Bering Sea Marine Invasive Species Assessment

Alaska Center for Conservation Science

Scientific Name: *Carcinus maenas*

Common Name *European green crab*

Phylum	Arthropoda
Class	Malacostraca
Order	Decapoda
Family	Portunidae

Final Rank 69.50

Data Deficiency: 0.00

Species Occurrence by Ecoregion

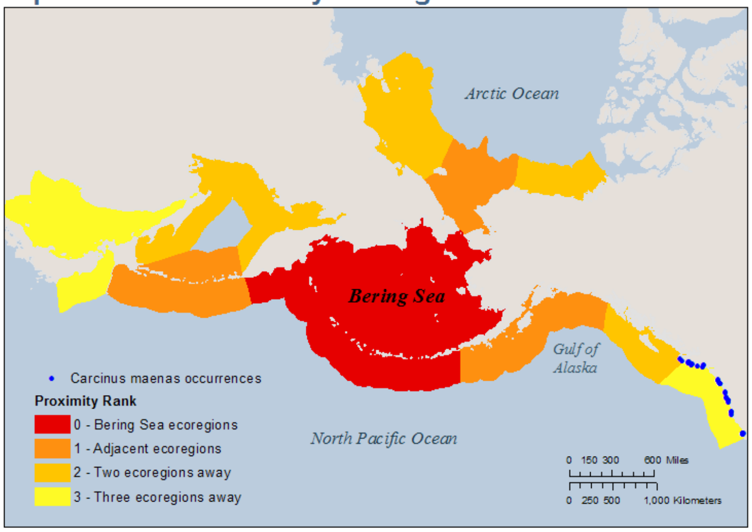

Figure 1. Occurrence records for non-native species, and their geographic proximity to the Bering Sea. Ecoregions are based on the classification system by Spalding et al. (2007). Occurrence record data source(s): NEMESIS and NAS databases.

Category Scores and Data Deficiencies

Category	Score	Total Possible	Data Deficient Points
Distribution and Habitat:	25	30	0
Anthropogenic Influence:	4	10	0
Biological Characteristics:	25.25	30	0
Impacts:	15.25	30	0
Totals:	69.50	100.00	0.00

General Biological Information

Tolerances and Thresholds

Minimum Temperature (°C)	-1	Minimum Salinity (ppt)	4
Maximum Temperature (°C)	35	Maximum Salinity (ppt)	54
Minimum Reproductive Temperature (°C)	9	Minimum Reproductive Salinity (ppt)	17
Maximum Reproductive Temperature (°C)	26	Maximum Reproductive Salinity (ppt)	35*

Additional Notes

Carapace color variable, usually mottled, dark brown to dark green, granules for the most part yellow. Adult size: From 6 to 10 cm in carapace width (Washington Department of Fish and Wildlife 2001). Adults can be dispersed by a variety of anthropogenic and natural mechanisms including: ballast water, hull fouling, hitchhiking on bivalves or packing materials (seaweeds), and transport by water currents.

Reviewed by Linda Shaw, NOAA Fisheries Alaska Regional Office, Juneau AK

Review Date: 8/31/2017

1. Distribution and Habitat

1.1 Survival requirements - Water temperature

Choice: B Moderate overlap – A moderate area (≥25%) of the Bering Sea has temperatures suitable for year-round survival

Score: 2.5 of 3.75

Ranking Rationale:
Temperatures required for year-round survival occur in a moderate area (≥25%) of the Bering Sea.

Background Information:
This species can tolerate temperatures ranging from -1°C to 35°C. Upper temperature limit is based on experimental data (Madeira et al. 2012).

Sources:
NEMESIS; Fofonoff et al. 2003   Madeira et al. 2012

1.2 Survival requirements - Water salinity

Choice: A Considerable overlap – A large area (>75%) of the Bering Sea has salinities suitable for year-round survival

Score: 3.75 of 3.75

Ranking Rationale:
Salinities required for year-round survival occur over a large (>75%) area of the Bering Sea.

Background Information:
Salinity tolerance ranges from 4 to 54 ppt (Crothers 1968; NEMESIS).

Sources:
NEMESIS; Fofonoff et al. 2003

1.3 Establishment requirements - Water temperature

Choice: B Moderate overlap – A moderate area (≥25%) of the Bering Sea has temperatures suitable for reproduction

High uncertainty? ☑

Score: 2.5 of 3.75

Ranking Rationale:
Temperatures required for reproduction occur in a moderate area (≥25%) of the Bering Sea. We ranked this question with "High Uncertainty" to indicate disagreements in model estimates.

Background Information:
Reproduction has been reported in temperatures between 3 and 26°C (Grosholz and Ruiz 2002), but temperatures of at least 9°C are needed for larval survival (Dawirs et al. 1986; Hines et al. 2004).

