



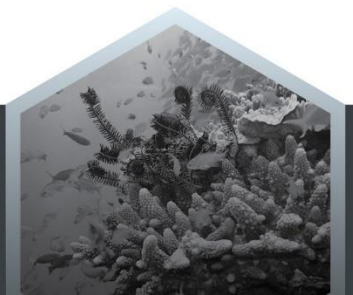
Australian Government

MARINE
PESTS

Rapid response manual for *Carcinus maenas*

Version 1.0, December 2015

Nationally agreed guidance material endorsed by the Marine Pest Sectoral Committee



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Disclaimer

These manuals are part of a series of documents providing detailed information and guidance for emergency response to key marine pest species or groups of pest species.

The manuals are made available on the understanding that the Commonwealth of Australia is not thereby engaged in rendering professional advice. The Commonwealth does not warrant the accuracy, currency or completeness of the guidelines, or their relevance for any particular purpose. In particular, it should be noted that legislation, regulations and by-laws may vary between different jurisdictions and ports in Australia. Consequently, the guidelines do not purport to state what is necessary or sufficient to comply with laws applying in any place.

Before relying on the manuals in any important matter, users should obtain appropriate professional advice to evaluate their accuracy, currency, completeness and relevance for their purposes.

Note

Rapid response manuals are a key element of the Australian Emergency Marine Pest Plan. They provide detailed information and guidance for emergency response to a marine pest incident. The guidance is based on sound analysis and links policy, strategies, implementation, coordination and emergency management plans.

Preface

In 2000 the Joint Standing Committee on Conservation and Standing Committee on Fisheries and Aquaculture National Taskforce on the Prevention and Management of Marine Pest Incursions recommended that a national system for preventing and managing marine pest incursions be implemented through development and establishment of three key elements:

- Prevention—systems to reduce the risk of introduction and translocation of marine pests (including management arrangements for ballast water and biofouling).
- Emergency response—a coordinated emergency response to new incursions and translocations.
- Ongoing control and management—management of introduced marine pests already in Australian waters.

The Australian Government Department of Agriculture and Water Resources maintains a series of emergency response documents to ensure national coordination of the emergency response to incursions by a variety of exotic pests and diseases. The Emergency Marine Pest Plan (EMPPPlan) Rapid Response Manuals for marine pests provide detailed information and guidance for emergency response to key marine pest species or groups of pest species.

The EMPPPlan is adapted from the Australian emergency plans for terrestrial and aquatic animal diseases—the Australian Veterinary Emergency Plan (AUSVETPLAN) and the Australian Aquatic Veterinary Emergency Plan (AQUAVETPLAN). The format and content have been kept as similar as possible to those documents to enable emergency response personnel trained in their use to work efficiently with these manuals in the event of a marine pest emergency.

This manual describes the principles for an emergency response to an incident caused by the suspicion or confirmation of incursion by the European green crab, *Carcinus maenas*. *C. maenas* is a known invasive marine pest species which is established in Australia, but not considered to be widespread. The species is present on the Consultative Committee on Introduced Marine Pest Emergencies' Trigger List (although under review, the list is still used for reporting purposes).

Dr Graeme Inglis and Ms Kimberley Seaward from the National Institute of Water and Atmospheric Sciences, New Zealand, and Ms Amy Lewis from the Department of Agriculture prepared this Rapid Response Manual. The Marine Pest Sectoral Committee of the Department of Agriculture and Water Resources reviewed the draft manual.

The manual will be reviewed every five years to incorporate new information and experience gained with incursion management of these or similar marine pests. Amended versions will be provided to relevant agencies and personnel in all Australian jurisdictions.

Recommendations for amendments

To recommend changes to this document, forward your suggestions to:

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Introduction

Emergency response operations are most efficient if they are based on detailed knowledge of the life history, biology, ecology and susceptibility of the species to eradication and control measures. Species-specific [rapid response manuals](#) have been prepared for several marine pests that the Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE) has identified as being of national concern.

During an emergency response, detailed technical information must be collected in the investigation phase of the response. At a minimum, information will be needed on:

- the nature of the pest, including its:
 - taxonomy
 - known distribution (global/Australian, native/non-native)
 - life history and ecology
 - environmental tolerances
 - impact potential
- pathways and vectors by which the species may be spread
- methods to prevent spread of the organism
- methods for undertaking surveys to
 - delimit established populations
 - trace an incursion
 - monitor the effectiveness of management measures
- methods to control or eradicate established populations in different marine environments
- federal, state and territory legislation and policy relevant to emergency responses.

This information must be assembled rapidly from reliable sources. Preference should be given to using primary sources of information, such as advice from scientists, engineers or other professionals with recognised expertise on the species or likely emergency operations, and from published, peer-reviewed literature. Reputable secondary sources of information, such as internet databases and 'grey' literature may be used to supplement this advice or to prepare summary information and plans for expert review.

This document provides guidance on:

- types of information needed to determine an appropriate response to the suspicion or confirmation of incursion by *Carcinus maenas*.
- types of expert advice that may need to be sought
- potential sources of information for preparing a response plan
- appropriate methods for containment, control and/or eradication of established populations.

1 Nature of the pest

Understanding the life history, ecology and biology of a marine pest is fundamental to an effective emergency response. Detailed knowledge of a species allows better evaluation of the threat it is likely to pose, the feasibility of response options and the design of efficient methods for surveillance, containment, eradication and control.

1.1 *Carcinus maenas*

The European green crab, *Carcinus maenas* (Linnaeus, 1758), is a medium-sized portunid crab (Photo 1) that has successfully established non-native populations in Australia, North America and South Africa. Isolated specimens have been discovered in Japan, South-East Asia and South America (Carlton & Cohen 2003; McGaw et al. 2011). It is an extremely hardy species, found in both the intertidal and shallow subtidal zones of bays and estuaries. *C. maenas* has wide environmental tolerances and is able to rapidly colonise a range of new habitats (Grosholz & Ruiz 1996). It has detrimental ecological and economic effects on native communities, including causing decline of native species through predation, severe impacts on commercial shellfish production, and indirect effects on shorebird feeding rates as a result of high levels of predation on native fauna (NIMPIS 2002).

Photo 1 Adult *Carcinus maenas*



Source: P. Gibson, Industry & Investment New South Wales

Photo 2 Juvenile male *Carcinus maenas*



Source: CSIRO

Table 1 Taxonomy of *Carcinus maenas*

Classification	<i>Carcinus maenas</i>
Phylum	Arthropoda
Subphylum	Crustacea
Class	Malacostraca
Subclass	Eumalacostraca
Superorder	Eucarida
Order	Decapoda
Suborder	Pleocyemata
Superfamily	Portunoidea
Family	Portunidae
Subfamily	Carcininae
Genus	<i>Carcinus</i>

1.1.1 Diagnostic features for identification

Carcinus maenas can be identified in the field and in the laboratory.

1.1.1.1 Field identification

Carcinus maenas are distinguished using physical characteristics. They have a broad triangular carapace, mottled khaki-green, with five marginal 'spines' on each side. *C. maenas* varies in colour from pale green through orange to a deep red-brown colour, which is most easily distinguished on the ventral side and limbs (McGaw & Naylor 1992). The legs are robust, with flattened but pointed tips, and the fourth walking leg has no paddle (Figure 1). The carapace width can reach up to 9 cm.

C. maenas has one sibling species, *Carcinus aestuarii* (= *C. mediterraneus*), which is found around the Mediterranean Sea and has been introduced to areas of Japan and South Africa. *C. aestuarii* can be

distinguished from *C. maenas* by the shape and curvature of the pleopods (paired appendages found under the male's abdominal flap). In *C. maenas*, the two pleopods curve outward, touching each other in the central part of the curve; in *C. aestuarii* the pleopods are straight and parallel and do not touch. However, making these distinctions can be difficult in the field. Synonyms in the scientific literature for this species include *Carcinides maenas*, *Portunas maenas*, *Portunus menoides*, *Cancer granulatus* and *Carcinus granulatus*.

Figure 1 Diagnostic features of *Carcinus maenas*

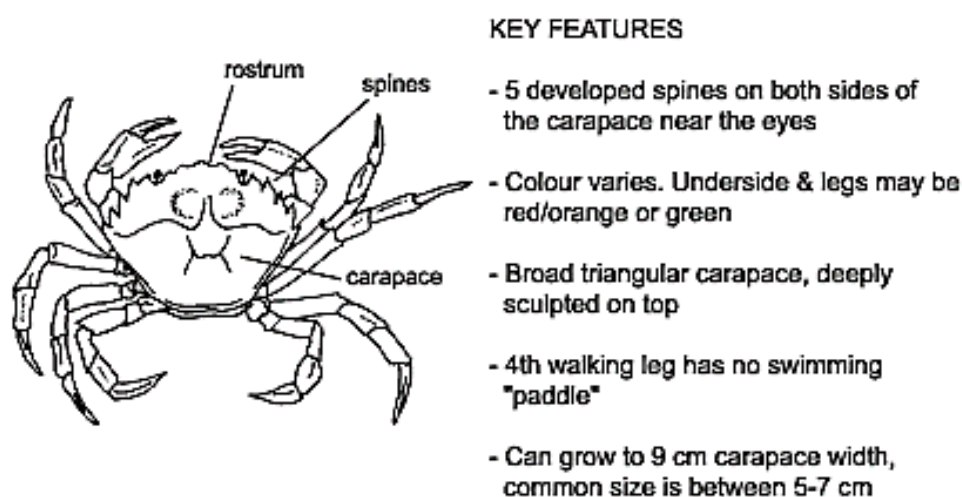


Image: CSIRO Marine Research

1.1.1.2 Laboratory identification

The dorsal surface of *Carcinus maenas* is granular and the posterolateral margin of the carapace is generally convex (Behrens Yamada & Hauck 2001; Behrens Yamada et al. 2001). The fifth anterolateral spine appears to point forward; the chelipeds are unequal and walking legs one to four are smooth and moderately stout. The ventral view of the breastplates, with the abdomen removed, show the pleopods, which in males are crescent shaped. The basal antennal article is immobile and there is no gap between the antennal article and the inner lower orbital margin (Poore 2004).

1.1.2 Life history and ecology

Understanding the ecology of *Carcinus maenas* involves examination of its reproduction, growth and life habit (Table 1Table 2).

Table 2 *Carcinus maenas* life history summary

Feature	Measure
Maximum size (carapace width)	Up to 96 mm
Maximum age	5 years
Mating strategy	Separate sexes
Type of mating	Broadcast spawner
Dispersal stage	Planktonic larva
Larval duration	Up to 80 days
Time to sexual maturity	1 year

Feature	Measure
Size at sexual maturity	34–50 mm
Feeding mode	Omnivorous
Depth range	Intertidal to subtidal
Preferred habitat	Sheltered bays or estuaries
Distribution	Gregarious settlement
Salinity tolerance	5–41 ppt
Temperature tolerance	0–36 °C

1.1.2.1 Reproduction and growth

In Europe, *Carcinus maenas* mates in summer when females moult. Males select a female shortly before she is ready to moult, and carry her around, pre-copular ventral side downward. Directly after moulting the male turns the female over and carries her ventrally (copula) until she hardens. Reproduction occurs at temperatures between 3 °C and 26 °C (Dawirs & Dietrich 1986). Once females are fertilised, they can each lay more than 185,000 eggs, which attach to the pleopods until ready to hatch. Eggs are generally orange but change to black before hatching. Females can mate multiple times in a year, and may produce more than one clutch a year (Grosholz & Ruiz 2002).

The larvae of *C. maenas* go through five zoeal stages and one megalopa stage before metamorphosing into the first crab stage. The duration of each larval stage varies greatly, depending on factors that affect their survival, such as temperature, salinity and diet. The first stage—the prezoal stage—occurs after the embryonic cuticle has been shed, and can last up to 30 hours. The first zoeal stage can last up to 12 days. At a temperature of 12 °C, the average duration of zoeal stages I, II, III and IV and the megalopa stage were 14.8, 7.9, 9.6, 10.0 and 15.4 days, respectively (Williams 1967). This suggests that it takes an average total development time of around 60 days from hatching to the first crab stage. However, the time spent as planktonic larvae can range from 17 to 80 days. They are, therefore, capable of being transported over large distances by coastal water currents.

Depending on the location and water temperature, *C. maenas* can reproduce up to three times a year and mature at between two and three years of age. In Argentina, females begin to mature when their carapace width reaches 40 mm, but in Maine, United States the minimum carapace width at sexual maturity is 34 mm (Vinuesa 2007). Although *C. maenas* can reach sexual maturity within a year, this appears to vary among geographic regions. It typically takes *C. maenas* two years to reach maturity in northern Europe, but in North America and Australia they appear to mature earlier (Grosholz & Ruiz 2002).

Vinuesa (2007) suggests that the duration of the reproductive period and embryonic development is temperature dependent. In *C. maenas*, the reproductive period is longer in warmer waters than in cold temperate waters. Multiple spawning episodes occur at warmer temperatures, but only single spawning periods occur in colder waters. Larvae are most abundant in the plankton in spring (late August to December), but a second peak in abundance can occur in late summer (February to March).

1.1.2.2 Life habit

Carcinus maenas has successfully established populations in the waters of five continents and is labelled as one of the worst invasive predators in coastal marine systems. The ecological and economic damage caused by its introduction has been well documented in several regions (de Rivera et al. 2007b). These crabs are highly effective predators with cosmopolitan feeding habits. They can occur in high numbers and their presence can severely affect the native biota in invaded regions (Tanner 2007).

C. maenas exhibits colour polymorphism; green colour morphs and red colour morphs exhibit significant behavioural, physiological and biochemical differences (Lewis 2010). Reid et al. (1997) suggested that colour change in *C. maenas* depends on the duration between moulting. More recent studies (such as Lewis 2010) show it is due to the different levels of expression in cytochrome P-450 (CYP) enzymes, which are involved with activation and inactivation of a group of moulting hormones.

In the wild, *C. maenas* prefers salinity in the range of 27 ppt to 41 ppt (McGaw & Naylor 1992); however, it is euryhaline and is known to tolerate salinities of between 4 ppt and 52 ppt (Klassen & Locke 2007). Its ability to survive at varying salinities has been associated with the colour morphs of an individual (McGaw & Naylor 1992). Red morphs have higher heart rates, lower apparent water permeability and are less tolerant of low salinity and anoxia than green morphs (Lovett et al. 2006).

C. maenas can survive up to 12 hours of total anoxia (Hill et al. 1991), with differences in response to decreasing oxygen concentrations associated with the intermoult stage. The variation from red to green between intermoult stages is also an indication of its ability to withstand decreasing oxygen concentrations (Legeay & Massabuau 2000). Red morphs have reduced tolerance to low oxygen concentrations compared with green morphs, and when sealed in closed vials, red morphs die first. The ability of *C. maenas* to withstand periods of deep hypoxia is remarkably high during spring and summer when most hypoxic events occur (Legeay & Massabuau 2000).

