility within an invasion site. The involved parties will assign the responsibilities of each agency and delineate the areas they need to manage as soon as possible to facilitate the rapid response to future invasions.

Logistics planning & management

Coordinating with other agencies will maximize the availability of resources and greatly enhance the feasibility and success of management. The lead agency should request inventories of available equipment and human resources from all cooperating agencies and organizations. Additional volunteers should be summoned to help in control and monitoring efforts with aid from local stakeholders such as shellfish lease owners, native peoples, and others (see Table 1). Once a management decision has been made, it is essential to secure sources of supplementary funding. It would also be highly effective to find emergency funding *a priori* that is already encumbered to respond rapidly to newly detected invasions (for example, Oregon and Idaho both have emergency state funds to respond quickly to potential incursions). Regionally, contact groups will be responsible for coordinating an action tree, equipment availability, permitting and personnel: Kachemak Bay Estuarine Research Reserve in Homer coordinating Kachemak Bay; Prince William Sound Regional Citizen's Advisory Council in Anchorage coordinating South Central and Western Alaska; National Marine Fisheries Service, Alaska Region in Juneau coordinating Southeast Alaska.

Objective 5: Control and management options once detected

Rapid response is essential

Early detection and a rapid response are critical to the effective management of introduced species. Rejmánek and Pitcairn (2002) found small invasions by terrestrial weeds (less than one hectare) are easily eradicated while larger infestations (larger than 1000 hectares) would require substantial financial investment to merely control. Numerous examples of marine invasions also highlight the efficacy of and need for rapid response to invasion. In Darwin, Australia, a highly disruptive non-native mussel (*Mytilopsis* sp.) was detected and in less than 3 weeks, the dense population (up to 23,650/m^2) was eradicated using pesticides (Bax et al. 2002). The rapid response to the detection of this non-native species is likely a major factor in the success of its eradication. In a southern Californian lagoon, the discovery of the killer alga, *Caulerpa taxifolia*, prompted rapid eradication efforts (Williams and Grosholz 2002). Due to the quick response (treatment 17 days after discovery), this population has been effectively eradicated despite its incredible propensity to thrive in other similar regions of the world (Anderson 2005). A small population of the alga *Undaria pinnatifida* was rapidly eradicated from a sunken vessel using a combination of physical removal of adult plants and heat treatment to destroy the gametophytes (Wotton et al. 2004). In contrast, delayed response of the invasion of *Spartina* in Washington has resulted in the expenditures of around $1-2 million per year for the last 10 years in control costs (WSDA 1998-2007). Had those populations been detected and immediately treated, it is likely that millions of dollars might have been saved. A rapid response to an invasion by *Carcinus* and an adaptive management strategy that is amenable to change (if the need arises) would also be critical to management and control efforts. While we review the possible techniques for controlling or managing populations of *Carcinus*, we do not recommend all of the techniques due to logistical constraints, potential impacts to non-target species, and/or the unforeseeable consequences of such treatments to native communities.

Control and management options

Physical removal methods

Currently, the preferred method of controlling existing *Carcinus* populations is physical removal. Larson et al. (unpublished) evaluated a variety of physical removal options for *Carcinus* (Table 6) including baited traps, habitat traps, pitfall traps, beach seines, trawls, snorkel transects, and capturing *Carcinus* by hand (hereafter: hand capture). While most of the physical removal options resulted in a substantial catch of green crabs, some techniques were clearly more effective than others. Preliminary results by Larson et al. (unpublished) indicate that the physical removal of *Carcinus* using baited Fukui folding and Minnow traps are highly effective in reducing *Carcinus* populations. By trapping and removing crabs 4-7 times a week for approximately one year, Larson et al. removed over 13,000 green crabs from Bodega Bay, CA. The vast majority of these crabs were removed within approximately the first 6 weeks of trapping. The intense removal of *Carcinus* resulted in 85% decrease in CPUE in only one year. Their results also indicate a quick response of the native community to the removal of *Carcinus*: in only one year, populations of the native shore crab *Hemigrapsus oregonensis* (a common competitor and prey item) increased by 400 percent. These preliminary results reveal trapping using baited traps is an effective technique to control *Carcinus* and appears to have a limited impact to non-target species.