Sources:
Hines et al. 2004   Grosholz and Ruiz 2002   Dawirs et al. 1986

1.4 Establishment requirements - Water salinity

Choice: A Considerable overlap – A large area (>75%) of the Bering Sea has salinities suitable for reproduction

High uncertainty? ☑

Score: 3.75 of 3.75

Ranking Rationale:
Although salinity thresholds are unknown, this species is a marine organism that does not require freshwater to reproduce. We therefore assume that this species can reproduce in saltwater (31 to 35 ppt). These salinities occur in a large (>75%) portion of the Bering Sea.

Background Information:
Larvae require at least 17-19 ppt to settle and metamorphose (Fofonoff et al. 2003). Upper reproductive salinity requirements are unknown.

Sources:
NEMESIS; Fofonoff et al. 2003

1.5 Local ecoregional distribution

Choice: **C**

Present in an ecoregion two regions away from the Bering Sea (i.e. adjacent to an adjacent ecoregion)

Score: 2.5 of 5

Ranking Rationale:
C. maenas has been reported as far north as British Columbia.

Background Information:
This species occurs from CA to BC on the west coast of North America.

Sources:
NEMESIS; Fofonoff et al. 2003

1.6 Global ecoregional distribution

Choice: **A**

In many ecoregions globally

Score: 5 of 5

Ranking Rationale:
This species has a global distribution and is found in many areas including both coasts of North America, temperate South America, Australia, and Japan.

Background Information:
The green crab's native range is from Norway and Iceland south to northern Africa. The green crab is now dispersed globally with established populations in South Africa, Japan, Australia, Argentina, and along the Atlantic and Pacific coasts of North America. On the West Coast, it occurs from CA to BC. It has failed to establish in many tropical areas including the Caribbean, Hawaii, and Sri Lanka. Its distribution may be limited by average summer surface temperature of ~22°C.

Sources:
NEMESIS; Fofonoff et al. 2003 U.S. Geological Survey; Fuller and Benson 2017

1.7 Current distribution trends

Choice: **A**

Recent rapid range expansion and/or long-distance dispersal (within the last ten years)

Score: 5 of 5

Ranking Rationale:
The green crab continues to expand its range and to be found in new areas.

Background Information:
The green crab has rapidly expanded its range in several introduced areas, including the Pacific coast of North America and South Africa (Grosholz and Ruiz 1996). Since its initial introduction to the West Coast in 1989, the green crab expanded its range over 750 km in less than ten years (Grosholz and Ruiz 2002). This species is predicted to become established in Alaska (Grosholz and Ruiz 2002; Hines et al. 2004). Several sites within Prince William Sound and elsewhere in Alaska appear warm enough to support self-sustaining green crab populations (Hines et al. 2004).

Sources:
Hines et al. 2000 NEMESIS; Fofonoff et al. 2003 Grosholz and Ruiz 1996 Grosholz and Ruiz 2002

Section Total - Scored Points:	25
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

2. Anthropogenic Transportation and Establishment

2.1 Transport requirements: relies on use of shipping lanes (hull fouling, ballast water), fisheries, recreation, mariculture, etc. for transport

Choice: A Has been observed using anthropogenic vectors for transport and transports independent of any anthropogenic vector once introduced

Score: 4 of 4

Ranking Rationale:
This species can be transported by anthropogenic vectors, but can transport independently of these once introduced.

Background Information:
This species can disperse using several anthropogenic vectors including: ballast water, hull fouling, and hitchhiking on packing materials, aquatic vegetation, and bivalves. While long-distance, transoceanic dispersals are likely the result of human activities, the European green crab is capable of natural, short-distance dispersal (Carlton and Cohen 2003). Its dispersal from Australia to Tasmania was likely the result of natural dispersal (Darling et al. 2008).

Sources:
Darling et al. 2008   Carlton and Cohen 2003

2.2 Establishment requirements: relies on marine infrastructure, (e.g. harbors, ports) to establish

Choice: D Does not use anthropogenic disturbance/infrastructure to establish

Score: 0 of 4

Ranking Rationale:
This species does not establish on anthropogenic substrates.

Background Information:
The green crab has colonized several natural habitats and substrates including mud, sand, vegetation, and rocks. Adult crabs live on the seafloor, while young crabs are often associated with seagrass habitat (Bedini 2002).

Sources:
NEMESIS; Fofonoff et al. 2003   Bedini 2002

2.3 Is this species currently or potentially farmed or otherwise intentionally cultivated?

Choice: B No

Score: 0 of 2

Ranking Rationale:
This species is not currently farmed.

Background Information:

Sources:
NEMESIS; Fofonoff et al. 2003

Section Total - Scored Points:	4
Section Total - Possible Points:	10
Section Total -Data Deficient Points:	0

3. Biological Characteristics

3.1 Dietary specialization

Choice: A Generalist at all life stages and/or foods are readily available in the study area

Score: 5 of 5

Ranking Rationale:
This species is a generalist predator and feeds on taxa that are readily available in the Bering Sea.

Background Information:
This species preys on large and small snails, clams, algae, mussels, juvenile fishes and other organisms. Green crabs are known to consume prey from at least 158 genera.