Temperature has been identified as a key variable limiting the range of *C. maenas* breeding populations (Carlton & Cohen 2003). *C. maenas* is eurythermic, as it is able to survive temperatures ranging from 0 °C to over 35 °C, but the temperature range needed for successful reproduction is 18 °C to 26 °C (Klassen & Locke 2007). Seasonal differences in their tolerance depend on the temperatures to which they are acclimated (Cuculescu et al. 1998). Temperatures below 7 °C to 10 °C inhibit adult feeding and growth and trigger partial migration to deeper, warmer and more saline waters; warmer temperatures increase development, growth and metamorphosis of *C. maenas* (Beukema 1991; Hines et al. 2004; McGaw & Naylor 1992). Male crabs die at around 0 °C and in European waters the abundance of all age groups is reduced after particularly cold winters (Beukema 1991).

C. maenas is found in both the intertidal and shallow subtidal zones of bays and estuaries and is rarely found on exposed, rocky or sandy coasts. In Tasmanian waters, it has been found in a wide range of habitat types within estuaries and bays, occupying heavily sea-grassed areas through to non-vegetated areas with a clean sandy bottom. In the United States, it is abundant on sand and mudflats in the intertidal zone. *C. maenas* is known to migrate into the intertidal zone at high tide. Some individuals remain there at low tide and are capable of withstanding limited periods of aerial exposure.

In South Australia, *C. maenas* has been found in habitats consisting of soft sediment benthos and low to moderate wave energy, with most individuals caught in sheltered bays or at the mouths of estuaries (Legeay & Massabuau 2000). However, no habitat characteristics can be used as suitable predictors to estimate the presence or abundance of *C. maenas*. Individuals were found in fine silt and highly vegetated areas at a variety of depths from immediate subtidal to low-tide depths. Individuals were also found in areas close to sources of urban runoff, clear oceanic water and in rivers well upstream of river mouths (Legeay & Massabuau 2000). However, habitat selection of *C. maenas* did exclude areas characterised by brackish water and exposed rocky shores and sandy beaches.

Several studies (Abelló et al. 1997; McDonald et al. 2004; Van der Meeren 1994) suggest aggregation or clustering of pre-moult or ovigerous female *C. maenas* in particular regions of the shoreline, raising the possibility of a lek-type mating system or specific spawning sites. In intertidal environments, ovigerous females are often found together under boulders or other structures (McDonald et al. 2004). Pre-moult females release pheromones in their urine that elicit increased search and mating-specific behaviours in male *C. maenas*, such as posing, posing search, cradle carrying, and stroking (Ekerholm & Hallberg 2005). Males compete for receptive females; larger males typically dominate smaller males and achieve greater mating success.

C. maenas is an omnivorous predator that feeds on a wide variety of prey, in particular molluscs, crustaceans and polychaetes. It forages for food mainly at night and at high tide, and its diet is determined by prey abundance and seasonal availability. In the Mondego Estuary (Portugal), *C. maenas* feeds on amphipods, cumaceans, shrimp and other decapods (including other *C. maenas* individuals), flies, bivalves, cephalopods, gastropods, polychaetes, gobies and algae. In other locations, the diet of *C. maenas* displays similar patterns depending on abundance and seasonality of available prey (Baeta et al. 2006).

Few known predators effectively control *C. maenas* abundance in invaded habitats. Potential predators include:

- birds such as Herring gulls (Dumas & Witman 1993)
- fish such as cod, flatfish and labrid fish in Europe (Pihl 1982)
- other crabs (de Rivera et al. 2007c; Griffen et al. 2008)
- minks and seals (Dunstone & Birks 1987; Mason & MacDonald 1980)
- otters (Sergeant 1951, cited in Cohen et al. 1995).

Cannibalism occurs in this species. Life strategy appears to influence habitat selection, resulting in life stage segregation. Young individuals reside in shallow waters during summer before migrating to deeper waters, and adult crabs migrate from deeper waters when the temperature starts increasing, which reduces the opportunity for adults to prey on younger *C. maenas* (Thresher 1997).

1.1.3 Global and Australian distribution

Carcinus maenas is native to Atlantic Europe and possibly northwest Africa. It was first recorded in two regions outside Europe in 1817, and is now established in southern Australia, South Africa, the northern Pacific, and Atlantic coasts of North America (Ahyong 2005) (Map 1).

The first extra-limital record for *C. maenas* was from the Red Sea before 1817. This was a one-time collection and no population appears to have established. It was then recorded in eastern North America in 1817. Single collections were made in Rio de Janeiro (1857), the Bay of Panama (1866), Sri Lanka (1866–1867), the Hawaiian Islands (1873), Pernambuco (before 1899), Madagascar (1922), Myanmar (1933), Perth (1965) and Pakistan (1971). Substantial populations established themselves in the waters of mainland Australia (1900), South Africa (1983), Japan (1984), western North America (1989–1990), Tasmania (1993) and the Patagonian Atlantic Coast (1999–2000).

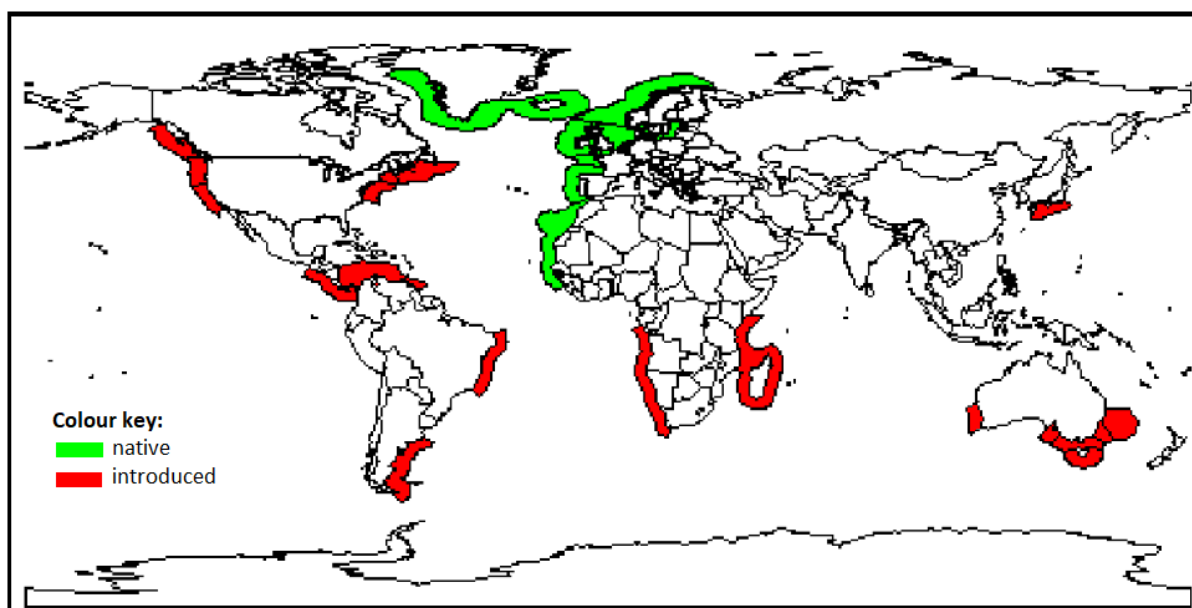
C. maenas was first recorded in Australian waters in the 1900s from Port Phillip Bay, Victoria (Ahyong 2005). Haswell (1882) did not mention *C. maenas* in monographs of Australian decapods, but it was suggested to have arrived in Port Phillip Bay by the 1870s or 1880s. In 1971, it was found in waters north of Victoria, in 1976 in waters to the west of Victoria and in 1993 on the northeast coast of Tasmania, in a pattern of dispersal similar to that seen in the north-western Atlantic (Carlton & Cohen 2003). Genetic analyses of Atlantic and Mediterranean types of the genus *Carcinus* revealed that the mainland Australian populations originated from Europe and the Tasmanian population from mainland Australia (Thresher 1997).

C. maenas has been reported around southern Australia from the Swan River, Western Australia, the Gulf of St Vincent and Coorong, South Australia, eastern Tasmania and Port Phillip Bay, Victoria to Burrill Lake, on the south coast of New South Wales (Furlani 1996; Proctor & Thresher 1997 cited in Ahyong 2005; DPI 2013). In 1965, a single specimen was found in the Swan River, Western Australia, but it has not subsequently been reported from that area (Thresher et al. 2003). The population in the Gulf of St Vincent, South Australia, appears to be localised but persistent (Thresher et al. 2003) and there was an unconfirmed record of its presence in Port Stanvac, South Australia (Hayes et al. 2007). *C. maenas* is also consistently found at sites all along the coasts of central and south-eastern Victoria and north, north-eastern, eastern and south-eastern Tasmania (Thresher et al. 2003).

C. maenas has also been reported historically from several sites in New South Wales; it was recorded in the port baseline survey of Eden, but not in baseline surveys of Sydney, Botany Bay or Port Kembla. Two specimens were collected from Sydney in 1891 and 1936, suggesting its presence in Sydney as early as it was known from Port Phillip Bay (Ahyong 2005). It was ‘regularly sighted’ in the littoral zone at Kyeemagh in Botany Bay between 1977 and 1987 (Ahyong 2005).

It has also been reported at some New South Wales coastal estuaries and lakes, including Durras Lake, Burrill Lake, Lake Conjola and Jervis Bay in December 1992 and November 1997, and Narrawallee Inlet in November 1985 (Ahyong 2005), as well as Narooma in 2007 and Nelson Lagoon in 2008.

Potentially suitable *C. maenas* habitats in Australia include the entire coastline of Tasmania, the entire southern coast of mainland Australia, as far north as Jurien Bay on the west coast of Western Australia, and up the coast of eastern Australia as far north as southern Queensland. These regions are associated with temperate shelf fauna (Carlton & Cohen 2003).

Map 1 Global distribution of *Carcinus maenas*

Source: NIMPIS 2002

1.1.4 Potential impact

Carcinus maenas has invaded the waters of much of the United States, eastern Canada, South Africa, Japan and parts of southern Australia. This species is usually more aggressive than native species and is a highly voracious predator (Hilliard 2005). It consumes a wide variety of prey including several commercial species of bivalves, and it has consequently damaged fisheries, aquaculture and local crab populations. This species is considered a serious threat to wildlife, fisheries and the aquaculture industry (Table 3).

C. maenas has severe effects on native flora and fauna, directly through predation, and indirectly through competition for food. In the Pacific Northwest this species is thought to have direct effects on the native Dungeness crabs and native birds through predation and/or competition for food. In Tasmania it has dramatically reduced the abundance of juvenile native Tasmanian clams (*Katelysia scalarina*) in intertidal and shallow subtidal marine environments (Walton et al. 2002). Predation rates on clams were much higher than any native predator tested (Walton et al. 2002). Invading populations of this species have no natural parasites and predators that help keep populations in check in native habitats (Hilliard 2005).

Table 3 Categories of potential impact caused by *Carcinus maenas*

Impact category	Description	Potential impact
Social amenity	Human health	No
Economy	Aquatic transport	Yes
	Water abstraction/nuisance fouling	Yes
	Loss of aquaculture/commercial/recreational harvest	Yes
	Loss of public/tourist amenity	No
	Damage to marine structures/archaeology	Yes
Environment	Detrimental habitat modification	No

Impact category	Description	Potential impact
	Alters trophic interactions and food-webs	Yes
	Dominates/out-competes and limits resources of native species.	Yes
	Predation of native species	Yes
	Introduces/facilitates new pathogens, parasites	No
	Alters bio-geochemical cycles	No
	Induces novel behavioural or eco-physical responses	No
	Genetic impacts—hybridisation and introgression	No
	Herbivory	No

Source: Hayes et al. 2005

2 Pest pathways and vectors

Population genetic studies of *Carcinus maenas* suggest that populations in Atlantic North America, Australia, South Africa and Japan were founded from European populations (Thresher 1997). Invasive populations in Pacific North America were established from the non-native Atlantic North American populations. This provides an indication of the movement and transport mechanisms responsible for relocation of this species. Consequently, Carlton and Cohen (2003) identified eight transport mechanisms as being responsible for global transport of *C. maenas*. These include: ship boring and fouling assemblages, solid ballast, fouled seawater pipes and seachests, semi-submersible exploratory drilling platforms, ballast water, seaweed transported with commercial fisheries products, education/research, and private releases for fisheries purposes. Table 4 lists the potential pathways and vectors by which *C. maenas* can be spread.

Table 4 Pathways and vectors for *Carcinus maenas*

Pathway	Description	Vector for spread
Biocontrol	Deliberate translocation as a biocontrol agent	No
	Accidental translocation with deliberate biocontrol release	No
Canals	Natural range expansion through man-made canals	Yes
Debris	Transport of species on human-generated debris	Yes
Fisheries	Deliberate translocation of fish or shellfish to establish or support fishery	No
	Accidental with deliberate translocation of fish or shellfish	Yes
	Accidental with fishery products, packing or substrate	Yes
	Accidental as bait	No
Individual release	Deliberate release by individuals	Yes
	Accidental release by individuals	No
Navigation buoys, marine floats	Accidental as attached or free-living fouling organisms	No
Plant introductions	Deliberate translocation of plants species (such as for erosion control)	Yes
	Accidental with deliberate plant translocations	No
Recreational equipment	Accidental with recreational equipment	No
Scientific research	Deliberate release with research activities	No
	Accidental release with research activities	No
Seaplanes	Accidental as attached or free-living fouling organisms	No
Ships	Accidental as attached or free-living fouling organisms	Yes
Ships	Accidental with solid ballast (such as with rocks or sand)	Yes
	Accidental with ballast water, sea water systems, live wells or other deck basins	Yes
	Accidental associated with cargo	Yes
		No

Source: Hayes et al. 2005

Ship boring and fouling assemblages were linked to older wooden vessels because the hull surface was easily eroded. It was thought that *C. maenas* was able to inhabit areas bored by other species. It is likely that *C. maenas* was introduced to Port Phillip Bay in the late 1800s through solid ballast from wooden vessels from Europe (Thresher 1997). The damp ballast holds have been known to transport a vast array of marine and terrestrial species, and the ability of *C. maenas* to live out of water for 60 days and survive without food for 94 days, suggests this as a likely transport mechanism in the nineteenth century. However, seawater uptake, ballast water or retention of water in internal spaces of vessels (such as bilge water, anchor wells) are likely to be the most common contemporary modes of transport. Fouled ships may also harbour *C. maenas* in the internal seawater pipes and seachests. Exploratory drilling platforms are known to have transported other crab species across the oceans, and may have transported *C. maenas* to South Africa (Le Roux et al. 1990).

Thresher et al. (2003) noted that when *C. maenas* is collected outside known populations, it is often in association with aquaculture activities. This may reflect inadvertent transportation of small *C. maenas* in shipments of seed or adult stock and equipment. It may also indicate higher rates of survival by recruits in areas of high food availability or greater vigilance and detection by aquaculturalists.

