(HYPOTHETICAL) ASIAN GREEN MUSSEL (*PERNA VIRIDIS)* INCURSION
Benefit – cost analysis for NEBRA

Summary

Asian green mussel has been detected in three ports in Queensland and in Darwin (NT). A benefit-cost analysis has been carried out which indicates that eradication would be a more cost-effective option than allowing the organism to become established.

Key Points

- Asian green mussel was detected in on a vessel on a slipway in Cairns and another vessel in Gladstone. A small isolated population was found in Brisbane.
- The costs of surveys to determine whether populations have become established in Cairns and Gladstone are estimated at $52,000 and $25,000 respectively.
- The total cost of a survey to delimit the extent of the population in Brisbane, eradicating the known population and a follow-up survey to confirm eradication is estimated at $61,000.
- Total response costs are therefore $138,000
- Impact costs, with no treatment, are estimated at about $800,000 for direct impacts and about $24 million for impacts on non-market values within the Great Barrier Reef Marine Park.

Recommendation

That it be noted that the benefit-cost ratio is strongly in favour of eradication as the preferred response to the incursion of Asian green mussel.

Background to Recommendation

1. Asian green mussel (*Perna viridis*) is a fouling species of mussel with the following biological characteristics:
   - Occupies the inter-tidal zone to a depth of 20 m (NIMPIS)
   - Large size: 80 – 100 mm shell (NIMPIS)
   - Highly fecund – can breed twice a year (NIMPIS)
   - Larval duration: 10 – 21 days (Shanks, 2009)
   - Larval dispersion: 33 km (Shanks, 2009)
   - Sexual maturity: 15-30 mm shell length (2 – 3 months age) (NIMPIS)
   - Forms dense colonies with densities of individuals up to 12,000 m2 (McDonald, 2012)
   - Generally colonises hard surfaces, e.g. wharves, jetties, vessel hulls and inside industrial pipework (NIMPIS).
2. *Perna viridis* has been assessed as a priority marine pest species that may cause significant impacts if they were introduced, established and spread in Australia. .
3. Typical impacts include:

   - Direct impacts on vessel performance (fuel consumption) and handling.
   - Fouling of industrial plant, power stations and desalination plants
   - Outcompeting native species
   - Fouling urban infrastructure including water inlets and water and sewage outlets

- High levels of accumulated toxins and heavy metals and linked to shellfish poisoning in humans (NIMPIS)

4. Only a limited number of potential impacts were costed when it became clear that the response costs were relatively small and that potential impacts were likely to be very large.
5. The full benefit-cost analysis is attached as Appendix 1 to this document.

Appendix 1: Case study.

Hypothetical Invasion Scenario. *Perna viridis*

On 2 May 2017 the Queensland Department of Fisheries confirmed the identity of Asian green mussels (*Perna viridis*) found on a vessel (Vessel X) that was being slipped in Cairns (Trinity Inlet). The mussels were between 25mm - 40mm long and expert opinion is that they were approximately 2-5 months of age. The vessel had initially arrived in Cairns on 12 February 2017 but had travelled to other Queensland locations before returning to Cairns for maintenance. Since 12 February, the vessel has been in Gladstone, Brisbane and Darwin before being slipped in Cairns. The source of the mussels could possibly be Singapore, where the vessel was located on 29 January - 2 February or Cairns, where a small incursion was detected in 2015, but subsequently believed to be eradicated. Following further investigations 12 individuals of *P.viridis* were found on a vessel (Vessel Y) in Gladstone located close to where vessel X had moored. There was also an isolated population detected on an artificial structure in Brisbane.

The species is listed on the Australian Priority Marine Pest List and deemed nationally significant by the National Biosecurity Management Group. Based on the delimitation surveys undertaken in Gladstone, Brisbane and Darwin the National Biosecurity Management Group on the advice of CCIMPE has deemed that it is deemed technically feasible to eradicate.

Table 1 Major steps in undertaking a benefit-cost analysis.