Sources:
GISD 2016   NEMESIS; Fofonoff et al. 2003

3.2 Habitat specialization and water tolerances

Does the species use a variety of habitats or tolerate a wide range of temperatures, salinity regimes, dissolved oxygen levels, calcium concentrations, hydrodynamics, pollution, etc?

Choice: B Requires specialized habitat for some life stages (e.g., reproduction)

Score: 3.25 of 5

Ranking Rationale:
This species has broad temperature and salinity ranges, and adults can occupy a variety of different habitats and substrates. Juveniles preferentially use seagrass, algal mats, or mussel beds as nursery habitat, rather than unstructured bottoms.

Background Information:
The green crab has a wide temperature and salinity range, although larval tolerances are more restricted (Hines et al. 2004). Juvenile crabs exhibit a habitat preference for vegetated habitat (seagrass and algae) and mussel beds, rather than unstructured substrates (Moksnes 2002). Globally, its distribution in tropical waters may be limited by an inability to colonize warmer waters (Cohen et al. 1995, qtd. in Fofonoff et al. 2003). This species inhabits a range of habitats in intertidal and subtidal zones, including mangroves, marshes, rocky shorelines and oyster reefs (Fofonoff et al. 2003). Its establishment in subtidal zones may be limited by predation and inter-specific competition.

Sources:
NEMESIS; Fofonoff et al. 2003   Hines et al. 2004   Moksnes 2002

3.3 Desiccation tolerance

Choice: A Highly tolerant (>7 days) of desiccation at one or more stages during its life cycle

Score: 5 of 5

Ranking Rationale:
This species can survive several days out of the water at very warm air temperatures. It can likely survive for more than seven days at milder temperatures.

Background Information:
Darbyson et al. (2009) exposed crabs to different treatments by placing crabs in crates containing a) only crabs, b) seawater, c) eelgrass, d) dry rope, or a combination therein. At 24°C, 50% of crabs stocked alone or with dry rope survived 68 h, and all crabs survived the first 48 h. Crabs in seawater or eelgrass treatments survived the whole length of the experiment (five days). In a second round of experiments at 29°C, 50% of crabs fully exposed to air survived 60 h, and a few survived for seven days.

Sources:
Darbyson et al. 2009

3.4 Likelihood of success for reproductive strategy

i. Asexual or hermaphroditic ii. High fecundity (e.g. >10,000 eggs/kg) iii. Low parental investment and/or external fertilization iv. Short generation time

Choice: B Moderate – Exhibits one or two of the above characteristics

Score: 3.25 of 5

Ranking Rationale:
This species is dioecious and highly fecund. Eggs are fertilized internally. Generation time is relatively short.

Background Information:
This species is dioecious and reproduces sexually. Eggs are fertilized internally, and then brooded as a mass of eggs between the abdomen and the body. The number of eggs varies with size, but averages 185,000-200,000. Females can produce more than one clutch per year. Larvae settle and metamorphose between 25 and 90 days from hatching, depending on temperature and food availability. It typically takes 2 years to reach maturity in northern Europe, but crabs appear to mature earlier in North America and Australia.

Sources:
NEMESIS; Fofonoff et al. 2003 Grosholz and Ruiz 2002 de Rivera et al. 2007

3.5 Likelihood of long-distance dispersal or movements

Consider dispersal by more than one method and/or numerous opportunities for long or short distance dispersal e.g. broadcast, float, swim, carried in currents; vs. sessile or sink.

Choice: A Disperses long (>10 km) distances

Score: 2.5 of 2.5

Ranking Rationale:
Long-distance dispersal events have been documented. Both larvae and adults can disperse naturally.

Background Information:
Dispersal by adults and juveniles is largely localized, but dispersal distances as far as 15 km have been documented (Gomes 1991, qtd. in Bizzarro 2009). Larvae can be dispersed passively by water currents, and have the potential to disperse long distances given the longevity of the larval stage (up to 90 days). Dispersal of green crabs along the Pacific coast has been attributed to larval transport by strong ocean currents during an El Niño year (Behrens Yamada et al. 2005, qtd. in Klassen and Locke 2007). Northward-moving coastal currents transported larvae up to 50 km/day during the El Niño of 1998 (Behrens Yamada and Becklund 2004, qtd. in Klassen and Locke 2007).

Sources:
Klassen and Locke 2007 NEMESIS; Fofonoff et al. 2003 Bizzarro 2009

3.6 Likelihood of dispersal or movement events during multiple life stages

i. Can disperse at more than one life stage and/or highly mobile ii. Larval viability window is long (days v. hours) iii. Different modes of dispersal are achieved at different life stages (e.g. unintentional spread of eggs, migration of adults)

Choice: A High – Exhibits two or three of the above characteristics

Score: 2.5 of 2.5

Ranking Rationale:
All life stages are capable of dispersing, and different mechanisms are used at different life stages. The larval stage is very long-lived.