Although *C. maenas* has long-lived planktonic larvae and is, therefore, capable of long-distance natural dispersal, this potential has not always been realised. The pattern of invasion and range extension appears to consist of periods of slow spread punctuated by rare, long-distance spread (Thresher et al. 2003). For example, *C. maenas* spread along the coast from northern California in the United States to Vancouver Island in Canada in a single year. This event appears to have correlated with unusually strong north-flowing coastal currents during the strong El Niño event of 1997–1998 (Behrens Yamada et al. 2005).

Similarly, the first arrival of *C. maenas* along the north and northeast coasts of Tasmania appears to have occurred almost simultaneously, suggesting a single successful recruitment event over a large area of coastline. In other areas, the pattern of spread has been less spectacular. On the eastern coast of North America, *C. maenas* took 79 years (1872–1951) to spread from Cape Cod to southern Canada, a distance of about 690 km (Thresher et al. 2003).

Warm winters have been linked to high *C. maenas* abundance and pole-ward range expansions. Severe winters lead to mass mortality and range contractions in the Pacific Northwest (Behrens Yamada et al. 2005).

In South Africa, *C. maenas* spread about 15 km along the coast from its initial point of invasion in Cape Town between 1983 and 1990 (Le Roux et al. 1990). In Australia and South Africa, locally abundant and reproductive populations have spread very little. With the exception of the American west coast and eastern Tasmania, the rate of range expansion of *C. maenas* in most studies has often been similar to the speed that tagged individuals can walk along the coast; meaning less than 10 km/year (Thresher et al. 2003).

3 Policy and rationale for incursion response

The policy and rationale for an incursion response is based on the generic policy for incursion response to marine pests in Australian waters, the control or eradication strategy for *C. maenas*, the policy on decision points and the policy on funding of operations and compensation. This chapter is an overview of marine pest emergency procedures and policy.

3.1 Generic policy for incursion response to marine pests in Australian waters

The [National Environmental Biosecurity Response Agreement](#) (NEBRA) establishes national arrangements for responses to nationally significant biosecurity incidents when there are predominantly public benefits. In the absence of a marine pest-specific deed, responses to marine pest incidents generally fall under the NEBRA. The NEBRA provides a mechanism to share responsibilities and costs for a response when eradication is considered feasible and other criteria are met. The [Biosecurity Incident Management System](#) describes the generic policy and procedures for managing a response to a marine pest emergency within Australian waters.

3.1.1 Commonwealth, state and territory authority responsibilities

Lead agencies in the response to a marine pest emergency must collaborate with CCIMPE in developing a National biosecurity incident response plan (NBIRP) as required under the NEBRA. CCIMPE will review the NBIRP and provide advice to the National Biosecurity Management Group (NBMG), which will determine whether national cost-sharing arrangements should be activated. If the NBIRP and cost-sharing arrangements are approved, CCIMPE will help an affected jurisdiction implement an NBIRP. State coordination centres must be established with responsibility for strategically managing a marine pest incursion and for ensuring that community and/or industry involvement and communications are in place.

Depending on the circumstances, a local control centre with responsibility for managing field operations in a defined area may be established to enable an efficient and effective operational response. While close communication between a state coordination centre and a local control centre is imperative for effective conduct of any emergency response, it is important that strategic management (state coordination centre) and operational management (local control centre) roles be kept separate to optimise effective decision making and implementation during a national biosecurity incident response.

When a national coordination centre is established to help manage concurrent incursions in more than one jurisdiction, national coordination will be effected through consultation with CCIMPE representatives and relevant industry and community sector organisations, as appropriate.

3.1.1.1 Consultative Committee on Introduced Marine Pest Emergencies

CCIMPE provides national coordination for managing marine pest emergencies and comprises senior representatives from each Australian jurisdiction with coastal borders (the Australian Capital Territory is not represented). CCIMPE is the national technical body that advises NBMG whether an

incursion by an introduced marine pest represents a marine pest emergency (in a national context), and coordinates the national technical response. CCIMPE also makes recommendations on possible Stand-down phase activities (such as monitoring).

3.1.2 Stages in an emergency response to a marine pest of national significance

Management of a marine pest emergency of national significance has four phases of activation:

- investigation phase
- alert phase
- operations phase
- stand-down phase.

The first two phases, while detailed separately in the rapid response manuals, may be run concurrently, as outlined in the [Biosecurity Incident Management System](#). Progression from one stage to the next depends on the nature of the emergency and available information.

3.1.2.1 Investigation phase

The investigation phase is in effect when relevant authorities are investigating a reported detection of a marine pest. The initial report of a suspected marine pest may come from port surveys, slipway operators, fishermen, members of the public and routine field and surveillance activities.

A notifying party must advise the reporting point of a suspected outbreak of a marine pest within 24 hours of becoming aware of it. When making a preliminary assessment, the notifying party may decide that a notification is likely to trigger a marine pest emergency alert when:

- the description matches a species represented on the CCIMPE Trigger List that is either not present in Australia or, if it is present, the detection represents a new outbreak beyond the known range of established populations of the species in Australia
- the species detected is not on the CCIMPE Trigger List but has a demonstrable:
 - invasive history
 - impact in native or invaded ranges on the economy, the environment, human health or amenity
- the species detected is inferred as likely to have major impacts in Australia based on available data and characteristics of Australian environments and marine communities
- the suspected outbreak cannot be managed through pre-existing cost-sharing arrangements
- one or more relevant translocation vectors are still operating.

If the investigation indicates that a marine pest emergency is highly likely, the notifying party will inform the reporting point and will direct implementation of the alert phase.

Given that *C. maenas* is already established in Australia, a suspected detection outside its current range will represent a possible range extension and trigger an emergency alert. If the subsequent investigation concludes that the situation does not constitute a marine pest emergency, the notifying party will inform the reporting point and the emergency alert will be cancelled.

The CCIMPE Trigger List is currently under review but is still used for reporting purposes. It lists 35 marine pests of national concern for which a marine pest emergency response may be declared. CCIMPE may also consider an emergency response to marine pests not on the trigger list if they meet at least one of the [National Environmental Biosecurity Response Agreement](#) national significance criteria.

3.1.2.2 Alert phase

The alert phase is in effect while confirmation of identification of a suspected marine pest is pending, and an incident management team is assessing the nature and extent of the suspected incursion. During the alert phase:

- all relevant personnel are to be notified that an emergency alert exists in the affected jurisdiction
- an incident management team is appointed to confirm the identification of the suspected pest and to determine the likely extent of an incursion
- control measures are initiated to manage the risk of pest spread from affected sites (for example, operational boundaries of restricted areas are established for potential vectors)
- the findings of an emergency investigation are communicated to CCIMPE and NBMG to enable a decision to be made on whether to proceed to the operations phase.

If an emergency investigation shows there is no incursion by a marine pest of concern or there is an incursion but it is unlikely to be eradicable, the notifying party will:

- ensure interim containment measures are implemented to minimise the risk of pest translocation from any infested waterway
- provide a situation report to the CCIMPE Secretariat for the information of CCIMPE representatives and request a CCIMPE teleconference to enable consultation with all jurisdictions
- on reaching agreement from CCIMPE, instruct that the stand-down phase be implemented
- ensure documentation relevant to the decision-making process is maintained and filed as a 'negative marine pest emergency alert' (when investigation shows there is no incursion by a marine pest of concern) or a 'non-eradicable marine pest emergency alert' (when there is a confirmed incursion by a marine pest of concern but eradication is not considered feasible).

If the emergency investigation shows there is an incursion by a marine pest of concern and it is potentially eradicable, the notifying party will:

- ensure appropriate emergency containment measures are continued to minimise the potential for pest translocation, both from and within any infested waterway
- provide a situation report and an NBIRP plan to the CCIMPE Secretariat for urgent consideration by CCIMPE representatives and request a CCIMPE teleconference to enable consultation with all jurisdictions
- following CCIMPE endorsement, submit the NBIRP to NBMG for consideration of national cost-sharing arrangements to help resource a national biosecurity incident response.

3.1.2.3 Operations phase

The Operations phase of an emergency response is in effect when the marine pest emergency is confirmed by agreement through the NBMG forum. During the operations phase of a national biosecurity incident response:

- all relevant personnel and agencies should be notified that a national biosecurity incident response is being undertaken in the affected jurisdiction
- a standing committee on conservation and a local control centre should be established, if necessary
- control measures initiated in the alert phase should remain in place to manage the risk of pest spread from affected sites
- measures to eradicate the pest from infested sites should be implemented
- information from infested sites about the pest and the progress of operations should be collected, documented and analysed to enable progress of a national biosecurity incident response to be monitored
- expenditure associated with all eligible costs under cost-sharing arrangements should be documented
- regular situation reports should be communicated to the CCIMPE forum
- a decision should be made, when appropriate, on when to proceed to the stand-down phase.

3.1.2.4 Stand-down phase

The stand-down phase is in effect when, following appropriate consultation between the affected jurisdiction and CCIMPE, all agree that there is no need to progress or continue with a national biosecurity incident response. During the stand-down phase:

- a systematic approach to winding down operations must be taken to ensure operational effectiveness is not jeopardised
- all personnel, agencies and industry contacts involved in the emergency response are to be notified of the stand down.

The stand-down phase must commence once operational objectives have been achieved, or otherwise in accordance with advice provided by CCIMPE and agreed by NBMG. The advice that an emergency eradication operational response is no longer needed must be communicated to the affected jurisdiction.

3.2 Control and eradication strategy for *C. maenas*

Carcinus maenas is listed on the CCIMPE Trigger List. This species is highly fecund and can form dense populations in intertidal and submerged marine habitats, where it predares on native Australian species. *C. maenas* can have serious economic consequences for aquaculture and wild fisheries.

C. maenas is known to be present in eastern and northern Tasmania, central and eastern Victoria, the Gulf of St Vincent (South Australia), and southern New South Wales to as far north as Burrill Lake (DPI 2013). It has been sighted historically further north in New South Wales as far as Port Jackson (Sydney). *C. maenas* is considered absent from all other Australian waters. Any reports of the

suspected presence of *C. maenas* in Australian waters, should initiate the [investigation phase](#) of an emergency response.

The methods used to control incursion of *C. maenas* in Australian waters depend on the location and size of the outbreak. If the emergency investigation revealed an incursion by *C. maenas* that was potentially eradicable, the Director of Operations would prepare an NBIRP and forward it to CCIMPE for urgent consideration.

The options for controlling an incursion by *C. maenas* in Australian waters are:

- 1) Eradication of the pest from the infested area.
- 2) Containment, control and zoning with the aim of containing the species and slowing its further spread to other areas.

Eradication is unlikely if initial investigations show the species is widely established in open marine environments. Each control option involves a combination of strategies, such as:

- establishing declared areas to define zones where the pest is present or suspected to occur, and where emergency management operations are to be implemented
- quarantining and restricting or controlling movement of potential vectors, such as submersible equipment, vessels, marine organisms (fauna and flora) and ballast water in declared areas to prevent spread of the pest
- decontaminating potential vectors for the pest, including vessels, aquaculture stock and equipment, maritime equipment, and water that may contain larvae of the pest
- treating established populations on natural and artificial habitats in the infested area
- delimiting and tracing surveys to determine the source and extent of the incursion
- surveilling and monitoring to provide proof of freedom from the pest.

3.3 Policy on decision points

The policy on decision points includes proof of eradication and decisions to stand down eradication or control operations.

3.3.1 Proof of eradication

Proof of eradication requires a robust and intensive monitoring program during the operations phase of the response. During the operations phase, the purpose of the monitoring program is to detect new outbreaks of *Carcinus maenas* for treatment and to determine the efficacy of the treatment procedure. This information can be used to refine and direct treatment.

Monitoring should also continue at sites potentially at risk of infestation. A decreasing trend in the number of new, untreated clusters of *C. maenas* detected over time in the infested area is evidence of the effectiveness of the control measures.

3.3.2 Stand down eradication or control operations

The optimal time to stand down monitoring, eradication and control operations is a trade-off between the costs of maintaining emergency operations, including ongoing surveys (C_s), the cost of escape (including likely impacts) if eradication is declared too soon (C_e), the probability of detecting the pest species given it is present (q) and the annual probability the species remains present (p). This rule of thumb can be used to calculate the optimal number of surveys:

$$n^* = \frac{\ln\left\{\frac{-C_s}{C_e \ln(r)}\right\}}{\ln(r)}$$

Where $r = p(1 - q)$ is the probability the pest is not detected but is still present in the survey area. See Regan et al. (2006) for guidance on calculating this decision point.

3.4 Policy on funding of operations and compensation

CCIMPE will help determine whether an incursion is likely to be eradicable and when national cost-shared funding under the NEBRA should be sought. Funding must be agreed by NBMG.

As detailed in the NEBRA, parties will share the eligible costs of emergency eradication responses as follows:

- a 50% share from the Australian Government
- a 50% share collectively from the states and the Northern Territory
 - this is calculated for each jurisdiction based on the length of coastline potentially affected by the species, and their respective human populations
 - only jurisdictions affected or potentially affected by the pest or disease are required to contribute.

NBMG may commit up to \$5 million (in annual aggregate) towards the eligible costs associated with an agreed national biosecurity incident response. If this \$5 million is exceeded in any one financial year, NBMG must seek ministerial approval from all parties to continue activities and/or begin new emergency responses.

Private beneficiary contributions to a response will be considered by NBMG on a case-by-case basis where there is one or more private beneficiary and no existing arrangements.

4 Principles for containment, control and eradication

Successful eradication of incursions by *Carcinus maenas* requires early detection and immediate action. Eradication is most likely to be successful in shallow, partially or fully enclosed waterways. In open coastal waters with moderate to high water exchange, larvae may be dispersed over a wide area. Where surveys indicate that an infestation is widespread, eradication is unlikely to be successful.

Characteristics of this species and the pathways by which it is spread make it difficult to eradicate. These include:

- high fecundity, with a planktonic larval stage that can be dispersed broadly by water currents
- presence in environments which are often prone to some form of disturbance or modification
- movements of non-commercial vessels and other vectors from infested ports or marinas are frequent and often difficult to trace.

The basis of eradication is rapid, effective quarantine of the infested area and any potentially contaminated vectors, and elimination of the pest where it is found.

4.1 Methods for preventing spread of the organism

Methods used to prevent the spread of the organism are quarantine and movement control, and treatment for decontamination of infested vectors.

4.1.1 Quarantine and movement controls

Quarantine and movement controls include an investigation phase, an alert phase and an operations phase.