Step	Actions	NEBRA key requirements
1	Specify the option(s).	2.1 Statement of Context
2	Decide whose costs and benefits count.	2.5 Consideration of Equity
3	Identify impacts (benefits and costs).	2.2 Identification of likely impacts of the threat and proposed response
4	Predict the impacts over time.	2.2 Identification of likely impacts of the threat and proposed response
5	Attach dollar values to impacts	2.3 Quantification of impacts of the threat and proposed response
6	Determine response costs	Nil. N.B. Response actions will be in NBIRP
7	Discount and compare costs and benefits of alternatives.	2.3 Quantification of impacts of the threat and proposed response; Part (c) Explain and justify the choice of discount rate
8	Calculate the costs and benefits using net present value.	nil
9	Perform sensitivity analysis.	2.4 Risk and Uncertainty 2.6 Transparency and accountability; Part (b) a critique to test the significance of all known assumptions, biases, and omissions
10	Assess the BCA and reach a conclusion.	nil

1. Specify the option(s).

- Confirm the national incident response plan
- Identify the base case

Additional investigation into the attributes of Trinity Inlet revealed the following key information:

1. AGM was only found on the ship's hull when it was slipped in Cairns. Investigations will be required to determine whether it has been moored alongside a wharf before it was slipped. Similarly, it will be necessary to determine where the vessel was kept when it first arrived in February. Surveys will be carried out in those locations if they are adjacent to infrastructure, e.g. a wharf. If the vessel was moored in the channel it is less likely that mussels will have become dislodged. There is, however, a risk that a spawning event may have occurred. Rajagopal et al.(2006), in their review of the success of *P. viridis* as an invasive species, note that it in some localities it has two distinct breeding seasons (centred on May (summer) and October (autumn) in the northern hemisphere). There is evidence that these are linked to increases in water temperature. If a similar scenario occurs in Cairns, where May equates to November in the northern hemisphere, it could be expected that a spawning event could have occurred when the vessel arrived in Trinity Inlet immediately before being slipped. This provides additional rationale for a survey in Trinity Inlet.

2. There was an incursion of *P. viridis* in Cairns in 2001-2003 on an apprehended foreign fishing vessel (FV *Wing Sang 108*). There is evidence that the organisms on the vessel reproduced at least once however only a very small number of individuals were found in Trinity Inlet and it was eventually concluded that the species had failed to become established (Stafford et al., 2007).

3. Vessel X is presumed to be the source of mussels found on Vessel Y in Gladstone. It is not clear how these mussel were discovered, whether it was by Vessel Y being slipped or observation from the ship or wharf. It will be necessary to determine where Vessel X was moored in Gladstone and for the surroundings to be inspected.

4. Similarly, although there are no reports from Darwin, it will be necessary to contact authorities in Darwin to determine where Vessel X was moored in Darwin and for the surroundings to be inspected.

5. An "isolated population" has been detected on an artificial structure in Brisbane. Unless surveys in Cairns, Gladstone and Darwin reveal populations there, this should be the focus of the eradication effort. No information is available yet on the location of this structure in Brisbane. All locations are well within the modelled maximum potential range of *P. viridis* (Figure 1).