Habitat traps and pitfall traps were also relatively effective in capturing *Carcinus* in Bodega Bay (Larson et al. unpublished). Minnow and collapsible Fukui habitat traps (unbaited and filled with the ephemeral green alga *Ulva* sp.) had CPUE values similar to baited traps. This indicates that even if bait is unavailable, box and minnow traps are still effective in catching *Carcinus*. Pitfall traps were also successful in catching *Carcinus* as they move across the sediment surface. The CPUE for pitfall traps was relatively high and reveals yet another technique that might be effective in removing *Carcinus*. However, pitfall traps also require constant maintenance to avoid bycatch mortality and to prevent the trap from filling with sediment. As summarized in *Objective 3: Detection & Monitoring*, beach seines, trawls, and snorkel surveys can detect and allow the capture of *Carcinus*, but the logistical difficulties combined with low CPUE indicate these techniques would not be feasible management techniques. Use hand capture in addition to other previously mentioned techniques any time the opportunity arises. While not quantitative, this technique still results in a positive catch and is relatively efficient.

Table 6. Summary of the CPUE (*Carcinus* per trap), total catch, and effort of physical removal options in Bodega Harbor, California 2006.

Removal Option	CPUE	Total Catch	Effort
Baited Collapsible	2.16	9583	4963 traps
Baited Minnow	0.76	3478	4873 traps
***Ulva* Collapsible**	1.38	265	274 traps
***Ulva* Minnow**	0.95	32	23 traps
Pipe trap	0.2	15	167 traps
Pitfalls (daily)	1.63	13	12 traps x 8 days
Snorkel (per transect)	0.06	1	8-50 m transects x 2 Seasons
Trawl (per haul)	0	0	3 transects at 1174, 902, 1275 meters each
Hand capture	NA	503	15 days (476 caught in 2 days)

[a.] Data from Larson et al. (unpublished)

Permitting and costs

A permit (organizational or individual) is required from the Alaskan Department of Fish and Game Division of Commercial Fisheries to trap for green crabs. New individuals can be added to the organizational permits by informing the permit coordinator. Additional federal permits may be required to sample in reserves, sanctuaries, and parks (these permits are available through each park or reserve of the relevant agencies) or to be in compliance with relevant federal laws (e.g., ESA if sampling in an area with endangered species).

Chemical treatments

The application of pesticide sprays and bait might be effective at reducing populations of *Carcinus*. The pesticide Carbaryl (Sevin®) is an effective pesticide of burrowing shrimp and other crustaceans (Dumbauld et al. 2001) and may also be effective in controlling *Carcinus*. However, broad application of aerial pesticides will also likely result in extensive mortality to many non-target species including those of commercial importance, thus it appears to be an unwise choice as a control measure. Poison bait has also been effective in controlling populations of *Carcinus* (Hanks 1961), but use of poison bait may also result in mortality of species that are attracted to the bait including many native crabs and fish. Chemical control are not yet targeted enough to impact only *Carcinus* and should only be implemented when impacts to non-target organisms is minimal.

<u>Sex pheromones</u>

Behrens Yamada (2001) reports that the olfactory cue from female green crabs appears to be very powerful and overrides other sensory and tactile cues in male green crabs. Male green crabs even attempt to mate with other male crabs or inanimate objects such as rocks and tennis balls that have been in contact with receptive females (Behrens Yamada 2001). These observations suggest female green crab sex pheromone could be an effective method to attract male green crabs. While the green crab sex pheromone is capable of being produced synthetically (Behrens Yamada et al. 2006), pilot studies revealed the pheromone is only effective at very short distances (<1m), for male *Carcinus*, and in water temperatures above 15°C. Thus, sex pheromones do not appear to be effective enough to warrant use in the field at this time.

<u>Biocontrol</u>

As reviewed in a previous section (Habitat distribution), several native predators and co-occurring species may limit the distribution and abundance of *Carcinus* within its introduced range (Hunt and Behrens Yamada 2003, de Rivera et al. 2005a, McDonald et al. 2006, Jensen et al. 2007). While studies have yet to examine how augmenting populations of native predators and competitors might affect *Carcinus*, there have been suggestions of introducing parasites as biocontrol agents to reduce populations of *Carcinus* (Lafferty and Kuris 1996). Introduced populations of *Carcinus* exhibit substantially lower rates of parasitism and larger size and biomass than native populations, which supports the hypothesis that non-native *Carcinus* populations may encounter an ecological release from parasites (Torchin et al. 2001). Currently, the only known potential control agent on *Carcinus* is a nemertean egg predator *Carcinonermertes epialti* (Torchin et al. 1996). Lafferty and Kuris (1996) suggest using parasitic barnacles (*Sacculina carcini* and *Portunion maenadis*) from the native range of *Carcinus*. In addition to reducing growth and feeding on the tissues of their host, these parasitic barnacles feminize and castrate the host crab (Behrens Yamada 2001). The nemertean *Carcinonemertes* attacks a range of native crabs as well as the target green crabs, and the castrating rhizocephalans *Sacculina carcini* (European) and *Heterosaccus lunatus* (Australian) have a broad range of hosts (reviewed in Secord 2003). Similarly, research on the potential impact of *S. carcini* on four species of west coast North American crabs, including *C. magister*, showed that the barnacle infected all the native crab species and killed them before they matured