4.1.1.1 Investigation phase

When the presence of *Carcinus maenas* is suspected in an area but a marine pest emergency has not yet been confirmed (see [section 3.1.2.1](#)), the notifying party should, when feasible, take steps to limit the spread of the suspect pest from the potentially affected site or area by initiating voluntary restrictions on movement of potential vectors. This may involve notifying relevant port authorities, marina operators, industry associations and vessel owners in the suspect site about the investigation into a possible marine pest emergency. Cooperation should be sought from these stakeholders to stop, restrict or inform the notifying party of movement of vectors from the site. Compliance with voluntary movement controls may be enhanced by distribution of appropriate public awareness materials about the pest.

The investigation phase should attempt to identify all potential vectors present at the site and their location. Possible vectors for the spread of *C. maenas* are described in [chapter 2](#).

4.1.1.2 Alert phase

If the initial investigation finds that *Carcinus maenas* is highly likely to be present (see [section 3.1.2.2](#)), the findings should be communicated to CCIMPE for consideration of the appropriate course of action to manage the risk of spread from affected sites. The incident management team must ensure appropriate measures are implemented. These could include:

- restrictions on movement of potential vectors, such as submersible equipment, fishing gear, vessels, marine organisms (fauna and flora) and ballast water into and out of suspect sites
- controlling movement of people (such as property owners, scientists, tourists) into or out of the suspect sites, as appropriate; this may include police involvement
- a hotline phone number for reported sightings of the pests and inquiries from affected parties
- tracing potential vectors that have left the site
- redirecting vessels that have already left the site to appropriate sites for inspection and/or decontamination, if appropriate
- notifying and, where appropriate, consulting relevant experts.

4.1.1.3 Operations phase

The operations phase will be guided by whether eradication of the marine pest of national concern is feasible or not feasible.

Eradication not feasible

If investigation reveals an incursion by *Carcinus maenas* that is unlikely to be eradicable, interim containment measures (to prevent translocation of a pest of concern from any infested waterway) should be implemented to minimise the risk of the pest being spread from the infested area. A stand-down phase may be entered either directly from the alert phase or from the operations phase when CCIMPE and NBMG agree there is no need to initiate a national biosecurity incident response.

Eradication feasible

If investigation reveals a potentially eradicable *C. maenas* incursion, quarantine and associated movement restrictions should be implemented.

Quarantine restrictions require establishing specified areas:

- infested area—all or part of a waterway in which a marine pest emergency is known or deemed to exist (pending confirmation of pest identification)
- dangerous contact area—an area close to an infested area in which a pest has not been detected but, due to its potential for infestation, will be subject to the same movement restrictions as an infested area
- suspect area—an area relatively close to an infested area that will be subject to the same movement restrictions as an infested area (pending further investigation)
- restricted area—a declared or gazetted area around an infested area that is subject to intensive surveillance and movement controls on potential vectors
- control area—a declared or gazetted area surrounding a restricted area in which defined conditions apply to the entry or exit of potential vectors or specified risk items.

Similar terminology is applied to potentially affected vectors within each area. For example, a vessel within a dangerous contact area would be classified as a 'dangerous contact vessel'; a vessel within an infested area would be classified as an 'infested vessel'.

The extent of each specified area for *C. maenas* should be determined based on:

- an initial delimiting survey of the area ([section 5.3](#))
- an evaluation of the length of time the species has been present and whether it has reproduced; this would be based on the size and distribution of the animals in the infested area, the number of cohorts apparent and, when possible, examination of reproductive tissue
- the strength and distribution of directional or tidal currents
- expert advice.

Movement restrictions include limiting:

- the movement of vessels, immersed equipment, aquaculture stock or equipment and other vectors for biofouling
- fishing activities within the control area
- the uptake or movement of ballast water or other water from within the control area.

Implementation of restrictions will be a dynamic process, determined by the location and extent of infestation and whether the aim is to eradicate the pest or to control its spread. Some restrictions may be deemed impractical or unnecessary in a particular circumstance, but others will be critically important to eradication or control.

Restricted Area Movement and Security Unit

The Restricted Area Movement and Security Unit of the Operational Pest Control Centre is responsible for controlling movement of goods, submersible equipment, vessels, water and other vectors including people into, within and out of the restricted area as appropriate to minimise the potential for pest spread.

The unit's main duties are to:

- issue movement permits to the public
- establish and operate road and water checkpoints in the restricted area, including liaison with state transport authorities, water authorities, police and local government
- coordinate movement and security activities across infested sites
- maintain registers of all movements (in restricted and infested areas), permits issued and staff deployed.

Experience of movement controls

The emergency response to the incursion by the black striped mussel, *Mytilopsis sallei*, in Cullen Bay Marina (Darwin) in 1999, used a combination of the powers in the *Fisheries Act 1988* (NT) and the *Quarantine Act 1908* (Cth) to impose sufficient quarantine measures to limit the spread of the

species. The *Quarantine Act 1908* can be used only in the absence of appropriate state or territory legislative powers and may only be used in certain circumstances, including directing a vessel:

- into port
- to not enter a port and to obey further instruction
- to undergo a treatment action the Operations Director deemed necessary.

Responsibility for directing and approving action under the *Quarantine Act 1908* resides with the Operations Director and all actions taken against a vessel should only be taken in relation to those identified as being at risk of spreading the invasive species (Ferguson 2000). Interim guidelines for using the *Quarantine Act 1908* in the absence of appropriate state and territory legislation are in [Appendix A](#). A provisional list of other Commonwealth and state powers for intervention and detention of vessels is in [Appendix B](#). The *Biosecurity Act 2015* will commence on 16 June 2016, replacing the *Quarantine Act 1908*.

Each state and territory should consider enacting relevant fisheries or other legislation to prevent or control fishing within a control area, and prevent or control translocation of stock and equipment from within it. Any requested movement of fishing gear or aquaculture stock or equipment should be subject to risk assessment consistent with procedures outlined in the National Policy for the Translocation of Live Aquatic Organisms (MCFFA 1999). All potentially infested fishing gear, aquaculture equipment or stock should be treated and inspected before removal from the control area.

4.1.2 Surveillance for high-risk vectors

In the event of an emergency marine pest response, movement controls on potential vectors and pathways will be easier to manage if efforts can be targeted at vectors that pose the greatest risk of spread.

All vessels and other vectors that have been within an infested area or dangerous contact area during the time the pest is known or suspected to have been present should be considered at high risk of transporting the pest. Vessels, oil rigs, barges and other moveable structures that have been present in suspect, restricted or control areas, that have high levels of marine fouling on them, should also be treated as high risk. The risk status of vessels may be changed if inspections or surveys find no sign of the pest

Vessels that have not been within the infested or dangerous contact areas, but which have been in close proximity to a high-risk vessel that have departed these areas or the control area should also be considered high risk. All high-risk vessels should be required to proceed to an approved inspection and treatment facility.

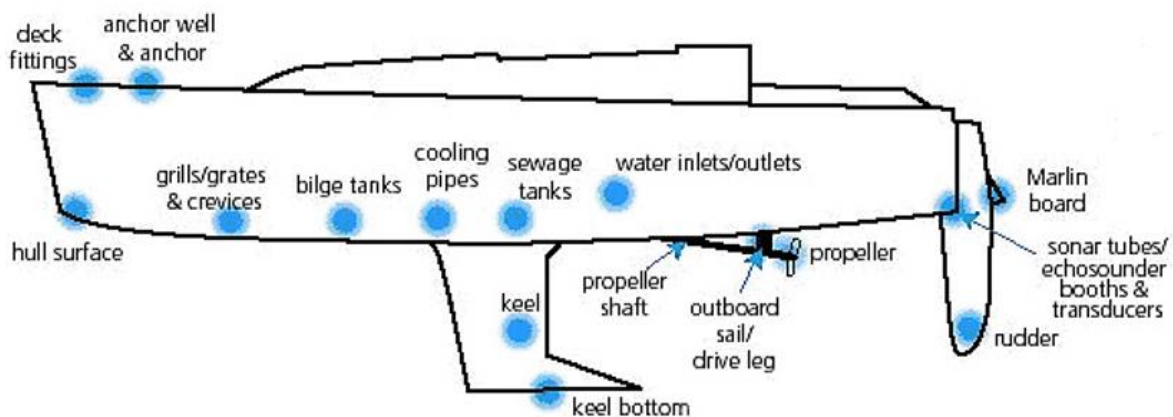
Where resources allow, all vessels and potential vectors within the control area should be inspected for signs of the pests. Medium-risk vectors should be required to remain within the control area until they can be inspected and declared free of the pest.

Divers should perform in-water inspection of vessels using a standardised search protocol. Biofouling is likely to be greatest in wetted areas of the vessel that are protected from drag when the vessel is underway and/or where the antifouling paint is worn, damaged or was not applied.

For vessels smaller than 25 m in length (Figure 2), particular attention should be given to inspecting:

- rudder, rudder stock and post
- propellers, shaft, bosses and skeg
- seawater inlets and outlets
- stern frame, stern seal and rope guard
- sacrificial anode and earthing plate
- rope storage areas and anchor chain lockers
- ropes, chains or fenders that had been left over in the water
- keel and keel bottom
- sounder and speed log fairings.

Figure 2 High-risk niche areas for inspection of biofouling on vessels less than 25 metres



For vessels larger than 25 m in length (Figure 3), additional high-risk niche areas include:

- dry docking support strips (DDSS)
- seachests and gratings
- sonar tubes
- bow thrusters
- keel and bilge keels
- ballast tanks and internal systems.

Figure 3 High-risk niche areas for inspection of biofouling on vessels greater than 25 metres

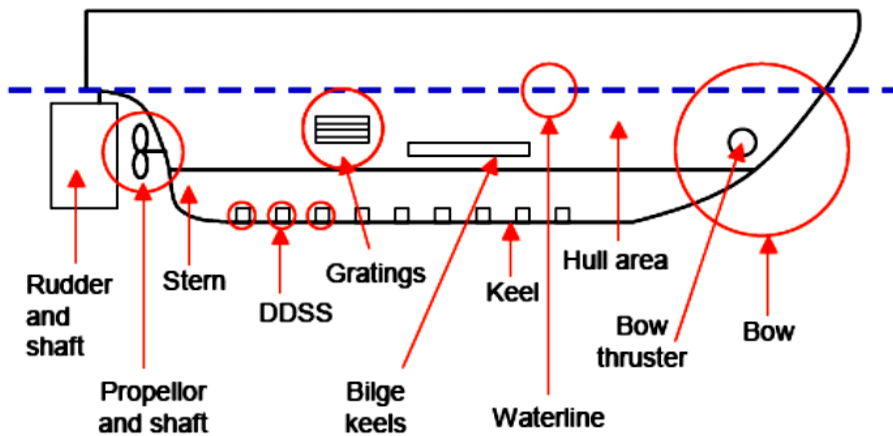


Image: Floerl 2004

Divers can inspect interior spaces and crevices (such as seachest, water intakes or outlets) using endoscopes.

All high-risk and medium-risk vessels that have recently left a control area should be contacted immediately. If they have not entered another port or marina they should be encouraged to remain at sea, no closer than 1.5 nautical miles to the nearest land until inspection and/or quarantine arrangements can be made. Quarantine risks detected before or during this inspection must be dealt with before the vessel can be brought further inshore. Where the vessel has entered another port or coastal area, it should be inspected immediately and, if signs of the pest are present, the vessel should be directed for treatment and surveys undertaken of the anchorages it has visited.

4.1.3 Treatment methods for decontaminating infested vectors

Treatment methods differ depending on the type of area in which the infestation occurred. It could have been found in ballast water, on vessels or on equipment and marine organisms.

Table 5 summarises management recommendations for different types of vectors.

Table 5 Management recommendations for different types of vectors

Potential vector	Suggested management
International and domestic yachts and other vessels smaller than 25 m	Clean external submerged surfaces Treat internal seawater systems Treat ballast (or residual ballast in empty tanks) Remove from the control area once cleaned
Domestic fishing vessels, ferries, tugs, naval vessels	Clean external submerged surfaces Treat internal seawater systems Treat ballast (or residual ballast in empty tanks)
Merchant vessels larger than 25 m departing for other Australian destinations	Inspect and (where possible) clean external submerged surfaces Treat or seal internal seawater systems Restrict uptake of ballast water from the control area Restrict ballast discharge within the Territorial Sea Recommend exchange of any ballast sourced inside the control area once the ship is in international waters (greater than 12 nautical miles)
Merchant vessels larger than 25 m departing for international waters	Inspect and (where possible) clean external submerged surfaces Treat or seal internal seawater systems Restrict uptake of ballast water from the control area Restrict ballast discharge within the Territorial Sea Recommend exchange of any ballast sourced inside the control area once the ship is in international waters (greater than 12 nautical miles)
Recreational craft (such as dinghies, jet-skis, kayaks, outboard motors)	Clean external submerged surfaces Clean and dry internal seawater systems Educate users and service agents of risk
Fishing gear and nets	Clean and dry on removal from area Educate users of risk
Aquaculture stock (fouled)	Remove from infested area and destroy
Aquaculture equipment (fouled)	Remove from infested area Clean thoroughly by high pressure (greater than 2,000 psi) water blasting Immerse in copper sulphate solution (4 mg/L) or liquid sodium hypochlorite (200–400 ppm) for 48 hours Rinse in seawater and air dry
Buoys, pots, floats	Clean and dry Restrict removal from the control area Educate users on risks
Water, shells, substratum, live hard-shelled organisms from the control area (such as aquaria, bait)	Restrict removal from the control area Educate users on risks
Flotsam and jetsam	Remove from water/shoreline Dry prior to onshore disposal If possible, use barriers to prevent escape from infested area
Fauna (such as birds, fouled crustacean)	Verify the importance of the vector during delimitation surveys
Stormwater pipes, intakes	Clean Where possible, seal until stand down of emergency response

Source: Bax et al. 2002

4.1.3.1 Ballast water

In the event of an emergency incursion response, all ballast water or seawater sourced from the control area should be deemed high risk to the Australian marine environment. Australian law prohibits discharge of high-risk ballast water anywhere inside Australia's territorial waters (12 nautical mile limit). Internal seawater systems that contain ballast water or residual ballast sourced from the control area will need to be treated or the ballast water contained or disposed of safely.

All vessels present in the control area, or which have been present in the control area when the pest was present, should be discouraged from taking on seawater for ballast, cooling or other uses, or prohibited from discharging water taken from the control area within Australian territorial waters.

When water has been sourced from the control area, it should be managed differently for vessels departing for international destinations and for vessels departing for Australian destinations.

Vessels departing for international destinations

Vessels leaving the control area for destinations outside Australia's territorial waters should be notified of the risk and required to exchange ballast water sourced from the control area in oceanic waters, outside 200 nautical miles at depths greater than 200 m, as specified by the International Maritime Organization (IMO) [International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004](#) (Ballast Water Management Convention). Permission should not be given for discharge of high-risk ballast within the 12 nautical mile limit. Options for oceanic exchange of ballast water are described in the [Australian Ballast Water Management Requirements](#) (Department of Agriculture and Water Resources 2017) and are consistent with the IMO's Ballast Water Management Convention Guidelines for Ballast Water Exchange.