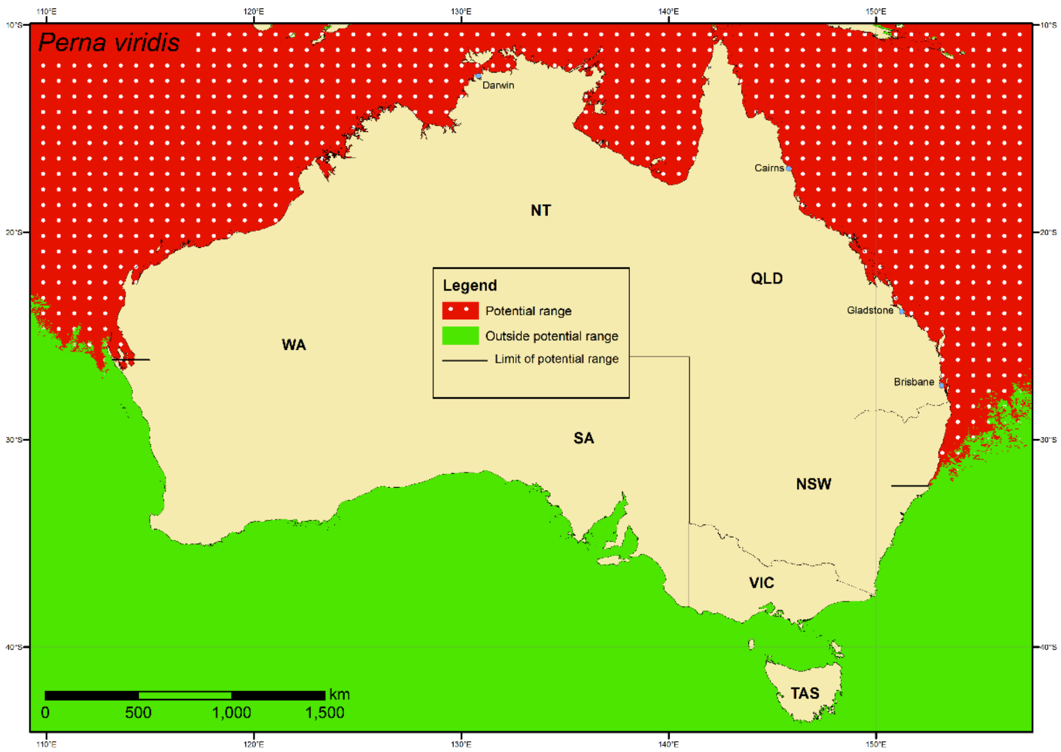

Figure 1. Modelled maximum potential range of *Perna viridis*, based on water temperature. **Source: Richmond et al. 2010.**

5. The source of the mussels infesting the hull of Vessel X has been speculated as being either Singapore, which the vessel visited in late January – early February, or from a previous incursion in Cairns. As noted above, since the incursion in 2001-03 in Cairns there have been no further detections so it seems highly unlikely that this is the case. It is much more likely that the hull was colonised during the visit to Singapore, which is well within *P. viridis*' native range and is known to harbour large populations. The age of the mussels on Vessel X are consistent with recruitment in Singapore.

6. The elapsed time between the discovery of the mussels on Vessel X is more than sufficient for them to reproduce and establish a founder population and for the latter to be a sufficient size to be detectable.

Eradication

Eradication of AGM will involve the following initial key actions:

- Surveys in Cairns and Gladstone to determine whether *P. viridis* has established a founder population.
- Delimitation survey in Brisbane to determine the limits of the incursion.
- Eradication attempt in Brisbane.
- Post-eradication survey in Brisbane

The 'do nothing' counterfactual

This is the situation that would most likely exist if the pest were allowed to spread unmanaged.

On the basis of two recent publications, the ‘do nothing’ scenario seems to be a reasonable approach. Heersink et al. (2015) demonstrate that despite a high approach rate (propagule pressure), *P. viridis* appears to have difficulty in becoming established in Australia. The failed incursion in Cairns in 2001-03 is a case in point. The authors were only able to speculate on the reason for this, suggesting that it may be due to predation, competition or some other factor. Similarly, Wells (2017) asks “If the Asian green mussel, *Perna viridis*, poses the greatest invasive marine species threat to Australia, why has it not invaded?” To date, no answers are forthcoming. It would, however, be a high risk strategy to assume, with no other information, that this species could not become established in Australia and therefore to take no action. Understanding the conditions for successful establishment of an invasive species remains elusive. There is however evidence that a combination of favourable conditions (particularly in disturbed habitats) and propagule pressure (multiple incursions) may lead to the establishment of a viable population (e.g. Wonham et al., 2013).

2. Determine the costs of the response action

The form of the incursion response will be laid out in the national biosecurity incident response plan (NBIRP). This section is to calculate (estimate) the costs of the NBIRP.

Five response actions are planned:

1. In-water survey of port infrastructure in Cairns

It is estimated that five days will be required to conduct a survey by diver covering the wharves along Trinity Inlet, Marlin Marina, the shoreline along Chinaman Creek and random inspections of vessels moored on the eastern side of Trinity Inlet (**Error! Reference source not found.**). The water visibility in Trinity Inlet is generally poor so it is not anticipated that every square metre could be reliably seen.