(Goddard et al 2005). We do not advocate or recommend introducing non-native parasites or diseases to control *Carcinus* due to the potential infection of commercially and ecological important crabs (such as *Cancer magister*).

<u>Genetic alteration</u>

Genetic alteration may be an effective control for populations of non-native species (Grewe 1997). Grewe (1997) reviewed several of the techniques that were effective in controlling non-native carp such as ploidy/chromosome manipulation, controlling the sex composition of populations, hormonal treatments, immunocontraception, and transgenic manipulation; such methods may be effective for *Carcinus*. Specifically, transgenic manipulation is currently being examined to produce an Inducible Fatality Gene that may control *Carcinus* populations in Australia (Grewe 1997). We are unaware of any updates on this research and it appears such techniques are likely years away from development. Even if effective genetic control techniques are developed, there are a host of other logistical, ecological, economic, and ethical concerns to consider before implementing this strategy.

Multiple year treatments and long-term monitoring

Few management strategies are completely effective after a single treatment. Successful management and control of *Carcinus* will require a long-term commitment to multiple years of treatment and monitoring. Thus it is important to coordinate between agencies to ensure the logistical and financial burden is minimized and shared evenly. A critical assessment of the total progress and efficacy of the management strategy is also important. Changes in aspects of the management technique or the entire strategy might be necessary to ensure success of the control or eradication of *Carcinus.*

Physical removal of any known populations in conjunction with multi-year efforts and monitoring of adjacent areas is the most effective management option that has the least impact on non-target organisms.

Summary of actions

Objective 1: Vector & source population management

Ballast water

- Determine high-risk times and areas for the intake of ballast water containing green crab larvae, and work with other Pacific coast states, Canada and the shipping industry to limit Ballast water intake in those high risk times and areas.
- Develop a state ballast water management program to reduce likelihood of introductions.
- Support removal of the tanker exemption from federal ballast water management guidelines.
- Support new requirements for in-state exchange.
- Work to change state ballast water laws to prohibit the untreated discharge of biological organisms into Alaskan waters.

Hull fouling and vessel infrastructure

- Work with U.S. Customs and Border Protection authorities to incorporate screening for *Carcinus* to their inspections to their existing operations at ports of entry.
- Develop a state program for hull maintenance of both commercial and recreational boats.
- Require drydocking and hull cleaning every 3-5 years for commercial ships.

Aquaculture and seafood products

- Develop state rules for cleaning and inspection of products and sterilization of packaging materials at the processing facility before export.
- Develop state rules to quarantine products during transit to avoid contamination.
- Work with U.S. Customs and Border Protection authorities to further develop a state program for inspecting seafood products to ensure the live product is free of *Carcinus* and other non-native species.
- Support development of national regulations for inspection of products and sterilization of living packaging materials (e.g., seaweeds) before export and quarantine during transit.

- Develop outreach programs for shellfish importers and exporters about the threat and mechanisms of spread of *Carcinus* and how to reduce spread.

<u>Live bait</u>

- Take action to revise state regulations to prohibit the sale or importation of live marine bait.

<u>Researchers and educators</u>

- Develop outreach programs for researchers and educators about the threat of *Carcinus* and other non-native species and the risks of releasing live specimens.

<u>Reduce propagule pressure through managing source populations</u>

- Support management of potential source populations.
- Initiate collaborations between US and Canadian institutions and agencies to manage or eradicate the high-density populations of *Carcinus* on the west coast of Vancouver Island, British Columbia, the closest population to Alaska.