Vessels departing for Australian destinations

When possible, vessels travelling to other Australian ports should be encouraged to exchange ballast sourced from the control area in oceanic waters. Australian law prohibits discharge of high-risk ballast water anywhere inside Australia's territorial waters (12 nautical mile limit). To avoid discharging high-risk domestic ballast water, the ship may elect to hold the ballast water on-board or transfer it from tank to tank within the ship. This is an acceptable way of managing ballast water risk. However, ships' masters should ensure that, when using this method, they have carefully considered their cargo plans to negate any need to discharge any high-risk ballast water within Australian ports.

Lifecycle modelling of *C. maenas* within Australian waters suggests it is unlikely to be able to complete its lifecycle and survive any further north than 28 °S (Hayes et al. 2007). Consideration should be given to whether ballast water sourced from a control area should be allowed to be discharged in locations north of this estimated survival threshold.

Once the IMO's Ballast Water Convention comes into effect, ballast water management systems will be an accepted alternative to ballast water exchange. These systems eliminate harmful pests from ballast water by using methods such as filtration, UV treatment, electrolysis, active substances and cyclonic separation. If a ship has a functioning ballast water management system installed before the Convention comes into effect, it may be accepted for use, provided sufficient documentation is received to allow a comprehensive review and analysis of the treatment method.

4.1.3.2 Biofouling of vessels and other possible vectors

Mechanical removal of biofouling on vessels includes land-based treatment, internal seawater systems and various in-water treatments.

Land-based treatment

Because *Carcinus maenas* may inhabit internal piping and water intakes and may be found among biofouling, they may not be readily visible underwater. Therefore, haul-out of vessels and other non-permanent structures (such as moorings, pontoons, ropes) for inspection and treatment on land is the preferred option for decontamination. This may only be possible for vessels smaller than 25 m in length where suitable haul-out or dry-dock facilities are available within or in close proximity to the control area. Larger vessels may need to be inspected and treated in the water.

Internal seawater systems

Internal seawater systems should be cleaned to the greatest extent possible with:

- 5% (by volume) industrial detergent (Conquest or Quatsan) in water (preferably fresh) for 14 hours (Lewis & Dimas 2007)
- chlorine at a concentration of 24 mg/L for 90 hours (Bax et al. 2002)
- copper sulphate solution at a concentration of 1 mg/L for 38 hours (Bax et al. 2002).

The Operations Director may approve other treatments. Alternative treatments (such as use of hot water or maintaining freshwater throughout internal systems for at least three days) may be acceptable only if it can be guaranteed that the required temperatures are met throughout the system for the required time (Gunthorpe et al. 2001).

There is a risk that any *C. maenas* dislodged during haul-out or cleaning of a vessel may remain viable and could start a new population if returned to the sea. The Operations Director must approve haul-out facilities used for decontamination. Such facilities should be fully contained so material removed from vessel hulls cannot return to the marine environment by any means, including direct disposal, run-off or aerosol drift. All macro (greater than 1 mm) particles removed from vessels cleaned out-of-water should be retained and disposed of in landfill (or as biohazard material if appropriate). All liquid effluent (runoff) from out-of-water vessel water blasting or cleaning should be collected for treatment in a liquid effluent treatment system.

Woods et al. (2007) provide guidance for identifying vessel cleaning facilities suitable for removing marine pests. Approved facilities should also comply with relevant state requirements for waste containment and disposal from slipways, boat repair and maintenance facilities.

High-pressure water blasting followed by prolonged (more than 5 days) aerial exposure may also be used to treat other fouled structures removed from an infested area (such as mooring blocks, pontoons, floats, fenders).). However, *C. maenas* has been known to survive for considerable periods out of water, especially in areas where humidity remains high

In-water cleaning

The [Anti-fouling and in-water cleaning guidelines](#) state that where practical, vessels and moveable structures should be removed from the water for cleaning, in preference to in-water operations. When removal is not economically or practically viable, the guidelines accept in-water cleaning as a management option for removing biofouling, provided risks are appropriately managed.

Applicants who wish to perform in-water cleaning in Australian waters should familiarise themselves with the principles and recommendations contained in the guidelines. In Commonwealth waters, applicants should first check their obligations under the [Environment Protection and Biodiversity Conservation Act 1999](#) (EPBC Act). If the activity does not need to be referred under the EPBC Act, then applicants should self-assess their activity using the decision support tool in Appendix A of the [Anti-fouling and in-water cleaning guidelines](#). Applicants who wish to perform in-water cleaning in state or territory waters should contact the relevant agency in each state or territory jurisdiction for advice.

Wrapping and encapsulation

Wrapping and encapsulation of the submerged surfaces of vessels using impermeable barriers, such as polyethylene plastic, have been used to treat fouling on vessels of up to 113 m long (Mitchell 2007). The wrapping deprives fouling species of light and food while continued respiration and decomposition of organisms within the barrier depletes dissolved oxygen in the water, thus creating an anoxic environment that is eventually lethal to all enclosed organisms.

Polyethylene silage plastic wrap (15 by 300 m, 125 µm thick) is cut to size to suit the vessel type and is deployed by divers in association with a topside support team. The plastic is passed from one side of the vessel to the other, overlapped and secured tightly using PVC tape or ropes to create a dark, anaerobic, watertight environment. Sharp objects on the hull (such as propeller blades) should be wrapped separately or covered with tubing or cloth before encapsulation to prevent tears in the plastic.

Properly deployed, the wrap should contain the pest species and its larvae; care should be taken to ensure that biofouling is not dislodged when the wrap is deployed. The wrap must remain in place for at least seven days to ensure mortality. Wrapping of vessels larger than 25 m in length is labour intensive and may take up to two days to deploy per vessel. In addition, the time needed for effective treatment (seven days) may be too slow when rapid treatment and turnaround of vessels is crucial.

This method of treatment is only suitable in relatively sheltered environments with slow current flow, since strong currents create difficulties in deploying the wrap and increase the chances of tears in the plastic.

Where very large vessels or several vessels need to be treated, the encapsulation technique will generate large amounts of plastic waste. Wrap and equipment used to deploy it must be disposed of in landfill or an approved solid waste treatment facility.

Commercial encapsulation tools are available. For example, Aquenal Pty Ltd is currently developing a mobile encapsulation tool called IMProtector™, which can be applied to a vessel arriving in port, or to a vessel at anchor, alongside a wharf or in a marina berth.

Relevant agencies in each state or territory jurisdiction should be consulted about the suitability of a wrapping and encapsulation method for a vessel or moveable structure.

Chemical treatment

Mortality can be accelerated by adding chemical agents to the encapsulated water (Coutts & Forrest 2005). For example, sodium hypochlorite (NaOCl, 12.5% w/v) can be added to the sea water enclosed in the sheath to achieve a concentration of 200 to 400 ppm. The sheath and chemical treatment remain in place for 36 to 48 hours for each vessel. Because this technique may release some chloride ions to the surrounding water, consent is required from relevant state or territory authorities to undertake the treatment.

4.1.3.3 Aquaculture stock and equipment

Treatments used to remove marine pests from ropes, culture lines and equipment include:

- immersion in or spraying with:
 - acetic acid—4% (Coutts & Forrest 2005; Forrest & Blakemore 2006; LeBlanc et al. 2007)
 - brine or lime solutions (Carver, Chisholm & Mallet 2003)
 - chlorine or sodium hypochlorite (Carver, Chisholm & Mallet 2003; Coutts & Forrest 2005; Gunthorpe et al. 2001; Rajagopal et al. 2002, 2003)
 - hot (50 °C) or cold (ambient) freshwater (Carver, Chisholm & Mallet 2003; Coutts & Forrest 2005; Gunthorpe et al. 2001; Nel, Coetzee & Vanniekerk 1996)
- air drying (Carver, Chisholm & Mallet 2003; Coutts & Forrest 2005; Gunthorpe et al. 2001)
- high pressure (greater than 2,000 psi) water blasting (Carver, Chisholm & Mallet 2003; Coutts & Forrest 2005).

Not all of these treatments have been trialled for effectiveness on *Carcinus maenas* and their utility for this species remains questionable.

Table 6 is a summary of treatments shown to cause 100% mortality (LD100) of *C. maenas*. These are largely based on laboratory trials and may need to be adapted to ensure complete mortality on more complex structures such as ropes or nets or for large applications.

Table 6 Treatments that achieved total mortality (LD100) of *Carcinus maenas* in laboratory conditions

Treatment	Duration of immersion and concentration for 100% mortality
Bleach solution (Black and Gold) ^a	4 hours at 2% concentration ^b
Detergent (DECON 90) ^c	Greater than 8 hours at greater than 18 °C ^b

a Active ingredient 3% sodium hypochlorite. **b** Gunthorpe et al. 2001. **c** Active ingredient less than 3% potassium hydroxide.

C. maenas can survive up to 12 hours of total anoxia (Hill et al. 1991) and, as a highly mobile animal, is likely to migrate from physically stressful conditions. Because of this, air drying of potentially contaminated equipment should be done well away from any watercourse to avoid the possibility of *C. maenas* re-entering waterways from the treatment area.

C. maenas is also tolerant of a broad range of salinity and exhibits high rates of survival after immersion in freshwater for eight or more hours (Gunthorpe et al. 2001). Reid et al. (1997) suggest some animals may survive for more than five days at salinity of less than 10 ppt.

Treatment with hot water can effectively kill *C. maenas* on non-living surfaces, but care should be taken when applying this treatment to aquaculture stock that may be more susceptible to temperature shock. To kill *C. maenas*, changes in water temperature must be rapid, as the crab quickly migrates into the air in response to warming of surrounding water (Taylor & Wheatly 1979).

Similarly, immersion in 2% bleach solution for more than four hours has been shown to cause 100% mortality of adult *C. maenas*, but is also highly toxic to shellfish stock and causes significant mortality after exposures as short as one hour. *C. maenas* is likely to exhibit avoidance behaviour in response to toxic chemicals in the water and may quickly migrate out of, or away from, treated equipment.

Laboratory trials have shown that immersion in 2% detergent (DECON 90) solution for eight hours causes 100% mortality of *C. maenas* (Gunthorpe et al. 2001), and shorter periods of exposure (up to four hours) were less effective. Native blue mussels (*Mytilus galloprovincialis planulatus*) survived exposure to detergent treatment for up to four hours without mortality (Gunthorpe et al. 2001). However, as this study does not address survival of mussels for longer periods, further trials may be needed to determine likely rates of shellfish survival before using a detergent solution on aquaculture stock with the intent of killing *C. maenas*.

The broad-spectrum insecticide carbaryl is highly toxic to crabs, although the literature reports wide variation in its toxicity, with LC50 values ranging from 0.005 to 2.0 g/m³ in acute toxicity tests (up to 96 hours) (Golder Kingett Mitchell 2007). Carbaryl is considered moderately toxic to fish and is moderately to very highly toxic to estuarine and marine invertebrates in acute toxicity trials (48-hour EC50 range, 0.0015 to 2.7g/m³), depending on the species. Carbaryl has long been used to control burrowing shrimp in oyster beds in the United States. Although it does not bioaccumulate in the food chain and is relatively short lived in the environment, it can have toxic and sublethal effects on shellfish and other non-target organisms (McEnnulty et al. 2001). Further trials are needed to determine appropriate dosages and exposure times for use of carbaryl to remove *C. maenas* from aquaculture stock and equipment. See Golder Kingett Mitchell (2007) for a more detailed review of the toxicity of Carbaryl to marine organisms.

Other chemical formulations trialled against *C. maenas* are summarised in [Appendix E](#).

Ropes and equipment

The protocols recommended for treating ropes and aquaculture equipment, such as buoys, floats, nets and traps, are:

- 1) Remove to land taking care not to dislodge crabs when removing structures from the water.
- 2) Clean thoroughly by high pressure (greater than 2,000 psi) water blasting.
- 3) Immerse in 2% liquid sodium hypochlorite (200–400 ppm) for at least four hours, or 2% detergent (DECON 90) solution for at least eight hours, or hot water (greater than 40 °C) for at least one hour (if practical).
- 4) Rinse in seawater and air dry for at least 48 hours.

Aquaculture stock

Some cultured species with hard shells (such as molluscs) and macroalgae may be habitat providers for *C. maenas* and may, therefore, be potential vectors for its spread. Utility of methods used to decontaminate aquaculture stock will depend on the relative robustness of the pest and cultured stock to the treatment.

Disinfection of bivalves and other aquaculture stock for external hitchhikers is not always effective and must be weighed against potential environmental impacts of any treatment and its effect on stock. Where the treatment cannot be to be effective, it may be precautionary to either destroy potentially contaminated stock and dispose of it to landfill or harvest and process stock for human consumption.

Based on laboratory by Gunthorpe et al. (2001) recommend treatments are:

- declump stock, then immerse in 2% detergent (DECON 90) for at least eight hours
or
- rinse in sterile sea4water and hold in quarantine facilities before redeployment into marine environments.

Further trials should be carried out to determine rates of mortality of the treatment on shellfish stock and *C. maenas*. These methods are also likely to be cost-effective ways to treat other fishing, aquaculture or boating equipment for *C. maenas*

4.2 Tracing an incursion

Tracing is used to discover the method and pattern of the spread of the pests and may include trace-forward and trace-back. It is crucial to defining and modifying the dimensions of the specified areas and requires investigations that determine:

- the length of time the species has been present
- the initial source and location of infestation
- whether the pest has reproduced
- the possible movement of water, vessels, animals, submersible equipment and other potential vectors for the pest
- the existence and location of other potentially infested areas.

The local control centre's Pest Investigations Unit is responsible for managing all tracing and surveillance activities within the control area.

Several methods are useful for estimating how long the pest has been present. The demography of the population may be inferred from the size distribution and reproductive state of animals collected during initial investigations.

For example *Carcinus maenas* that have a carapace width of more than 35 mm are likely to be reproductively mature. However, females are capable of storing sperm from a previous mating encounter for up to a year for use in subsequent spawning episodes, making it difficult to determine the state of the population (Hedgpeth 1993)

4.2.1 Data sources for tracing vectors

Tracing the movements of vessels to and from an incursion is made difficult by lack of a consolidated system for reporting or managing data on vessel movements in Australian waters. Some potentially useful data sources on movements of large, registered commercial vessels are:

- The [Lloyd's List Intelligence](#) maintains real-time and archived data on movements of more than 120,000 commercial vessels worldwide. It contains arrival and departure details of all vessels larger than 99 gross tonnes from all major Australian and international ports. The database contains a searchable archive that includes movement histories of boats since December 1997. Searches can be purchased for specific ports, vessels or sequences of vessel movements.
- The [Australian Fisheries Management Authority](#) manages data on the locations of all fishing vessels that have Commonwealth fishing concessions. All Commonwealth fishing concession holders must have installed and be operating an integrated computer vessel monitoring system. The system is also required for some fisheries managed by state and territory fisheries management agencies (such as the Queensland East Coast Trawl Fishery).
- The [Bureau of Infrastructure, Transport and Regional Economics](#) maintains statistics on maritime trade, markets, shipping lanes, key trade routes, traded commodities and passenger services throughout Australia.
- The [Department of Agriculture and Water Resources](#) and the [Australian Border Force](#) maintain data on all vessels arriving in Australian waters from overseas. These data are for proclaimed first ports of entry into Australia.
- The [Australian Maritime Safety Authority](#) deals with maritime safety, protection of the marine environment and maritime and aviation search and rescue services. It also coordinates a vessel tracking program, which works as an umbrella for managing related vessel information from the Modernised Australian Ship Tracking and Reporting System (MASTREP) the Great Barrier Reef and Torres Strait Vessel Traffic Service, the Automatic Identification System, the Long Range Information and Tracking system and the Australian Maritime Identification System.
- The aquaculture industry deals with equipment, stock and boat movements between aquaculture sites.