Background Information:
Different dispersal mechanisms are possible at different life stages, including planktonic drifting, active swimming/crawling, transport in ballast water, and transport with other species. Rafting has not been documented in adults or juveniles.

Sources:
Klassen and Locke 2007

3.7 Vulnerability to predators

Choice: **B** Few predators only in its home range, and not suspected in the Bering Sea or neighboring regions

Score: 3.75 **of** 5

High uncertainty? ☑

Ranking Rationale:
This species is preyed upon by several taxa found in the Bering Sea. However, European green crab may be able to avoid predation by using low salinity habitats that exceed the salinity thresholds of native predators such as the red rock crab (L. Shaw, pers. comm., 31 August 2017).

Background Information:
Native crab species prey upon or aggressively compete with green crabs (Jensen et al. 2007). Fish predation and competition with larger crabs may be a major factor limiting C. maenas in subtidal waters (Donahue et al. 2009, qtd. in Fofonoff et al. 2003). This species is also predated upon by lobsters and birds.

Sources:
NEMESIS; Fofonoff et al. 2003 Jensen et al. 2007

Section Total - Scored Points:	25.25
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

4. Ecological and Socioeconomic Impacts

4.1 *Impact on community composition*

Choice: **A** — High – Entire community and/or may cause extirpation or extinction at the species or trophic level

Score: 2.5 of 2.5

Ranking Rationale:
This species has severe impacts on several taxa including native bivalves, crabs, snails, fish, and eelgrass.

Background Information:
The green crab has had widespread and severe impacts across its range (Grosholz and Ruiz 2002), and was cited as one of the world's 100 worst invasive species by the IUCN (Lowe et al. 2000). Several native species have declined by more than 90% as the direct result of green crab predation (Grosholz et al. 2000). Species affected include several commercially important bivalve species, eelgrass, fish, and native invertebrates (Grosholz et al. 2000; Grosholz and Ruiz 2002; Malyshev and Quijón 2011; Matheson et al. 2016). In many cases, the impacts of green crab can be extreme, leading to drastic declines and extirpation. For example, underwater video surveys in Newfoundland indicated 50% to 100% declines in eelgrass percent cover since the arrival of green crab in 1998, and a tenfold decline in abundance and biomass of fish (Matheson et al. 2016). Grosholz et al. (2000) documented severe declines in the abundance of native clams and shore crabs, as well as several other invertebrates, in Bodega Bay Harbor, California, within 3 years of the green crab's arrival.

Sources:
Grosholz and Ruiz 2002   Matheson et al. 2016   Lowe et al. 2000   Malyshev and Quijón 2011   Grosholz et al. 2000

4.2 *Impact on habitat for other species*

Choice: **B** — Moderate – Causes or has potential to cause changes to one or more habitats

Score: 1.75 of 2.5

Ranking Rationale:
Green crabs destroy eelgrass habitat by grazing on shoots and by disrupting the sediment. We expect C. maenas to have moderate effects on habitat in the Bering Sea given the extent of eelgrass habitat in the Bering Sea and the severity of the green crab's effects,

Background Information:
In Newfoundland, Matheson et al. (2016) observed 50% to 100% declines in eelgrass percent cover since 1998 at sites with green crabs. In field and laboratory experiments, Malyshev and Quijón (2011) observed significant declines in eelgrass biomass as a result of uprooting and grazing by both adults and juveniles. Several other studies have reported negative impacts of green crabs on eelgrass (e.g., Davis et al. 1998; Garbary et al. 2014; Neckles 2015).

In Alaska, eelgrass ranges almost continuously from southeast Alaska, west along the Gulf of Alaska and north into the Bering Sea up to about 67°N (qtd. in Hogrefe et al. 2014). Eelgrass meadows are highly productive marine habitats that provide refuge from predators, and serve as a nursery ground to juvenile fish and shellfish, including herring (Winfree 2005; Orth et al. 2006).

Sources:
Matheson et al. 2016   Winfree 2005   Orth et al. 2006   Hogrefe et al. 2014   Malyshev and Quijón 2011   Davis et al. 1998   Garbary et al. 2014   Neckles 2015

4.3 *Impact on ecosystem function and processes*

Choice: A High – Is known to cause moderate to severe changes to food webs and/or ecosystem functions; effects have been documented in several areas

Score: 2.5 of 2.5

Ranking Rationale:
Through predation and habitat alteration, the European green crab has been shown to impact whole ecosystems, including causing the decline of several taxa, reducing eelgrass habitat, affecting nutrients, and facilitating the establishment of other invasive species. These effects have been documented in several areas and on both coasts of North America.