Objective 2: Outreach & education

- Ensure that written material and signage are current, distributed and posted clearly.
- Inventory current outreach materials to identify areas where additional outreach is needed.
- Expand present efforts to inform the public about *Carcinus* and other non-native species at boat ramps, parks, and other public access points.
- Incorporate public service seminars and expansion of present efforts to inform the public about *Carcinus* and invasive species in general.
- Continue to cultivate working partnerships and collaborations between local, state, federal agencies, industries, native corporations, non-governmental institutions, universities, and conservation groups to enhance monitoring efforts and outreach.
- Establish a website for citizens to learn about and report non-native species that have invaded or may invade Alaska.
- Enhance dissemination of information through the distribution of printed material and creation of needed materials.

- Conduct outreach about the risks and spread of *Carcinus* to citizen scientists and professionals, including developing outreach programs for shellfish importers and exporters and researchers and educators.

Objective 3: Detection & monitoring

- Continue monitoring in present sampling locations.
- Expand monitoring plan to incorporate additional sites that are suitable to *Carcinus*, as predicted by habitat suitability models and aerial photography.
- Delineate and assign management and monitoring areas among agencies and organizations.
- Develop a broader volunteer base by expanding efforts to engage and recruit citizen scientists, special interest groups, and school groups.
- Monitor by trapping at least yearly during the late summer. When possible, increase trapping effort following ENSO events and particularly mild winters.
- Whenever possible, complement trapping by opportunistically scanning for *Carcinus* carapaces along the shoreline where flotsam has accumulated.
- Explore other sampling methods including habitat traps, seining and pitfall traps.
- Determine utility of detecting *Carcinus* larvae in coastal waters and in ballast waters using molecular techniques as an alternative means of early detection.

Objective 4: Coordination of management activities

The Alaska Department of Fish and Game has agreed to lead and organize efforts to prevent the invasion of *Carcinus* in Alaska.

Determine management strategy and establish capacity to implement it

- Establish clear jurisdictional and management responsibilities for invasions of *Carcinus* and other aquatic non-native species for all involved agencies and organizations.
- Establish a rapid communication system such as a phone tree or an official listserv for all agencies and organizations that have management responsibilities potentially affected by *Carcinus* and other interested parties.

Actions upon detection

- Confirm the report through identification by trained personnel of a photo or a specimen.
- Contact stakeholders via the listserv or phone tree.
- Immediately expand the monitoring effort in the detected sites and additional monitoring sites to assess the statewide status of the invasion of *Carcinus*.
- Coordinate management activities through the Alaska Invasive Species Working Group (or Alaska Invasive Species Council, if House Resolution 12 is ratified).
- Identify all participants who would be involved in response to this invasion.
- Request inventories of available equipment and human resources from all cooperating agencies and organizations.
    - *Based on inventory results and needs assessment, acquire and stockpile any additional equipment needed*.
- Establish a timeline for the management strategy for the specific incursion, detailing project milestones. This timeline needs to include a milestone for assessment of successes of techniques and status, and determining if the strategy must be adapted.
- Assign the responsibilities of each agency to be involved with the specific incursion and delineate the areas they need to manage as soon as possible to facilitate the rapid response to future invasions.
- Estimate required funding for several invasion scenarios and identify funding sources.

Objective 5: Control and management options once detected

Short-term response

- Immediately initiate management protocols and timeline: rapid response is essential.
- Summon additional volunteers to help in short-term control and monitoring efforts.

Multiple year treatments and long-term monitoring

- Establish a protocol to allow for maximum coordination between agencies to ensure the logistical and financial burden is minimized and shared evenly.
- Assess the progress and efficacy of the management strategy.

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Figure and photograph credits

Cover. Amy Larson, ABRPI

Figure 1A. Drawing courtesy of Tim Sullivan.

Figures 1B, 2A-B. Amy Larson, ABRPI

Figures 3, 5. de Rivera et al. (2007a)

Figure 7. Scott Groth, Oregon Department of Fish and Wildlife

Figure 8A. Amy Larson, ABRPI

Figure 8B. Sylvia Behrens Yamada, Oregon State University; Timothy M. Davidson, ABRPI

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Appendices

Appendix A: Contact information for organizations conducting *Carcinus* monitoring.

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Prince William Sound Regional Citizens' Advisory Council

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PWSRCAC Anchorage Office

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http://www.pwsrcac.org/outreach/volunteer.html

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Appendix B: Partial list of recognized *Carcinus maenas* experts on the Pacific coast of North America

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Appendix C: Draft European green crab monitoring manual and Crab identification guide. Prepared by the Kachemak Bay Research Reserve (KBRR). Reproduced with permission.