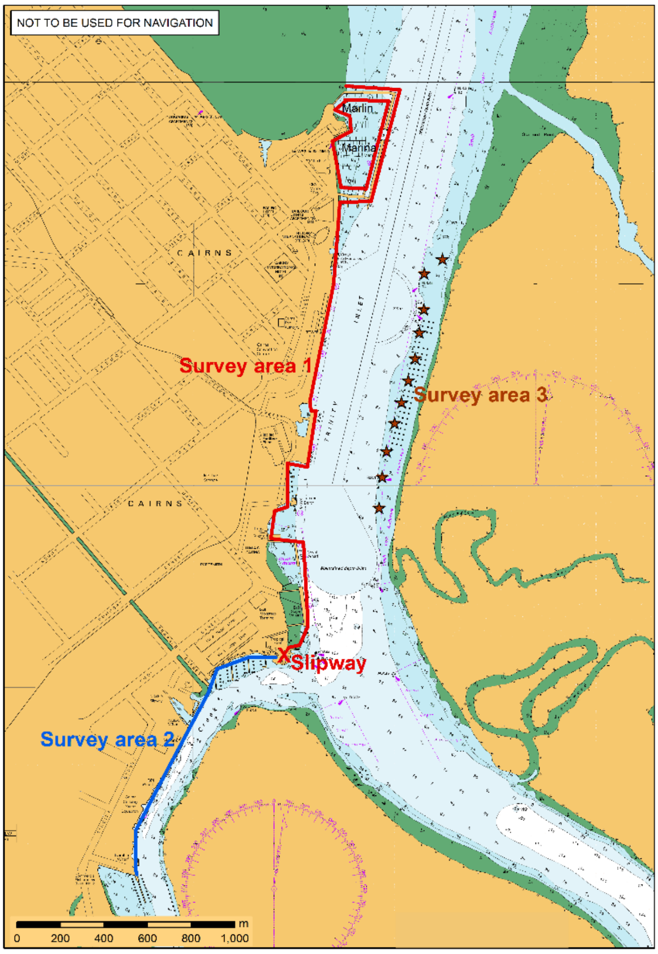

Figure 2. Location of the shipyard in Cairns where Vessel X was slipped and the three proposed survey areas. Source: RAN Hydrographic Service charts AUS 263 & 264.

The wharf and shoreline frontage from Tropical Reef Shipyard where Vessel X was slipped to the offshore outer edge of Marlin Marina is about 3 km. If this could be inspected at the rate of one kilometre per day, which equates to 167 metres per hour or 2.8 m per minute, that would take three days. This would include inspections inside Marlin Marina. Similarly, the western shoreline of Chinaman Creek could also be inspected for a distance of about 1 km upstream. A further day could be spent randomly inspected some of the recreational vessels

moored along the eastern side of Trinity Inlet. It is anticipated that the survey will be carried out by commercial divers but could be done with an ROV is a risk assessment rules out the use of divers.

In addition to a diver survey, a shoreline inspection will be carried out at low tide on both banks of Trinity Inlet – the east bank as far as it is possible and safe to do so.

If any *P. viridis* are encountered in small numbers, they will be removed by the divers on the spot and collected in a dive bag. The location(s) will be recorded for follow-up action if necessary or monitoring in the future.

Costs: The estimated cost for a survey team for one day, including diver, supervisor, standby/attendant and support vessel and coxswain is $6000. This is based on a six hour day.

The total cost of the diver survey is therefore $30,000.

The cost of a shoreline survey is approximately one day for two people. The daily rate is $1000. The total cost is therefore $2000.

In addition to the visual surveys, five settlement plate arrays are to be deployed under the wharves on the western side of Trinity Inlet and in Marlin Marina. Construction, deployment, monitoring, retrieval and sorting and identification are estimated to cost $4000 per array – a total of $20,000.

The total cost for the survey of Cairns is therefore $52,000.