There are no consolidated data on domestic movements of smaller coastal vessels within Australian waters. Ports and some marina operators keep records of vessels that have used their facilities. Local industry groups (such as fishing, petroleum exploration) may provide points of contact for vessels from individual industry sectors that have visited the infested area. Some data may also be available from sources such as the Australian Volunteer Coast Guard, in the form of logged vessel trip reports.

Some states and territories have developed vessel-tracking systems for a range of vessel types. During the operational period of the *Mytilopsis sallei* incursion in Darwin, the Northern Territory Police and the Australian Government Department of Agriculture, with support and input from the Darwin Port Authority, Australian Border Force, the Northern Territory Fisheries Division Licensing Branch, the Australian Fisheries Management Authority and Coastwatch, developed an access database that contained vessel names and contacts, current location, history of individual vessel movements and the health status of the vessel.

5 Controlling, eradicating and treating established populations

The feasibility of controlling a *Carcinus maenas* infestation in Australian waters depends on the nature and location of the incursion and the management strategy adopted. Two control options are available:

- eradication or complete elimination of *C. maenas* from the infested area (highest level of control measure and cost)
- or
- containment and control by limiting the species to the infested area, preventing further spread and protecting uninfected areas.

5.1 Eradication

Eradication of *Carcinus maenas* requires complete removal from the infested area. Eradication is unlikely to be successful or feasible if initial investigations determine that the species is widespread, cannot be contained, is difficult to detect, or is present or potentially present in open coastal environments.

Because the planktonic larvae of *C. maenas* can be spread rapidly over large distances by movement of tidal and coastal currents, eradication may be impossible in open coastal waters where there is high exchange of water. Eradication is most likely to be feasible when:

- the area inhabited by *C. maenas* is small (less than 1,000 m²)
- the infestation occurs within an area of minimal flushing or exchange of water
- the available habitat occurs in relatively shallow waters (less than 5 m)
- the population is relatively aggregated and has not yet reached reproductive maturity.

5.2 Containment and control

If the decision is made not to attempt eradication but to implement containment and control, the Operations Director will recommend that interim containment measures be implemented to minimise the risk of pest translocation from the infested waterway. This may include movement controls on potential vectors, public awareness campaigns, policies and practices (in consultation with stakeholders) for vessel and equipment sanitation and surveillance, and control of secondary infestations outside the infested waterway.

[National control plans](#) (NCPs) have been developed for several marine pests—including *Carcinus maenas*—that are already established in Australia and are having significant impacts on the marine environment or marine industries. The purpose of the NCP is to reflect an agreed national response to reduce impacts and minimise spread of agreed pests of concern.

Each plan includes:

- practical management actions and cost-effective approaches to control or reduce the impact of the marine pest
- recommendations for future research and development, including cost–benefit analysis and planning tools
- links to the National System monitoring strategy
- recommendations for additional public awareness and education strategies
- an implementation strategy.

5.3 Guidelines for delimiting surveys

A delimiting survey establishes the boundary of an area considered to be infested by or free from a pest. The survey should be conducted to establish the area considered to be infested by the pest during the emergency response and to decide if eradication is feasible. The Operational Pest Control Centre will plan a survey strategy with reference to appropriate confidence limits based on:

- the location where the pest was initially detected
- pest biology—survival, reproductive rate, spread, dispersal and influence of environmental factors
- pest habitat—distribution and suitability of potential habitats around restricted areas and control areas
- survey design—should take into account the sensitivity of the methods to detect the pest species and the ease with which a sample may be obtained
- sampling methods—should take into account the area of expected occurrence
- a predictive analysis of areas where the pest is likely to occur
- expected prevalence of the pest if unrestricted
- biometric methods to specify the different confidence limits for targeted and general surveillance.

When possible, the survey should be consistent with national standards and contain estimates of confidence based on best available information.

5.4 Design of a delimiting survey

The location at which the pest was first detected is a useful starting point for a delimiting survey, but it is important to recognise that it is not necessarily the initial site of the infestation. When designing a delimiting survey, it can be useful to work backward, to try to trace the initial source of the incursion (trace-back) and also to try to predict where the pest has, or could, spread to (trace-forward).

The geographic extent of an incursion will be determined by:

- how long the pest has been present at the site before it was detected
- the frequency and quantity of reproductive output from the population since the initial incursion
- the effects of environmental and human factors on the spread of dispersal stages.

If available, aerial photographs and/or hydrographic charts can be useful for identifying areas that may contain habitat suitable for the pest. Where they exist, hydrodynamic models (for example, CSIRO's [Connie 2](#)) may also be useful for simulating the likely directions of current flow and the possible rate and extent of spread of planktonic larvae from the known area of infestation. Trace-forward techniques should be used to identify locations outside the infested area that may have been exposed to the pests by vectors that have departed the area known to be infested.

The greatest survey effort should be made at the margins of the known infestation. Adaptive sampling designs with sample points located on systematic grids or gradients away from the site of known infestation (Eberhardt & Thomas 1991; Gust & Inglis 2006) are most useful to ensure the greatest possible area is covered, while providing the best chance of detecting established and founding populations.

5.4.1 Sampling methods

The type of sampling method chosen should be based specifically on the species being targeted, the habitat being searched and the conditions at the site. In subtidal waters where *Carcinus maenas* is typically most abundant, trapping surveys are the most efficient means of capturing adult crabs, as a large area can be sampled relatively quickly.

Commercially available Fukui collapsible box traps are an effective way to catch adult *C. maenas* (Behrens Yamada et al. 2005; Thresher et al. 2003). Fukui traps are 62 cm long, 42 cm wide and 20 cm high and are made of 0.4 mm diameter plastic-coated wire, covered with 1.3 cm² plastic netting. Crabs enter the trap through slits at the apex of inwardly directed panels at each end. Each trap contains a perforated bait-saver which should be baited with oily fish (jack mackerel, Australian salmon or similar). The traps are generally set in the afternoon or evening and left to fish for 15 to 24 hours. They are deployed on the seabed attached to an anchor or weighted line to stop them moving with the currents.

Pitfall and minnow traps can be deployed in high intertidal waters to sample smaller, 0+ cohort crabs (Behrens Yamada et al. 2005). Pitfall traps can be constructed in intertidal soft sediments by sinking 20L buckets filled with seawater into the substrate so the rim is flush with the sediment surface. Foraging crabs fall into the buckets and are unable to escape. Minnow traps are small (21 by 31 cm),

cylindrical baited traps with a mesh size of about 0.5 cm. Crabs enter the traps through funnel-shaped entrances at each end of the trap. These traps are effective for crabs of between about 30 and 70 mm carapace width (Behrens Yamada et al. 2005).

Trapping can be augmented by visual searches of intertidal environments at low tide. During low tide, *C. maenas* can be found sheltering in rock pools, under rocks or cobbles, or foraging on the shoreline. Divers can search around complex artificial structures, such as wharf pilings, pontoons and niche areas of vessels. However, the ability of divers to detect *C. maenas* depends on sufficient training in identification and search techniques, water clarity at the site and abundance and degree of aggregation of the population. Where underwater visibility is less than one metre, visual surveys will be compromised.

The South Australian Research and Development Institute has developed a qPCR assay which has undergone laboratory specificity testing and, based on available controls, has been found to be specific to *C. maenas*. The qPCR assay has been trialled by testing plankton samples from Port Adelaide and some Western Australian locations, but the test needs further validation from a wider range of localities and to determine the assay's sensitivity for detection of *C. maenas* in field samples.

Mitochondrial cytochrome c oxidase I gene markers have been developed overseas for *C. maenas* and *C. aestuarii* and may be used for their identification (Roman & Palumbi 2004). However, the larval development of *C. maenas* is well described (Rice & Ingle 1975), such that trained personnel can distinguish *C. maenas* larvae in plankton samples. A protocol for collecting plankton samples for analysis is described in [Appendix C](#).

Larval collectors can also be deployed to detect the presence of settling *C. maenas megalopae* (Moksnes et al. 1998). A standard protocol for the design and deployment of crab post-larval collectors, following that described by Metcalf et al. (1995) and Moksnes et al. (1998), is provided in [Appendix D](#). The collectors can be deployed from wharves, docks, moorings and buoys, but greatest natural densities of settled megalopae tend to occur in mussel beds, seagrass and filamentous algal patches (Moksnes 2002). Aggregations of megalopae tend to occur in surface coastal waters mainly during nocturnal flood tides, but they are also present at smaller densities during other phases of the tidal cycle.

See the [Australian marine pest monitoring guidelines](#), version 2 (NSPMMPI 2010) for additional information that can be adapted for delimiting surveys.

6 Methods for treating established populations

Methods used to treat established populations of *Carcinus maenas* will vary in efficacy according to the size and location of the incursion. This chapter summarises treatment options for closed or semi-enclosed coastal environments and for open coastal environments.

6.1 Closed or semi-enclosed coastal environments

Eradication is most achievable in closed or semi-enclosed coastal environments (such as locked marinas and coastal lakes) because the pest can be more easily contained and it is possible to maintain conditions necessary to achieve mortality for longer. Various treatment options are possible in these circumstances, including draining, de-oxygenation and/or flushing of the waterway with fresh water, application of chemical biocides, physical removal and ecological control (Aquenal 2007).

If the infestation is confined to relatively small, enclosed or semi-enclosed waterways, it may be possible to treat the entire water body and all marine habitats within it. If this is not possible, the success of management will depend more heavily on the ability of monitoring and delimitation surveys to locate and treat all clusters of the population. Where resources allow, all habitat potentially suitable for *Carcinus maenas* should be treated. Where this is not possible, habitats should be based on suitability for the pest and delimitation survey results.

6.1.1 Chemical treatments

Major constraints for chemical treatment of water bodies are the volume of water that needs to be treated (a function of the area, depth and degree of flushing of the waterway), the presence and susceptibility of valued non-target organisms that may also be affected, residual effects of any toxicants on the surrounding environment and human health and safety management when handling large volumes of chemicals. Legal issues can also influence the ability to administer chemicals as a rapid response, due to the large number of chemical products available and different legislative requirements between Australian states and territories (Aquenal 2007). Consideration should be given as to whether a permit for the use of chemicals is required from the relevant state or Northern Territory environment agency or the Australian Pesticides and Veterinary Medicine Authority.

6.1.1.1 Broadcast chemicals

Use of chemicals, such as pesticides, to eradicate invasive species has been thoroughly examined and a fine line is often found between potential environmental effects of a pesticide and the need to eradicate an invasive species. The toxicity endpoint for many chemicals has been established with *Carcinus maenas*, as well as combinations of chemical and physical treatment methods. Under laboratory conditions, not all examined chemicals are acutely toxic to *C. maenas* but several have been identified as being at least moderately toxic.

Both aerial pesticide application and poison baits have been suggested as chemical methods for controlling *C. maenas* (Grosholz & Ruiz 2002; McEnnulty et al. 2001).

Carbaryl

Carbaryl (1-naphthyl methylcarbamate) is a broad-spectrum insecticide used in many terrestrial applications to control insects, including wasp nests. It does not bioaccumulate in the food chain and is degradable, with abiotic and microbial action causing dissipation in the environment. Carbaryl is very toxic in the aquatic environment, with an LC50 of 0.0072 mg/L in crustaceans (ERMA 2007).

Carbaryl has been applied to intertidal oyster beds in Washington State since 1963 to control burrowing thalassinid shrimp. It is applied by helicopter as a wettable powder, which then slowly hydrolyses into water and breaks down into carbon dioxide. It causes nervous system impairment, paralysis and death of the shrimp. Carbaryl is likely to be effective against *C. maenas* because it is targeted at arthropods and kills other crabs. Carbaryl is relatively short-lived in the marine environment and does not bioaccumulate in the food chain, but it is likely to have significant impact on non-target species.

Significant safety issues associated with handling carbaryl must be considered in any control strategy. For example, a recent review by the Australian Pesticides and Veterinary Medicines Authority recommended tighter restrictions on domestic and commercial use of carbaryl in Australia, due to toxicological risks (Aqueen 2007).

Deploying carbaryl in traps may increase crab catch numbers and make delivery of the chemical more specific to *C. maenas*. However, in New Zealand a proposed trial of carbaryl-laced baits in a control program for the introduced swimming crab, *Charybdis japonica*, was abandoned because of strong opposition from local authorities and stakeholders (Golder Kingett Mitchell 2007). Opposition was based on concerns about effects of the poison on non-target species in the area.

6.1.1.2 Growth inhibitors

Other pesticides based on insect growth regulators are also likely to be effective against crabs. These work by inhibiting an enzyme, chitin synthase, in arthropods (Palli & Retnakaran 1999). As crustaceans have hard exoskeletons and go through similar life phases to insects, chitin synthase inhibitors are also effective at regulating their growth. Benzoylphenylurea inhibitors include diflubenzuron (DimilinTM), teflubenzuron, chlorfluazuron, hexaflumuron, lufenuron and novaluron. Benzoylphenylurea is used as an insecticide. The antibiotic puromycin interferes with transfer RNA function and inhibits protein synthesis in the blue crab, which is essential for chitin formation (Palli & Retnakaran 1999). The effect of these growth inhibitors is seen during moulting, when new externae are not correctly formed or when a female broods sterile eggs. However, their specific effectiveness on *C. maenas* has not yet been established.

The amount of chemical needed to reach lethal concentrations of 50% in *C. maenas*, and the time taken to reach those concentrations, have been investigated using various substances; concentrations of zinc chloride and cadmium chloride caused 100% mortality in five and seven days, respectively ([Appendix E](#)).

Although the specific toxicity of these chemicals to *C. maenas* has been shown in laboratory conditions, their effectiveness in natural environments and effects on non-target species are not well known.