Kachemak Bay National Estuarine Research Reserve

European Green Crab

Community Monitoring Manual

DRAFT

March 18, 2008

This manual provides detailed instructions on monitoring for Green crabs with folding, minnow, and pit traps.

SAFETY:

Please be aware that coastlines can be hazardous areas to work in. If you think an area is potentially hazardous and are uneasy about accessing it, DON'T DO IT! Be mindful of the tides and if possible, conduct your surveys during low tides. Be sure to let someone know where you are going and when you plan to return. Be careful when traversing uneven ground, especially slippery surfaces such as wet rocks or seaweed. Be aware that mud flats can be like quicksand. Do not go out too far on a mud flat.

When accessing monitoring sites, please respect private property boundaries, and only access via private property if you have permission from the owner.

COLLECTION PERMITS:

A scientific collection permit is required to study and/or collect any live crab in the state of Alaska. Please make sure all traps are labeled with a permit number, and contact name and number.

EQUIPMENT:

The most important equipment is that which protects you. **Dress appropriately for all weather**. Rain Boots are required. Raingear, hat and gloves are recommended.

Before leaving to check traps, make sure your kit includes all of the following:

<u>Deployment equipment</u>:

Shovel	Bucket
Traps (6)	Wooden or metal stakes
Zip Ties	Bait
Parachute Cord	Bricks (6)

Optional: GPS, thermometer, salinity meter

<u>Monitoring equipment:</u>

Map	Tide book
Watch	Clipboards
Data sheets	Pencils
Bucket for holding crabs	ID cards
Vernier calipers	Camera
Photo box	Laminated photo numbers

Crab kits are the property of the Kachemak Bay Research Reserve and must be returned at the end of the monitoring season.

MONITORING SITE:

All monitoring sites will be identified as safe for the volunteers, ecologically important, and areas where equipment can be retrieved relatively easily. Prior to volunteer monitoring, these sites will be chosen by Kachemak Bay Research Reserve personnel, catalogued by GPS coordinates, and identified with a numbered wooden stake.

DEPLOYING TRAPS:

Arrive at site at least one hour before desired time of deployment. All sites will deploy 6 folding traps. For each folding trap you will need cable ties, stakes, bait containers, and bricks.

Location: Deploy traps at a minimum of a -1 ft mean low tide, or approximately 2 hours before the morning low tide. List monitoring location, trap deployment date and time on the datasheet. Draw a sketch of the trap layout and habitat on the back of the datasheet. Check boxes for all appropriate habitat descriptions. If taking temperature and salinity, enter results on back of data sheet.

Distance: Set traps far enough apart so they won't interfere with each others fishing range. Approximately 10 meters (30 feet) is effective. The longer the shoreline you are sampling, the farther apart the traps should be situated. If the habitat on the beach you're sampling varies widely, look for suitable habitat instead of placing traps a uniform distance apart. If eel grass is present, put at least one trap in that area. Be sure to place traps as low as possible, but not so low that they will not be uncovered at the following days low tide.

Securing traps: These traps are light and need to be anchored to the ground. Secure your traps to the beach by staking it with a 2 foot stake, rebar or PVC pipe. Pound stakes in so that only 4-5 inches remains exposed. Tie trap to the stake with approximately 4 foot of rope and weigh down the trap with placing a brick or rocks inside.

Time Period: Deploy gear for a minimum 24 hour soak period that covers a full tidal and day/night cycle. It is important to check and empty your traps after the designated soak period. The longer the trapped animals are unprotected from the effects of sun and air the less likely they will survive until they can be released.

Other details: All traps should have an escapement hatch and a permit tag with contact information in case of the unlikely event of a trap being washed away.

Frequency: The preferred minimum sampling frequency from April through September is once a month per site. If monitors can survey more frequently, we encourage this. Sampling more often increases the chances of finding an invasive green crab. ***If a green crab is found anywhere in Kachemak Bay, sampling frequency and trapping density will be increased.***

Baiting Traps: Specify type of bait used on data sheet. Use any of the following types of bait as available such as: herring, halibut, salmon, cat food. Place bait in supplied container. Suspend container from top of crab trap with zip ties or weigh bait trap down with water so it is not floating as the tide comes in.