2. In-water survey of port infrastructure in Gladstone

The exact location of Vessel Y when it became infested with *P. viridis* is not known, nor what type of vessel it was. Given the maximum size of vessel that the shipyard in Cairns can handle is 100 m length, that suggests that it is not a large trading vessel. The implication of this is that most of the wharves in Gladstone are dedicated to handling large bulk carriers and tankers. Only the Auckland Point wharves and the Boat Harbour are intended to cater for smaller vessels. Two survey areas have been identified: Auckland Point wharves and Gladstone Boat Harbour (**Error! Reference source not found.**).

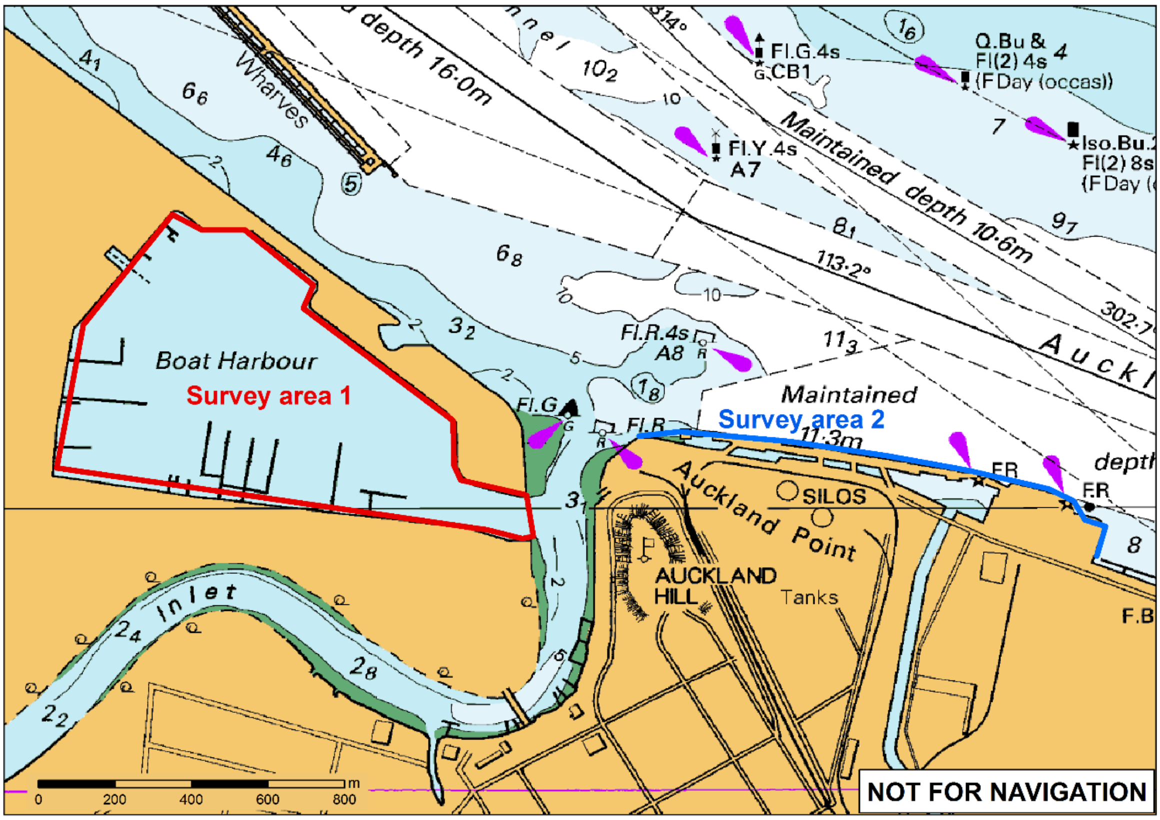

Figure 3. Gladstone Harbour: Gladstone Boat Harbour and Auckland Point – survey areas 1 & 2. **Source: RAN Hydrographic Service chart AUS 245.**

The perimeter of Survey area 1 is about 3 km and the length of Survey area 2 is about 1.2 km. Given the length of time that has elapsed since Vessel Y was found to be infested (and subsequently cleaned) it is planned to initially survey the shoreline of the Boat Harbour on foot and charter a dive crew for one day to survey the wharves and other infrastructure in the Boat Harbour. In addition, it is planned to conduct a rapid survey of the Auckland Point wharves (Survey area 2) on an opportunistic basis between ship visits. It is hoped that this can be achieved in one day but two days will be allowed for. A total of three days' dive team is therefore planned for. **Error! Reference source not found.** shows two views of Gladstone Harbour.