6.1.1.3 Salinity manipulation

Carcinus maenas has various life stages that can be more or less susceptible to different concentrations and variations in salinity. Larval stages are less tolerant of extremes in temperature and salinity than post-larval or adult crabs, and successful development generally increases with increasing salinity (Grosholz & Ruiz 2002). However, this species is generally tolerant of a range of salinity concentrations and adults actively migrate away from unfavourable environmental conditions. Salinity manipulation is unlikely to be a successful way to treat an established population of *C. maenas* unless salinity can be maintained at very low levels for at least a month.

6.1.2 Physical treatments

Physical removal is the most socially and environmentally acceptable way of removing unwanted organisms from a marine system. Methods used to remove mobile invertebrates include hand collection, trapping, bounties on the pest, and physical barriers to limit adult transport.

6.1.2.1 Traps

Selective harvest using traps has been recommended for *Carcinus maenas* control programs because it is relatively easy to implement, has few environmental constraints (such as timing to avoid capture and release of all other non-target animals) and requires little upfront research to implement. The advantages of using traps are the ease with which they can be deployed, the negligible investment of time and the low costs associated with their use. However, the effectiveness of trapping depends on the ability to remove individuals from the population at a faster rate than they are added (Bomford & O'Brien 1995). The fecundity of *C. maenas* means that large numbers of individuals can enter the population from relatively few successful matings. Good estimates of the size (or density) and distribution of the local population, and the selectivity of the trapping methods are needed so fishing efforts can be tailored accordingly (Walton 2000). For trapping to be effective as an eradication technique (as opposed to a method for control or mitigation), densities must be reduced to levels that significantly reduce mating success and increase the likelihood of the Allee effect (that is, reduction in population viability at low densities) thereby driving the population to extinction.

Population modelling of the introduced swimming crab, *Charybdis japonica*, in Waitemata Harbour (New Zealand) showed that, depending on the size of the population, reducing densities to levels that significantly reduce mating success can require a substantial fishing effort. It was estimated that up to 33,000 trap lifts would be needed each month for two or three years to increase the extinction probability by between 13 and 17% (Breen et al. 2005). Since traps act by luring animals from the surrounding environment, the density of trap placement in the infested area must be sufficiently high for most vulnerable animals to be exposed to the possibility of capture at some stage during the program.

Studies have shown that adult *C. maenas* can be easily caught by trapping in areas of high abundance (Thresher 1997). Baseline trapping data collected from regularly visited sites along the northeast and southeast coasts of Tasmania consistently returned catches of 200 to 300 crabs per trap (Thresher 1997). Oyster farmers in Tasmania have used trapping as a control method for *C. maenas* but information on the effectiveness of this method is lacking (Thresher 1997).

Trial control programs for *C. maenas* have been implemented using intensive trapping in Martha's Vineyard, Massachusetts (Walton 2000) and in Bodega Harbour, Washington (de Rivera et al. 2007a) in the United States. The Massachusetts trial involved trapping in relatively enclosed ponds for two

weeks and, although it was short-term, there was a significant decline in *C. maenas* abundance and a concomitant reduction in predation of cultured bivalves. The Washington study occurred over 66 days, during which time the catch per unit effort of *C. maenas* declined by as much as 90%, with apparent improvement in survival of native shore crabs occurring (de Rivera et al. 2007a). The trapping program used a combination of baited, minnow, and collapsible fish traps set in the lower intertidal zone to submerged areas where an earlier survey had observed the crabs in abundance. The minnow traps caught small crabs and more females than the large traps. The percentage of trapped females also increased over time. Trapping and trawling in the channel did not catch any *C. maenas*.

Whether the reduction in *C. maenas* abundance due to trapping in each study was sufficiently large due to reduced mating success and subsequent recruitment events is unknown.

The Washington trapping program resulted in initial recommendations to:

- perform an initial survey to determine crab distribution
- focus trapping effort in the lower intertidal to submerged areas
- employ a variety of trap types
- focus trapping efforts when temperatures are warmer
- persist with trapping well beyond decreased catches of large males to ensure female and juvenile crabs are also removed.

Employing multiple methods for removing crabs is important, because trap catches of decapod crustaceans tend to be dominated by large, sexually mature males (Caddy 1989). Mature females—especially those carrying eggs—and juveniles are less vulnerable to baited traps because they feed less frequently than males, are less mobile, and may be deterred from entering the traps by encounters with larger males (Miller 1990). In small populations, severely reducing male numbers through trapping may affect mate location and consequently reproductive success, but it is likely to be less effective at causing extinction than directed harvest of mature females (McDonald et al. 2004). Male portunid crabs are polygynous and mating success is often high with more than 90% of females inseminated (Hines et al. 2003). Because females are highly fecund and can store sperm, a single mating can fertilise multiple broods, each of which can produce several hundred thousand offspring. Combinations of trapping or other techniques that effectively remove male and female crabs are needed to increase the chances of eradication.

Many studies have examined the selectivity of different types of traps used by various fisheries. Miller (1990) summarised some of the issues and made recommendations for overcoming some of the biases, including recommendations on trap design, bait, soak time and target species behaviour.

Trap design

Different trap types have different selectivity for crabs of different species, sexes and sizes. Fukui design box traps have routinely been used for surveys of *C. maenas* (Behrens Yamada et al. 2005; Thresher et al. 2003). Their low cost, ease of use and relatively good catch per unit effort means they are recommended for monitoring studies of this species (Sutton & Hewitt 2004). However, their effectiveness for *C. maenas* relative to other trap designs has not been tested. Trials with different trap types should indicate differences in selectivity for juvenile, male and female *C. maenas*.

Mesh size can affect capture rates, with square mesh tending to result in higher capture rates of small individuals compared with hexagonal mesh designs (Guillory 1998).

Bait

Fresh fish bait (such as mackerel) is most effective for *C. maenas*. Other successful baits include whitefish, salmon, calamari, oysters, razor clams, mussels and cat food (Holmes 2001). Thresher et al. (2003) used about 300g of oily fish (jack mackerel or salmon) housed in a perforated bait-saver to trap *C. maenas*.

Baited traps may be less effective where a locally abundant natural food supply is available (Hayes et al. 2005).

Soak time

It is logical that traps must remain in the water for long enough for crabs to find the baits and enter the trap (Browne & Jones 2006). Thresher et al. (2003) deployed traps in the afternoon or evening and left them to soak for 15 to 24 hours.

Saturation levels are reached after a certain time as a result of trap size, large aggressive individuals monopolising the trap, or reduced effectiveness of baits. Catch rates can be increased by determining optimal soak times for *C. maenas* (Miller in Gust et al. 2002).

Soak times need to consider cost effectiveness and environmental constraints. Increasing soak time increases the number of field sampling days (Gust et al. 2002).

Target species behaviour

Since crabs approach baited traps by moving up a current, following an odour trail, catches can be enhanced by aligning the trap parallel with the direction of the water current (Vazquez Archdale et al. 2003).

C. maenas are less likely to enter traps in winter when they are less actively foraging for food (Sutton & Hewitt 2004).

Large male crabs are generally dominant over small males and females and may prevent other individuals from entering traps (Smith et al. 2004). Domination of the trap by aggressive males can be overcome with shorter soak times, more frequent trap resets, or addition of poison to the baits (Jones et al. in Aquenal 2007).

Higher catch rates may be obtained for females if trapping targets specific seasonal life traits of the target species (McEnnulty et al. 2001). Some evidence suggests that male blue crabs, *Callinectes sapidus*, release a sex pheromone which attracts pre-moult females, so restrained live males may be effective bait for trapping female crabs (Bamber & Naylor 1997). Pre-moult and post-moult female *C. maenas* actively approach restrained males, but this appears to be dictated by visual rather than olfactory cues and there is little evidence that male *C. maenas* release a sex pheromone (Bamber & Naylor 1997; Sneddon et al. 2003). Recently moulted individuals may be less likely to enter traps (Bellchambers & de Lestang 2005). Triggers on the entrance of traps allowing entry but not allowing escape may improve capture rates (Saltaug 2002).

Directed trapping efforts can be augmented by incentives for stakeholders to participate. A bounty system was used in Edgartown, United States, in 1995 as a response to the threat *C. maenas* posed to commercial shellfish production. About 10 metric tons of crabs were trapped and removed and a price of 40 cents a pound was offered; however, the impact on the scallops as a result of the significant removal was not known (Walton 1997). Such bounty systems are not recommended in emergency responses, owing to the high possibility of misuse such as new introductions or induced breeding for monetary gain. These programs also need to actively track the catch per unit effort and respond with higher prices when the pest becomes harder to catch (Holmes 2001).

6.1.2.2 Removable structures

Ropes, mooring lines, buoys, floating pontoons and other structures within the infested area that can be removed from the water should be removed and treated on land. Procedures for treating these structures are described in [section 4.1.3.3](#) and could include:

- disposal to landfill
- air-drying for a minimum of seven days
- high-pressure water blasting
- immersion in chemical or fresh water baths.

6.1.2.3 Hard substrata and structures that cannot be removed from the water

Hard substrata and structures that cannot be removed from the water include intertidal and submerged habitats.

Intertidal habitats

Hard intertidal substrata, such as wharf piles, exposed jetties and rocky shorelines may be treated when they are exposed at low tide.

Manual collection may be useful for reducing intertidal populations of *C. maenas*. Searchers should concentrate efforts around rock pools and under boulders and other structures located in the mid shore to low shore area.

Submerged habitats

Many traditional methods are used for removing mobile species. For submerged habitats the most commonly used treatment has been manual removal, but slow removal rates limit this method for large-scale efforts. Manual removal and trapping are likely to be the only effective means of response to a *C. maenas* incursion. Dredging is not likely to be effective with a mobile species, and removal from hard substrates using encapsulation may be appropriate if the infestation is of recently recruited *C. maenas* (Aguenal 2007).

All methods of manual removal need a high level of control and containment as well as a continued high removal effort. Trapping and other methods of physical removal will be most effective if migration of crabs into and out of a treated area can be prevented or reduced by construction of physical barriers. It may not be possible to prevent recruitment of post-larval crabs into treated areas, but adult crabs move by walking and do not readily enter the water column to swim. Low fences and other physical barriers may be erected temporarily to prevent movement from an area being treated, searched or trapped for *C. maenas*. Systematic movement of barriers and rotation of treatment within the infested area will ensure effective control and containment of crabs.

Encapsulation techniques are most suited to treating small to medium-sized incursions (less than 10,000 m²) in relatively sheltered waters. The procedure is labour intensive and hazardous for divers. The wrap is susceptible to puncture and tearing by shipping, strong water currents and sharp oysters or tubeworms, which reduces its effectiveness. The technique is non-selective; all organisms contained within the wrapping will be killed.

Black polyethylene plastic bale wrap (1 metre wide and 50 µm thick) is wrapped over the structures, with an overlap of approximately 0.4 m on each successive layer of wrap, and secured using PVC tape to achieve a watertight seal. Procedures for deploying the wrap on different structures and details on the costs involved with this treatment technique are provided in Aquenal (2007). The wrappings can remain in place for extended periods (up to 12 months), providing some protection from reinfection. Should the outside of wrappings become reinfested, their removal provides a second treatment option provided the animals can be retained when the wrap is removed.

Encapsulation or other containment techniques may also be used in combination with chemical treatment to achieve faster kill rates. Chemicals are injected into the covered area to maintain elevated concentrations of the biocide in close proximity to the fouled surface (Aquenal 2007).

6.1.2.4 Soft sediment habitats

Adult *Carcinus maenas* can live in soft-sediment habitats. New recruits tend to be found in the intertidal zone on hard substrata, in wet sand or loose gravel, and among seagrass beds. If it is found in soft sediment habitats, eradication methods can include manual removal and trapping (Aquenal 2007). Dredging is unlikely to be effective because of the mobile nature of *C. maenas* and dredging in Australian waters is restricted under the Environment Protection (Sea Dumping) Act 1981 unless consent is obtained from the Department of the Environment.

An alternative to sediment removal is smothering by deposition of uncontaminated dredge spoil (Aquenal 2007). Technical advice should be sought on the source, type and quantity of sediment needed to ensure mortality of crabs in treated areas. The efficacy of dredge spoil as a treatment option is also influenced by conditions at the site. It is most likely to be a viable option in sheltered areas where the seabed topography is relatively simple, to maximise persistence of capping. Deposited sediment will be dispersed rapidly in high energy, or highly complex habitats (such as rocky reef). The availability of a sufficient volume of uncontaminated dredge spoil should also be considered, along with any permits or government requirements (Aquenal 2007). However, because of the mobile nature of *C. maenas*, this treatment may not be effective in many habitats.

6.2 Open coastal environments

Carcinus maenas is rarely found in exposed, open coastal environments. It is most common in sheltered bays and estuaries. Limited emergency eradication response options are available to deal with marine pest incursions occurring in open coastal environments, particularly on high energy coastlines or in deep water (more than 10 m). Many treatment options described in [section 6.1](#) may be applied to small-scale incursions in these environments, but the main difficulties occur in containing the larvae and maintaining treatment conditions in a lethal state for sufficient time. The latter requires deployment of structures or application technologies that allow delivery of chemicals or encapsulation techniques over large areas and which are robust to water movement.

Successful eradication of small incursions may be possible using simple methods (such as manual removal, smothering, small-scale containment and chemical treatment) if the incursion is detected early or where site-specific conditions allow removal or containment of the *C. maenas* and treatment method.

6.3 Monitoring and ongoing surveillance

Monitoring and surveillance are used to detect new populations and to inform eradication and control programs. Active surveillance for the presence of *Carcinus maenas* in restricted and control areas should continue until the incursion is declared eradicated or until the emergency response is stood down. If a zoning program is implemented, it will be necessary to implement targeted active surveillance for the species outside the restricted and control areas to support declaration of zones free from *C. maenas*. The Australian Monitoring Design Package (Version 1c), including the [Australian marine pest monitoring manual and guidelines](#), should be used to help determine appropriate sampling intensity for ongoing surveillance.

Several methods may be appropriate for surveillance:

- systematic, targeted trapping of suitable or treated sub-tidal habitat within the restricted area or at sites at risk of infection using baited box traps, minnow traps and pitfall traps
- systematic, targeted searches by shoreline observers of suitable or treated intertidal habitat within the restricted area or at sites at risk of infection
- targeted searches and inspection of vessels and other vectors, including aquaculture stock and equipment, departing, or which have left, the control area
- regular monitoring of settlement within the restricted area or at sites at risk of infection using larval collectors ([Appendix C](#)) and visual surveys of intertidal habitats
 - larval collectors should be deployed from wharves, docks, moorings and buoys and near mussel beds, seagrass and filamentous algal patches
 - special attention in visual searches should be given to intertidal mussel and oyster beds that may provide food and shelter for 0+ crabs
- regular screening of plankton tow samples for *C. maenas* larvae using visual identification of larvae or the molecular probe currently under development for *C. maenas* ([Appendix C](#)).