Note: When walking to and from your monitoring site, it is important to do a visual scan of your beach for European green crab molts (exoskeletons) and carapaces (back shell). Frequently, the presence of European green crab is initially revealed through the discovery of a molt before a live animal sighting. (this is true of Willapa Bay, Washington)

MONITORING:

Traps should be checked only after being submerged for 24 hours, or a full tide cycle.

Having at least two people working a trap is best. Have one person assigned as data recorder. Have another person removing crabs from trap. One person should be measuring and sexing each crab. Any other monitors can be charged with releasing crabs into the water where they will not be preyed upon, and taking pictures.

1. Fill out monitoring information:

Site and Monitors: Fill out site information prior to pulling traps. Each site should have a documented site name and site description. Make sure all observer names are recorded.

Trap Check Date and time: Write the trap check date and start time on the datasheet.

2: Fill out crab information:

Crab Removal: Open trap and put all captured organisms into the bucket. This is most easily done by gently shaking the trap upside down and collecting crabs as they shake loose. Wear gloves so as not to get bit. Be gentle removing crabs from trap, and hold them gently by their main body cavity, not by claws or legs. If crabs are missing appendages or have parasites, be sure to note this on data sheet. **If the trap is empty, write "Empty" adjacent to trap number. For each individual crab, record the following:**

Assign each crab to a trap number. Record and list information for all crabs *individually*—each crab should be reported on a separate line. If more space is required, begin a new data sheet and be sure to number the pages.

Crab ID: Using the provided ID guides, all crabs captured in each trap should be identified if possible. Any crab that is not easily identified or is suspected of being an invasive crab should be photographed in the provided photo box. Be sure to place a laminated photo number in the box with the crab, and record the photo number on the data sheet.

Crab Size: Measure carapace lengthwise using calipers. The size of a crab is determined by measuring its carapace (back) width. The carapace width is the distance across the crab's back at the widest point. (See Figure 1)

Figure 1

Crab Sex: The sex of a crab is determined by the width of its abdomen (shaded area) which curls around the crab's underside. The male crab has a narrow, triangular abdomen, while the female has a much broader abdomen. (See Figure 2)

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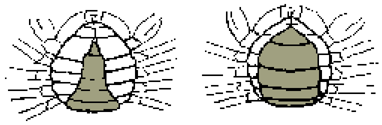


Figure 2

Unidentified Crabs: If a crab is not easily identified or if you suspect it may be an invasive species:

a. Place it in the provided photo box along with a laminated photo number (begin with "1," and so on as necessary).
b. Frame the view with the box edges and take the photograph.
c. Record the photo number on the data sheet along with the crab's size/sex info.

Reporting Green Crabs: In the event that you catch a European green crab - or any other unidentifiable crab – after you have recorded the data, place the animal in the container marked "preserved specimen" and place it in your freezer. Fill out the label on the container with the date the trap was set, trap location (be specific), the name of the surveyors and phone number, as well as the name of the organization. IMMEDIATELY contact your monitoring coordinator (907) 226-4663 to confirm the crab's identity and contact the Invasive Hotline at 1-877-INVASIV (1-877-468-2748). It is important to get identification confirmation as soon as possible.

Bycatch: Any other non-crab organisms caught in the trap should also be identified (or photographed), counted, and recorded at the bottom of the data sheet.

Check End Time: Note your finishing time on the data sheet.

Report data: The data sheet provided by the Reserve (see attached) should be filled out completely and returned to the Reserve as soon as possible.

TRAP REMOVAL:

Please be sure to clean all debris, plants, and animals out/off your traps between surveys. Remove stakes, clean traps and fold them flat. If continuing your monitoring during the next tide series, store in a safe place. Otherwise, return to the Kachemak Bay Research Reserve 226-4658.

On-Site Checklist

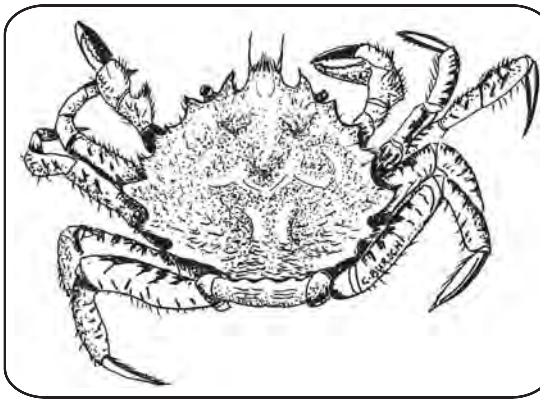
Trap Deployment:

- ☐ Securely place number stakes in ground at least 30 feet apart. Stakes should be placed deep enough, that only 4 -5 inches are exposed.
- ☐ Enter the number of traps deployed on data sheet.
- ☐ All traps should have permits and be tied securely to numbered stakes.
- ☐ Weigh all traps down with either bricks or rocks.
- ☐ Place bait containers (with bait!) in each trap. Either attach containers to trap with zip ties, or weigh them down with water.
- ☐ Fill out date and time of deployment on data sheet.
- ☐ Draw a sketch of the traps and fill out the habitat description on data sheet.