Background Information:
The European green crab is a voracious and opportunistic predator that can cause the decline of several prey species including shellfish, crustaceans, and polychaetes (e.g. Neira et al. 2006). Moreover, by digging for prey, C. maenas alters and disrupts habitat and eelgrass meadows, with subsequent effects on invertebrate communities and nutrients (Neira et al. 2006; Lutz-Collins et al. 2016). In Atlantic Canada, C. maenas may have facilitated the spread of the invasive tunicate Styela clava and the clam Gemma gemma by predating upon their predators and competitors (Grosholz 2005; Locke et al. 2007). In San Francisco Bay, C. maenas may reinforce the ecosystem effects caused by invasive hybrid cordgrass (Spartina spp.) (Neira et al. 2007). Important ecosystem-level effects have also been documented in Newfoundland, where invasion by the European green crab led to severe eelgrass decline and impacts the abundance and composition of fish communities (Matheson et al. 2016).

Sources:
Neira et al. 2006   Matheson et al. 2016   Locke et al. 2007   Grosholz 2005   Lutz-Collins et al. 2016   Neira et al. 2007

4.4 *Impact on high-value, rare, or sensitive species and/or communities*

Choice: A High – Is known to cause degradation of multiple species or communities and/or is expected to have severe impacts

Score: 2.5 of 2.5

Ranking Rationale:
The green crab has had significant, negative impacts on ecologically important species including eelgrass and oysters.

Background Information:
The green crab can drastically reduce eelgrass cover and biomass (Malyshev and Quijón 2011; Matheson et al. 2016). Green crabs have also had severe impacts on bivalves, including ecologically significant species such as Crassostrea gigas (Grosholz and Ruiz 2002).

Sources:
Matheson et al. 2016   Grosholz and Ruiz 2002   Malyshev and Quijón 2011

4.5 *Introduction of diseases, parasites, or travelers*

What level of impact could the species' associated diseases, parasites, or travelers have on other species in the assessment area? Is it a host and/or vector for recognized pests or pathogens, particularly other nonnative organisms?)

Choice: D No impact

Score: 0 of 2.5

Ranking Rationale:
Although the green crab can harbor parasites and diseases, negative impacts resulting from these associations have not been reported.

Background Information:
The green crab is host to a variety of parasites and pathogens (Grosholz and Ruiz 2002); however, negative impacts resulting from these associations have not been reported.

Sources:
Grosholz and Ruiz 2002

4.6 Level of genetic impact on native species

Can this invasive species hybridize with native species?

Choice: **D** No impact

Score: 0 of 2.5

Ranking Rationale:
Hybridization with C. maenas is not expected to impact the Bering Sea because there are no native Carcinus species in the Bering Sea.

Background Information:
Hybridization between C. maenas and C. aestuarii may occur in regions of overlap outside of their native range. However, the existence of these hybrids has not been verified by genetic analyses, and no impacts have been reported.

Sources:
Galil et al. 2011

4.7 Infrastructure

Choice: **D** No impact

Score: 0 of 3

Ranking Rationale:
This species is not expected to impact infrastructure in the Bering Sea.

Background Information:
No impacts have been reported. Although this species can be transported by fouling, it does not establish on anthropogenic structures.

Sources:
Klassen and Locke 2007

4.8 Commercial fisheries and aquaculture

Choice: **A** High – Is known to cause degradation to fisheries and aquaculture and/or is expected to have severe impacts in the region

Score: 3 of 3

Ranking Rationale:
The shellfish industry in Alaska is estimated at $1 million, with 95% of sales coming from Pacific oysters (PSI Alaska 2017). Although it is only practiced in a limited region of the Bering Sea, we expect the green crab to have high impacts on commercial bivalves given that it has already had severe impacts in several parts of its introduced range.

Background Information:
Through predation, green crabs have had severe impacts on several commercially important shellfish species, including blue mussels and Pacific oysters (Grosholz and Ruiz 2002). These impacts have represented a 40% loss of production in certain years (Grosholz and Ruiz 2002). Damages to commercial shellfishery from green crab predation are estimated at $22.6 million per year on the East Coast of the United States (Lovell et al. 2007). Although current damages on the West Coast are low, the potential future damages are likely to increase to $0.84 million per year, if Green Crab invades Puget Sound (WA) and Alaska. The estimated annual value of damages to eelgrass restoration projects ranges from $60 000 to $77 000, and from $6000 to $47 000 on the East and West Coasts, respectively (Lovell et al. 2007).

Sources:
Grosholz and Ruiz 2002   Lovell et al. 2007   PSI Alaska 2017

4.9 Subsistence

Choice: B — Moderate – Causes or has the potential to cause degradation to subsistence resources, with moderate impact and/or within only a portion of the region

Score: 1.5 of 3

Ranking Rationale:
Through predation, the green crab has had severe impacts on bivalve populations in several parts of its introduced range. In the Bering Sea, shellfish comprise a smaller percentage of subsistence catch (when measured by weight) than salmon or finfish (with the exception of the Aleutians West; Mathis et al. 2015). We expect the green crab to have moderate impacts on subsistence resources in the Bering Sea region.

Background Information:
Green crabs predate heavily on harvested shellfish species such as blue mussels and Pacific oysters (Grosholz and Ruiz 2002).