Figure 4. Gladstone Boat Harbour (L) and Auckland Point wharves (R). **Source: Janet Hughes.**

If any *P. viridis* are encountered in small numbers, they will be removed by the divers on the spot and collected in a dive bag. The location(s) will be recorded for follow-up action if necessary or monitoring in the future.

Costs: The estimated cost for a survey team for one day, including diver, supervisor, standby/attendant and support vessel and coxswain is $5000 (less expensive than in Cairns). This is based on a six hour day.

The total cost of the diver survey is therefore $15,000.

The cost of a shoreline survey is approximately one day for two people. The daily rate is $1000. The total cost is therefore $2000.

In addition to the visual surveys, three settlement plate arrays are to be deployed, two under the Auckland Point wharves and one in Gladstone Boat Harbour. Construction, deployment, monitoring, retrieval and sorting and identification are estimated to cost $4000 per array – a total of $8,000.

The total cost for the survey of Gladstone is therefore $25,000.

3. Delimitation survey of the "isolated population detected on an artificial structure in Brisbane"

The exact location of the infestation in Brisbane has not been specified but an assumption has been made that it is the TSHD (trailing suction hopper dredge) *Brisbane* Service Area at the southern end of the General Purpose Wharf that has become infested with *P. viridis* (Figure 5**Error! Reference source not found.**).

Figure 5. TSHD *Brisbane* service area, Port of Brisbane. Source: ABARES

The *Brisbane* is a trailing suction hopper dredge. Its primary function is to maintain the channel into Brisbane and along the wharf front but it is periodically contracted out to other ports. It was recorded in Cairns, which also has a dredged channel, in August and September 2016 and spent extensive periods in Gladstone in October 2016. Its movements in 2017 are not yet known. A dredge arriving in Geraldton in 2002 was found to be extensively fouled, including with four species of molluscs (Wells et al., 2009).

The *Brisbane* service area (**Error! Reference source not found.**) is 145 m long and comprises a small wharf (15 x 20 m), 7 pylons with decking and at least one dolphin (standalone mooring structure). The pylons appear to be made of concrete. 5 are square with each face approximately 2.5m, and one is about 4 m square and the other 5 m square. It is assumed that the wharf has solid faces.

Water turbidity in the Brisbane River is generally high; Fearon and O'Brien (2001) report that visibility varied between 0.15 m and 0.8 m, which is sufficient to identify *P. viridis*, however.

Figure 6. TSHD *Brisbane* service area wharf. The long narrow structure is 145 m long.
Source: Google Maps

The area to be surveyed to delimit the extent of the incursion should be the length of the TSHD *Brisbane* service area, the shoreline behind it southwards for at least 100 m and northwards behind the General Purpose and Coal wharves for a distance of 500 m. The General Purpose and Coal wharves should be inspected by diver and possibly also the dolphin that comprises the Caltex crude oil wharf. The BP crude oil wharf on the other side of the river and the northern headland of Bulwer Island should also be inspected (Figure 7). **Error! Reference source not found.** lists the types of surveys required at each site and the estimated time taken.