Checking Traps:

- ☐ Enter all monitor names on data sheet.
- ☐ Enter date and start time on data sheet.
- ☐ For each trap:
  - Removed crabs gently and place in holding bucket if necessary
  - If trap is empty:
    - Enter trap number and "empty" on data sheet.
  - For each crab enter on the data sheet:
    - trap number
    - crab species (use identification card)
    - sex (abdominal flap is pointed in males, rounded in females)
    - carapace length (widest part of carapace measured in mm using calipers)
    - any appropriate notes (parasites, broken appendages)
  - For any non-crab species enter on data sheet under bycatch:
    - trap number
    - species
    - any appropriate notes
  - For any unidentified crabs, take photo for identification. If you think it may be an invasive crab, do not release! Place unknown crab species in provided container and return to Kachemak Bay Research Reserve for identification.
  - Release all other crabs and bycatch back into the water.
- ☐ Make sure all data is easy to read.
- ☐ Fill out end time on your data sheet
- ☐ Remove bait from traps.
- ☐ Fold traps, remove any debris
- ☐ Remove stakes if not monitoring at next tide cycle.
- ☐ Return data to Kachemak Bay Research Reserve in timely manner.

Crab identification guide
Invasive crab monitoring project

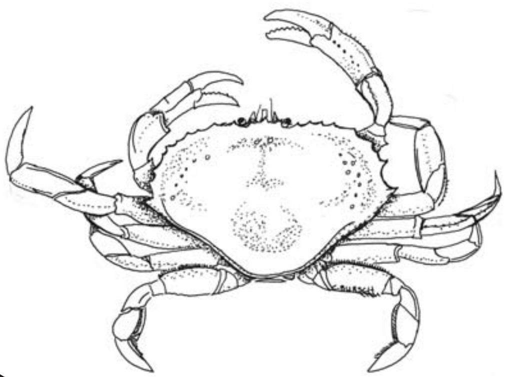


Helmet or horse crab
Telmessus cheiragonus

Large jagged teeth on each side of the carapace

Entire body covered with stiff bristly hairs

Frontal area proptrudes past eyes

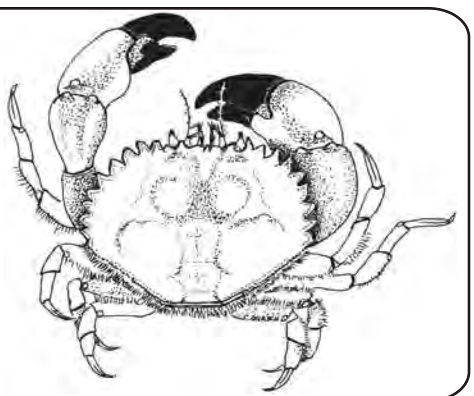


Dungeness crab
Cancer magister

Broadly oval, uneven carapace with ten teeth, widest at the 10th and final tooth

Narrow frontal area with five unequal teeth

Light-colored leg tips



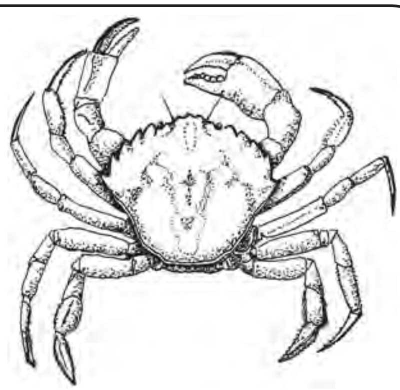
Pygmy cancer crab
Cancer oregonensis

Large claws, tips black

Carapace nearly circular in outline, widest at 7th or 8th tooth

Legs very hairy

INVASIVE



INVASIVE

European green crab
Carcinus maenas

Five teeth on each side of the carapace

Three rounded lobes between eyes

May or may not be green in color