Appendix A: Using the *Quarantine Act 1908* during an emergency response

The following (adapted from Ferguson 2000) is an interim process for using the *Quarantine Act 1908* (Cth) for action on vessels to treat contaminations by a marine pest of national significance. The Act should be used only in the absence of appropriate state or territory legislative powers. The Act may be used in certain circumstances to direct a vessel:

- into a port
- not to enter a port and to obey further direction
- to undergo treatment action deemed necessary by a biosecurity officer.

The conditions of using the Act are:

- the Australian Government Department of Agriculture and Water Resources is to be contacted before taking the proposed action to determine the appropriate provisions of the *Quarantine Act 1908* that apply
- directions to take action under the Act are to be given by a biosecurity officer
- actions under the Act should only be taken for vessels currently recognised as at risk of spreading a marine pest of national significance.

Responsibility for directing and approving action under the Act rests with the biosecurity officer, but the actual vessel control and treatment actions are handled by the Operational Pest Control Centre. Information that should be provided to the Australian Government Department of Agriculture and Water Resources to help determine appropriate application of the Act includes:

- the proposed course of action
- the location of proposed action
- details to identify the vessel involved in the proposed action
- contact details of local management agencies that will be managing the vessel control and treatment.

Appendix B: State and territory legislative powers of intervention and enforcement

The Intergovernmental Agreement on Biosecurity (IGAB), which came into effect in January 2012, is an agreement between the Australian, state (except Tasmania) and territory governments. The agreement was developed to improve the national biosecurity system by identifying the roles and responsibilities of governments and outlining the priority areas for collaboration to minimise the impact of pests and disease on Australia's economy, environment and community. The [National Environmental Biosecurity Response Agreement](#) was the first deliverable of the IGAB and sets out emergency response arrangements, including cost-sharing arrangements, for responding to biosecurity incidents primarily affecting the environment and/or social amenity and when the response is for the public good. In combination with the IGAB, all states and territories are responsible under their principle fisheries management legislation to respond consistently and cost-effectively to a marine pest incursion.

Table B1 State and territory legislation covering emergency response arrangements

Jurisdiction	Agency	Principle fisheries management Acts	Marine pest contact website
Commonwealth	Department of Agriculture and Water Resources	<i>Fisheries Management Act 1991</i>	agriculture.gov.au/fisheries
New South Wales	NSW Department of Primary Industries	<i>Fisheries Management Act 1994</i> Fisheries Management (General) Regulation 2010 Fisheries Management (Aquaculture) Regulation 2012 <i>Ports and Maritime Administration Act 1995</i> <i>Marine Parks Regulation 1997</i> <i>Marine Safety Act 1998</i>	dpi.nsw.gov.au/fishing/pests-diseases
Victoria	Victorian Fisheries Authority	<i>Fisheries Act 1995</i> (protection of fisheries) <i>Environment Protection Act 1970</i> (management of ballast water) <i>Marine Safety Act 2010</i> (power of Harbour Masters to direct vessels and duty of harbour masters to minimise adverse impacts on environment)	vfa.vic.gov.au/operational-policy/pests-and-diseases/noxious-aquatic-species-in-victoria

Jurisdiction	Agency	Principle fisheries management Acts	Marine pest contact website
		<i>Port Management Act 1995</i> (where no harbour master appointed, powers to direct vessels and act to minimise adverse effects on the environment)	
Queensland	Department of Agriculture and Fisheries	<i>Fisheries Act 1994</i>	daff.qld.gov.au/fisheries/
South Australia	Primary Industries and Regions SA	<i>Fisheries Management Act 2007</i>	pir.sa.gov.au/biosecurity/aquatics
Western Australia	Department of Fisheries	<i>Fish Resources Management Act 1994</i> (under review)	fish.wa.gov.au/Sustainability-and-Environment/Aquatic-Biosecurity/Pages/default.aspx
Tasmania	Department of Primary Industries, Parks, Water and Environment	<i>Living Marine Resources Management Act 1995</i>	dpiwwe.tas.gov.au/biosecurity-tasmania/aquatic-pests-and-diseases
Northern Territory	NT Department of Primary Industry and Resources	<i>Fisheries Act 1988</i>	nt.gov.au/d/Fisheries/index.cfm?header=Aquatic%20Biosecurity

Appendix C: Using plankton samples to detect *C. maenas* larvae

Guidelines for collecting and preserving plankton samples to detect and quantify *Carcinus maenas* larvae. The material in this appendix is sourced from Bax et al. 2006 and Queiroga et al. 1994.

Plankton samples should be collected using a 70 cm diameter, 100 µm mesh bongo net. To gather samples, tow the bongo net behind a vessel obliquely from the sea floor (if shallower than 10 m depth) to the water surface. Tow duration may vary between two and 10 minutes, depending on the biomass obtained in the samples. A mechanical flow meter should be fitted to the net frame and used to estimate the volume of water filtered for each tow. After each deployment, the net should be rinsed using a bilge pump and the sample from each net washed in separate small 100 µm mesh net sieves to remove as much seawater as possible.

Alternatively, plankton samples may be obtained using a centrifugal, motor-driven pump with a throughput of about 0.5 m³/minute (Queiroga et al. 1994). Pump output should be measured and kept approximately constant for all samples. Samples should be taken throughout the top 20 m of the water column at 1 metre depth intervals or greater, but no closer than 0.5 m from the bottom. Water retrieved by the pump should be passed through a 500 µm net to retain the larvae. After each deployment, the net should be rinsed using a bilge pump and the sample from each net washed in separate small 100 µm mesh net sieves to remove as much seawater as possible.

Samples that are intended to be sorted visually should be preserved in 4% buffered formaldehyde immediately after collection.

Samples that will be analysed using the molecular probe should not be put into formalin. Instead, they should be rinsed into sample jars with SET-buffered, reagent-grade ethanol, ensuring that the ratio of biomass to SET buffered ethanol is no more than 1 to 3.

Each sample should be labelled with:

- details of the location in which it was collected (latitude and longitude)
- the method used to collect the sample (plankton tow or pump)
- the sample identifier (such as number in sequence of samples)
- the date collected
- the name of the collector.

Additional information collected with the sample (such as environmental variables, tow speed and duration, depth of collection) should be recorded separately and should also include details of the date of collection, the sample identifier, the method used and location details.

Appendix D: Collecting and preserving *C. maenas* post-larvae samples

Guidelines for collecting and preserving samples of *Carcinus maenas* post-larvae (megalopae) for detection and quantification. The material in this appendix is sourced from Metcalf et al. 1995 and Moksnes et al. 1998.

Crab post-larval collectors consist of a cylindrical PVC frame (38 to 40 cm long by 10 to 20 cm diameter) covered with a removable sheath of air-conditioning filter material (loosely interwoven polypropylene 'hog's hair'). They are weighted at the bottom and suspended from floats so they remain vertical in the water and are within 10 cm of the water surface. They can be deployed from jetties, pontoons and other fixed structures but care must be taken to ensure they do not rub or knock against structures as the tide and current move. Alternatively, they may be deployed from weighted, buoyed lines.

Each collector is deployed in the morning and left for 24 hours (overnight). They are retrieved by rope and/or using a dipnet. At least three collectors are deployed at each location.

Once removed from the water, each collector is placed in a separate bucket. The bucket is filled with fresh water and the sheath removed and left to soak in the bucket for 20 minutes. The sheath is removed and rinsed with fresh water into a second bucket. The water from the first bucket in which the sheath was soaked and the water from the rinsing in the second bucket is then carefully passed through nested 3 mm and 0.5 mm mesh sieves. Material retained on the sieves should be rinsed into sample jars with SET-buffered, reagent-grade ethanol, ensuring that the ratio of biomass to SET-buffered ethanol is no more than 1 to 3.

Alternatively, if the samples are intended to be sorted visually and molecular analysis is not needed, they should be preserved in 4% buffered formaldehyde immediately after collection.

Appendix E: Chemicals and applications achieving *C. maenas* mortality

Table E1 Concentrations and exposure durations of chemicals to achieve mortality in *Carcinus maenas* under laboratory conditions

Chemical	Mortality endpoint	Exposure duration (days)	Exposure type	Concentration (µg/L)	Concentration minimum (µg/L)	Concentration maximum (µg/L)	Reference
Phosphorodithioic acid, O,O-Dimethyl S-[2-(methylamino)-2-oxoethyl] ester	LC50	2	Renewal	NR	0.3	1	Portman & Wilson 1971
(1a alpha, 2 beta, 2a alpha, 3 beta, 6 beta, 6a alpha, 7 beta, 7a alpha)-3,4,5,6,9,9-Hexachloro-1a,2,2a,3,6,6a,7,7a-octahydro-2,7:3,6-dimethanonaphth[2,3-b]oxirene	LC50	2	Renewal	NR	10	33	Portman & Wilson 1971
Formic acid	LC50	2	Renewal	NR	80,000	90,000	Portman & Wilson 1971
Acetic acid	LC50	2	Renewal	180,000	NR	NR	Portman & Wilson 1971
Hydroxytriphenylstannane	LC50	4	Static	464,900	319,100	677,300	Office of Pesticide Programs 2000
2-Hydroxy-1,2,3-propanetricarboxylic acid	LC50	2	Renewal	160,000	NR	NR	Portman & Wilson 1971
O,O,-Dimethyl S-(4-oxo-1,2,3-benzotriazin-3(4H)-yl) ester, Phosphorodithioic acid	LC50	2	Renewal	NR	33	100	Portman & Wilson 1971
Phenol	LC50	2	Renewal	56,000	NR	NR	Portman & Wilson 1971
6-Chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine	LC50	2	Renewal	10,000	NR	NR	Portman & Wilson 1971
Potassium cyanide	LC50	2	Renewal	5,000	NR	NR	Portman & Wilson 1971
Thiocyanic acid, sodium salt	LC50	2	Renewal	500,000	NR	NR	Portman & Wilson 1971
1,2,3,4,5,6-Hexachlorocyclohexane	LC50	2	Renewal	100,000	NR	NR	Portman & Wilson 1971
2,6-Dichlorobenzonitrile	LC50	2	Renewal	10,000	NR	NR	Portman & Wilson 1971
Sodium sulfide	LT50	1.3	Static	50,000	NR	NR	Theede et al. 1969

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Chemical	Mortality endpoint	Exposure duration (days)	Exposure type	Concentration (µg/L)	Concentration minimum (µg/L)	Concentration maximum (µg/L)	Reference
6-Chloro-N-ethyl-N'-(1-methylethyl)-1,3,5-triazine-2,4-diamine	LC50	2	Renewal	10,000	NR	NR	Portman & Wilson 1971
Copper ^a	LC50	4	Static	51,800	NR	NR	Elumalai et al. 2002
Cupric chloride	LT50	5	Renewal	10,000	NR	NR	Bjerregaard & Vislie 1986
Mercuric chloride	LC50	2	Renewal	1,200	NR	NR	Portman & Wilson 1971
Cobalt chloride	LC50	4	Static	227,000	227,000	454,000	Amiard 1976
Zinc chloride	NR-LETH	5	Injection	2	NR	NR	Martin & Rainbow 1998
Hydrochloric acid	LC50	2	Renewal	240,000	NR	NR	Portman & Wilson 1971
Sulfuric acid	LC50	2	Renewal	NR	70,000	80,000	Portman & Wilson 1971
Nitric acid	LC50	2	Renewal	180,000	NR	NR	Portman & Wilson 1971
Sulfuric acid, zinc salt (1:1)	LC50	2	Static	1,000	NR	NR	Connor 1972
Sulfuric acid, copper(2+) salt(1:1)	LC50	2	Renewal	109,000	NR	NR	Portman & Wilson 1971
Sulfuric acid, copper(2+) salt(1:1)	LC50	2	Static	600	NR	NR	Connor 1972
Nitric acid, silver (1+) salt	LC50	4	Static	6.35	NR	NR	Amiard 1976
Chromic acid, disodium salt	MATC	12	NR	NR	40,000	60,000	Raymont & Shields 1963
Sulfuric acid, nickel(2+)salt (1:1)	LC50	2	Renewal	255,000	NR	NR	Portman & Wilson 1971
alpha-(Nonylphenyl)-omega-hydroxypoly(oxy-1,2-ethanediyl)	LC50	2	Renewal	100,000	NR	NR	Portman & Wilson 1971
alpha-[(1,1,3,3-Tetramethylbutyl)phenyl]-omega-hydroxypoly(oxy-1,2-ethanediyl)	LC50	2	Renewal	100,000	NR	NR	Portman & Wilson 1971
Antimony trichloride	LC50	4	Static	NR	534	5340	Amiard 1976
Chlorine oxide	LC50	2	Renewal	500,000	NR	NR	Portman & Wilson 1971
Cadmium chloride	NR-LETH	7	Injection	2.9	NR	NR	Martin & Rainbow 1998
Strontium chloride	LC50	4	Static	NR	5,530	55,300	Amiard 1976

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Chemical	Mortality endpoint	Exposure duration (days)	Exposure type	Concentration (µg/L)	Concentration minimum (µg/L)	Concentration maximum (µg/L)	Reference
Gamlen Oil spill remover	LC50	2	Static	20,400	NR	NR	Portman & Connor 1968
BP 1002	LC50	2	Static	15,000	NR	NR	Portman & Connor 1968
Sodium vanadate	LC50	9	Renewal	35,000	NR	NR	Portman & Connor 1968
N-[[[4-Chlorophenyl]amino]carbonyl]-2,6-difluorobenzamide	LC50	4	Static	1,000,000	NR	NR	Portman & Connor 1968
Essolvane	LC50	2	Renewal	NR	10,000	33,000	Portman & Connor 1968
Atlas 1901	LC50	2	Static	150,000	NR	NR	Portman & Connor 1968
Cleansol	LC50	2	Renewal	NR	100,000	330,000	Portman & Connor 1968
Dermol	LC50	2	Static	435,000	NR	NR	Portman & Connor 1968
Polyclens	LC50	2	Static	23,200	NR	NR	Portman & Connor 1968
Slickgone 1	LC50	2	Renewal	NR	3,300	100,000	Portman & Connor 1968
Slickgone 2	LC50	2	Static	21,300	10,000	NR	Portman & Connor 1968
Slix	LC50	NR	Renewal	330,000	NR	NR	Portman & Connor 1968
Dobs 055	LC50	2	Renewal	100,000	NR	NR	Portman & Wilson 1971

^a test was performed in freshwater rather than seawater.

LC50 lethal concentration to 50% of organisms. **NR-LETH** 100% mortality of organism. **MATC** maximum acceptable toxicant concentration. **LT50** time to 50% mortality of organism, **NR** not recorded.

Source: US EPA 2008

Glossary

Term	Definition
CCIMPE	Consultative Committee on Introduced Marine Pest Emergencies
EMPPan	Emergency Marine Pest Plan
IMO	International Maritime Organization
NBIRP	National biosecurity incident response plan
NEBRA	National Environmental Biosecurity Response Agreement
NIMPIS	National Introduced Marine Pest Information System
RRM	Rapid response manuals

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