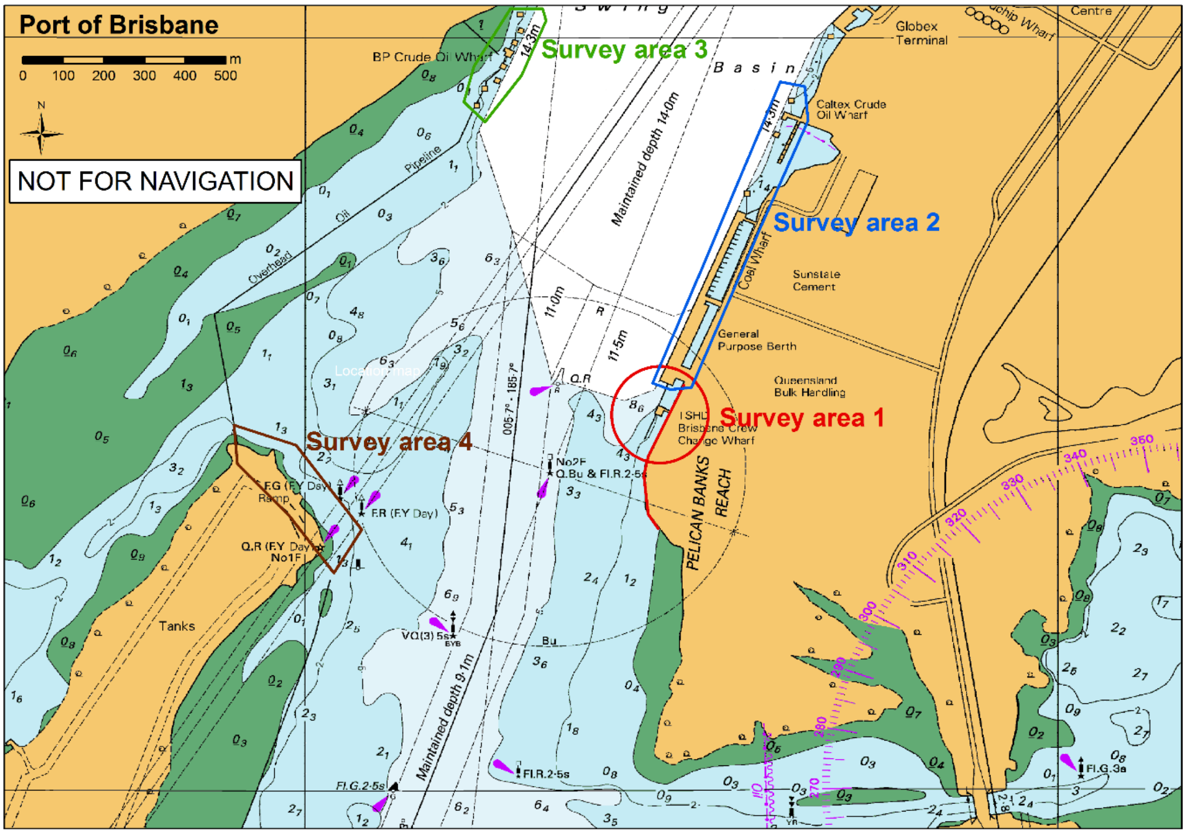

Figure 7. Brisbane incursion delimitation survey areas.

Source: RAN Hydrographic Service chart AUS 237.

Table 2. Brisbane incursion delimitation surveys.

Survey area	Name	Type of survey	Time
1. (incursion site)	TSHD Brisbane Service area	Diver Shoreline survey	8 hours 1 hour
2.	General purpose and coal wharves	Diver Shoreline survey	8 hours 1 hour
3.	BP Crude oil wharf and overhead oil pipeline supports	Diver	8 hours
4.	Bulwer Island	Shoreline survey	1 hour

As noted above, divers are generally contracted for a day (approximately 8 hours) so it seems feasible to conduct the diver surveys within one 8 hour day, assuming that access to the wharves is possible within one period of time. The cost of a team of divers, including work boat, is approximately $5,000 for one day's work. The diver survey costs are therefore $15,000.

The shoreline surveys could be carried out by two people in half a day though that does not take into account the time taken to drive across the river. It is therefore estimated that the shoreline surveys would take a total of one day for two people, which at a cost of $1000/day would cost $2000.

The total cost for the survey of Brisbane delimitation survey is therefore $17,000.

4. Eradication of the population in Brisbane

Assuming that the delimitation survey found no further infestations outside the TSHD *Brisbane* wharf and jetty then there is no reason why the eradication should not follow straight on from the delimitation survey. It is assumed that the incursion is restricted to the TSHD *Brisbane* wharf and adjacent pylons, and is in isolated patches. Given that the incursion is described as “an isolated population”, which implies a small population, the most effective method of eradication will be manual removal by divers using scraper tools and nets/bags to catch the debris.