Sources:
Grosholz and Ruiz 2002   Mathis et al. 2015

4.101 Recreation

Choice: C — Limited – Has limited potential to cause degradation to recreation opportunities, with limited impact and/or within a very limited region

Score: 0.75 of 3

Ranking Rationale:
By predating upon bivalves, the green crab may impact recreational harvesting of shellfish in the Bering Sea. Given the geographic distribution of shellfish species (and their harvesters) in this region, we expect impacts on recreation to be limited.

Background Information:
Predation by the green crab has had dramatic impacts on harvestable species such as blue mussels and Pacific oysters (Grosholz and Ruiz 2002). These species are found and harvested in Alaska, although the recreational harvesting of shellfish is discouraged on untested beaches because of the potential for paralytic shellfish poisoning (PSP).

Sources:
Grosholz and Ruiz 1996

4.11 Human health and water quality

Choice: C — Limited – Has limited potential to pose a threat to human health, with limited impact and/or within a very limited region

Score: 0.75 of 3

Ranking Rationale:
This species can bioaccumulate toxins and, under rare circumstances, may cause poisoning in humans.

Background Information:
Green crabs can concentrate marine biotoxins consumed by bivalve prey. There has been at least one case of shellfish poisoning after ingestion of a large number of green crabs contaminated with okadaic acid.

Sources:
Klassen and Locke 2007   Aquenal Pty Ltd. 2008

Section Total - Scored Points:	15.25
Section Total - Possible Points:	30
Section Total -Data Deficient Points:	0

5. Feasibility of prevention, detection and control

5.1 History of management, containment, and eradication

Choice: **C** Attempted; control methods are currently in development/being studied

Score: of

Ranking Rationale:
Several control methods are currently being studied.

Background Information:
Control methods that have been considered or attempted for green crabs include sound pulses, air exposure, chemical control, biological control, genetic manipulations, physical barriers, manual removal, harvesting, trapping, and parasitic castrators.

Sources:
Klassen and Locke 2007

5.2 Cost and methods of management, containment, and eradication

Choice: **A** Major long-term investment, or is not feasible at this time

Score: of

Ranking Rationale:
Although some methods have been successful in certain contexts, control of green crab populations has been largely unsuccessful and remains an important management priority.

Background Information:
Eradication is not a viable option for established populations of C. maenas because adults are highly mobile (up to 15 km; Gomes 1991 qtd. in Bizzarro 2009) and larvae are planktonic.

Sources:
Bizzarro 2009

5.3 Regulatory barriers to prevent introductions and transport

Choice: **A** Little to no regulatory restrictions

Score: of

Ranking Rationale:
Although there are regulations for ballast water and hull fouling transport, no regulations exist to reduce the spread of species that are transported by hitchhiking.

Background Information:

Sources:
CFR 2017

5.4 *Presence and frequency of monitoring programs*

Choice: **B** — Surveillance takes place, but is largely conducted by non-governmental environmental organizations (e.g., citizen science programs)

Score: of

Ranking Rationale:
Non-governmental organizations are conducting monitoring for this species is occurring in some parts of Alaska.

Background Information:
Non-governmental organizations are monitoring for this species at some sites in southeastern and southcentral Alaska (e.g. Alaska Sea Life Center, Kachemak Bay National Estuarine Research Research, Southern Southeast Regional Aquaculture Association). Government-sponsored monitoring is inactive in Alaska at this time (L. Shaw, pers. comm., 31 August 2017).

Sources:
USFS 2014

5.5 *Current efforts for outreach and education*

Choice: **C** — Educational materials are available and outreach occurs only sporadically in the Bering Sea or adjacent regions

Score: of

Ranking Rationale:
Outreach and education for this species is taking place, but outreach efforts are sporadic in Alaska.

Background Information:
Educational materials are available (ADF&G 2017), but outreach only occurs sporadically (L. Shaw, pers. comm., 31 August 2017).

Sources:
ADF&G 2017

Section Total - Scored Points:

Section Total - Possible Points:

Section Total -Data Deficient Points:

Literature Cited for *Carcinus maenas*

- Darbyson, E. A., Hanson, J. M., Locke, A., and J. H. M. Willison. 2009. Settlement and potential for transport of clubbed tunicate (Styela clava) on boat hulls. Aquatic Invasions 4(1):95-103.

- Locke, A., Hanson, J. M., Ellis, K. M., Thompson, J., and R. Rochette. 2007. Invasion of the southern Gulf of St. Lawrence by the clubbed tunicate (Styela clava Herdman): Potential mechanisms for invasions of Prince Edward Island estuaries. Journal of Exp

- GISD (Global Invasive Species Database). 2016. IUCN SSC Invasive Species Specialist Group (ISSG). Available from: http://www.iucngisd.org/gisd/. Accessed 30-Jan-2017.

- Hines, A. H., Ruiz, G. M., Hitchcock, N. G., and C. de Rivera. 2004. Projecting range expansion of invasive European green crabs (Carcinus maenas) to Alaska: Temperature and salinity tolerance of larvae. Prepared for the Prince William Sound Regional Citi

- Grosholz, E. D., and G. M. Ruiz. 1996. Predicting the impact of introduced marine species: Lessons from the multiple invasions of the European green crab Carcinus maenas. Biological Conservation 78:59-66.

- Grosholz, E., and G. Ruiz, editors. 2002. Management plan for the European green crab. Report prepared by the Green Crab Control Committee for the Aquatic Nuisance Species Task Force. 55 pp.

- Darling, J. A., Bagley, M. J., Roman, J., Tepolt, C. K., and J. B. Gellers. 2008. Genetic patterns across multiple introductions of the globally invasive crab genus Carcinus. Molecular Ecology 17(23):4992-5007. doi: 10.1111/j.1365-294X.2008.03978.x

- Carlton, J. T. and A. N. Cohen. 2003. Episodic global dispersal in shallow water marine organisms: the case history of the European shore crabs Carcinus maenas and C. aestuarii. Journal of Biogeography 30:1809-1820. doi: 10.1111/j.1365-2699.2003.00962.x

- Bizzarro, J. J. 2009. Pacific Northwest aquatic invasive species profile: the European green crab, Carcinus maenas (Linnaeus, 1758). School of Aquatic & Fishery Sciences, University of Washington, Seattle, WA, U.S.A.

- Klassen, G., and A. Locke. 2007. A biological synopsis of the European green crab, Carcinus maenas. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2818. Fisheries and Oceans Canada, Moncton, NB, Canada.

- Jensen, G. C., McDonald, P. S., and D. A. Armstrong. 2007. Biotic resistance to green crab, Carcinus maenas, in California bays. Marine Biology 151:2231-2243. doi: 10.1007/s00227-007-0658-4

- Matheson, K., McKenzie, C. H., Gregory, R. S., Robichaud, D. A., Bradbury, I. R., Snelgrove, P. V. R., and G. A. Rose. 2016. Linking eelgrass decline and impacts on associated fish communities to European green crab Carcinus maenas invasion. Marine Ecolog

- Locke, A., Hanson, J. M., Ellis, K. M., Thompson, J., and R. Rochette. 2007. Invasion of the southern Gulf of St. Lawrence by the clubbed tunicate (Styela clava Herdman): Potential mechanisms for invasions of Prince Edward Island estuaries. Journal of Exp

- Fuller, P., and A. Benson, editors. 2017. Nonindigenous Aquatic Species Database, Gainesville, FL. Available from: http://nas.er.usgs.gov. Accessed: 26-Jan-2017.

- 33 CFR § 151.2050 Additional requirements - nonindigenous species reduction practices

- Galil, B. S., Clark, P. F., and J. T. Carlton, editors. 2011. In the Wrong Place - Alien Marine Crustaceans: Distribution, Biology and Impacts. Springer, London, UK. 664 pp.

- Hines, A. H., and G. M. Ruiz. 2000. Biological invasions of cold-water coastal ecosystems: Ballast-mediated introductions in Port Valdez/Prince William Sound, Alaska. Prepared for the Prince William Sound Regional Citizen's Council, Valdez, AK, U.S.A. 340
- Klassen, G., and A. Locke. 2007. A biological synopsis of the European Green Crab, Carcinus maenas. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2818, Fisheries and Oceans Canada, Gulf Fisheries Centre, Moncton, NB, Canada. 75 pp.
- Mathis, J. T., Cooley, S. R., Lucey, N., Colt, S., Ekstrom, J., Hurst, T., Hauri, C., Evans, W., Cross, J. N., and R. A. Feely. 2015. Ocean acidification risk assessment for Alaska's fishery sector. Progress in Oceanography 136:71–91. doi: 10.1016/j.poce
- Fofonoff, P. W., G. M. Ruiz, B. Steves, C. Simkanin, and J. T. Carlton. 2017. National Exotic Marine and Estuarine Species Information System. http://invasions.si.edu/nemesis/. Accessed: 15-Sep-2017.
- Winfree, M. 2005. Preliminary aerial reconnaissance surveys of eelgrass beds on Togiak National Wildlife Refuge, Alaska, 2004. U.S. Fish and Wildlife Service, Togiak National Wildlife Refuge, Dillingham, AK, U.S.A.
- Orth, R. J., Carruthers, T. J. B., Dennison, W. C., et al. 2006. A global crisis for seagrass ecosystems. BioScience 56(12):987-996.
- PSI Alaska. 2017. Alaska Mariculture Initiative: Economic Analysis to Inform a Statewide Strategic Plan. Pacific Shellfish Institute. Available from: http://www.pacshell.org/AKprojects.asp Accessed 28-Feb-2017.
- Madeira, D., Narciso, L., Cabral, H. N., Vinagre, C., and M. S. Diniz. 2012. HSP70 production patterns in coastal and estuarine organisms facing increasing temperatures. Journal of Sea Research 73: 137–147. doi:10.1016/j.seares.2012.07.003
- Bedini, R. 2002. Colour change and mimicry from juvenile to adult: Xantho poressa (Olivi, 1792) (Brachyura, Xanthidae) and Carcinus maenas (Linnaeus, 1758) (Brachyura, Portunidae). Crustaceana 75(5): 703–710. doi:10.1163/156854002760202688
- Moksnes, P.-O. 2002. The relative importance of habitat-specific settlement, predation and juvenile dispersal for distribution and abundance of young juvenile shore crabs Carcinus maenas L. Journal of Experimental Marine Biology and Ecology 271(1):41–73.
- Lowe, S., Browne, M., Boudjelas, S., and M. De Poorter. 2000. 100 of the world's worst invasive alien species: a selection from the global invasive species database. Published by the Invasive Species Specialist Group (ISSG), Species Survival Commission (S
- Malyshev, A., and P. A. Quijón. 2011. Disruption of essential habitat by a coastal invader: New evidence of the effects of green crabs on eelgrass beds. ICES Journal of Marine Science 68(9):1852–1856. doi:10.1093/icesjms/fsr126
- Grosholz, E. D., Ruiz, G. M., Dean, C. A., Shirley, K. A., Maron, J. L., and P. G. Connors. 2000. The impacts of a nonindigenous marine predator in a California bay. Ecology 81(5): 1206–1224. doi:10.1890/0012-9658(2000)0811206:TIOANM2.0.CO;2
- Aquenal Pty Ltd. 2008. National Control Plan for the European green shore crab Carcinus maenas. Prepared for the Australian Government. Hobart, Tasmania. 44 pp.
- Hogrefe, K. R., Ward, D. H., Donnelly, T. F., and N. Dau. 2014. Establishing a baseline for regional scale monitoring of eelgrass (Zostera marina) habitat on the lower Alaska Peninsula. Remote Sensing 6: 12447-12477.
- Davis, R. C., Short, F. T., and D. M. Burdick. 1998. Quantifying the effects of green crab damage to eelgrass transplants. Restoration Ecology 6(3): 297–302. doi.org/10.1046/j.1526-100X.1998.00634.x
- Garbary, D. J., Miller, A. G., Williams, J., and N. R. Seymour. 2014. Drastic decline of an extensive eelgrass bed in Nova Scotia due to the activity of the invasive green crab (Carcinus maenas). Marine Biology 161(1): 3–15. https://doi.org/10.1007/s00227
- Neckles, H. A. 2015. Loss of eelgrass in Casco Bay, Maine, linked to green crab disturbance. Northeastern Naturalist 22(3):478–500. doi:10.1656/045.022.0305

- Grosholz, E. D. 2005. Recent biological invasion may hasten invasional meltdown by accelerating historical introductions. Proceedings of the National Academy of Sciences of the United States of America 102(4): 1088–91. doi.org/10.1073/pnas.0308547102
- Galil, B.S., Clark, P.F., and J.T. Carlton, eds. 2011. In the Wrong Place – Alien Marine Crustaceans: Distribution, Biology and Impacts. Invading Nature – Springer Series in Invasion Ecology 6. pg. 664.
- Lovell, S., Besedin, E., and E. Grosholz. 2007. Modeling economic impacts of the European Green Crab. Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Portland, OR, U.S.A.
- USFS. 2014. Invasive Species - Status. Section 7, 2014 Tongass Land Management Plan Monitoring & Evaluation Report. Tongass National Forest, U.S. Forest Service.
- ADF&G. 2017. Green Crab Monitoring by Alaskan Citizen Scientists. Alaska Department of Fish & Game. Available from: http://www.adfg.alaska.gov/index.cfm?adfg=invasiveprofiles.europeangreencrab_getinvolved Accessed 28-Feb-2017.
- Neira, C., Grosholz, E. D., Levin, L. A., and R. Blake. 2006. Mechanisms generating modification of benthos following tidal flat invasion by a Spartina hybrid. Ecological Applications 16:1391–1404.
- Lutz-Collins, V., Cox, R., and P. A. Quijón. 2016. Habitat disruption by a coastal invader: Local community change in Atlantic Canada sedimentary habitats. Marine Biology 163:1–13. doi:10.1007/s00227-016-2947-2
- Neira, C., Levin, L. A., Grosholz, E. D., and G. Mendoza. 2007. Influence of invasive Spartina growth stages on associated macrofaunal communities. Biological Invasions 9:975–993. doi:10.1007/s10530-007-9097-x
- Dawirs, R. R., Puschel, C., and F. Schorn. 1986. Temperature and growth in Carcinus maenas L. (Decapoda: Portunidae) larvae reared in the laboratory from hatching through metamorphosis. Journal of Experimental Marine Biology and Ecology 100: 47–74.
- de Rivera C. E., Hitchcock N. G., Teck S. J., Steves B. P., Hines A. H., and G. M. Ruiz. 2007. Larval development rate predicts range expansion of an introduced crab. Marine Biology 150:1275–1288. doi: 10.1007/s00227-006-0451-9