The tidal range in Brisbane on 14 November 2017 (today’s date) is 1.54 m. *P. viridis* can colonise water depths down to 20 m below the surface; the water depth in the area of the TSHD *Brisbane* wharf is greater than 5 m north of the wharf and less than 5 m south of the south so the pylons and wharf need to be examined and cleared to the full depth of the water column. The area/time calculations are given in Table 3.

Table 3. Eradication area dimensions and time estimations.

ID	Description	Dimensions (approx.)	Surface area (m^2)	Time (hours)
1	Northern end	3 x 3 x 5 m	60 m^2	1 - 2
2	Next southward	3 x 3 x 5 m	60 m^2	1 - 2
3	Larger pylon	4 x 4 x 5 m	80 m^2	2 - 3
4	Next southward	3 x 3 x 5 m	60 m^2	1 - 2
5	Wharf	22 x 17 x 5 m	390 m^2	6 - 12
6	Pylon south of wharf	3 x 3 x 5 m	60 m^2	1 - 2
7	Next southward	3 x 3 x 5 m	60 m^2	1 - 2
8	Southernmost pillar	4 x 4 x 5 m	80 m^2	2 - 3

The total time required is therefore 15 - 28 hours. Taking the worst case scenario, 28 hours, and a seven hour day, eradication is estimated to take 4 person/days. At a cost of $5000/day, **the cost of eradication is $20,000**.

5. Post-eradication survey in Brisbane

A post-eradication survey should be carried out 10 – 12 weeks after the eradication. This will allow sufficient time for any larvae that might have been in the water column to settle and grow large enough to be detectable but, hopefully, before they are able to reproduce. The focus of the post-eradication survey should be in and around Survey Area 1 as the first priority in case some individuals were missed during the eradication attempt. Survey Area 2 should also be examined. Again these surveys should be done with a combination of divers and shoreline surveys and it is estimated that two days will be required for a thorough survey. The cost for the divers will therefore be $10,000, and $1000 for the shoreline surveys.

In addition to the post-eradication surveys, five settlement plate arrays are to be deployed: one at TSHD *Brisbane* wharf, two under the general purpose and coal wharves, one under the BP crude oil wharf and one at the northern end of Bulwer Island. Construction, deployment, monitoring, retrieval and sorting and identification are estimated to cost $2500 per array – a total of $12,500.

The total cost for the post-eradication survey in Brisbane, including the deployment of settlement arrays, is therefore $21,000.

6. Total cost of incursion response

The total cost of the response is summarised in Table 4. It has been assumed that, for example, no detections were made in Cairns or Gladstone that would necessitate an eradication attempt and that the eradication attempt in Brisbane was successful at the first attempt. It should be noted that

Table 4. Total response costs in Queensland

Location	**Cost**
Cairns	$52,000
Gladstone	$25,000
Brisbane	$60,500
TOTAL	**$137,500**

The response costs are limited to those incurred in Queensland. It is assumed that the Northern Territory will submit their own response costs.

The response costs are limited to the direct response costs, i.e. surveys and eradication and are principally the costs of divers plus the deployment of settlement plate arrays and the identification of the organisms that have settled on the plates. Indirect costs, such as moving TSHD *Brisbane* to another wharf or travel costs for Queensland Departmental staff visiting one or more locations have not been included as they are difficult to conceptualise in a hypothetical situation. If there are staff costs from the Department of Agriculture and Fisheries (Queensland), these will need to be added to the total costs.

3. Identify the impacts and select measurement indicators.

- **Identify and categorise the likely positive and negative impacts of the pest**
- **Consider how the impacts will be measured**

Identifying impacts

In this section the potential impacts of *P. viridis* are identified and impact measurement indicators are selected.

Impacts on business activity

Fouling vessels.

- Direct impacts on vessel performance (fuel consumption) and handling
- Costs of antifouling protection (already being done) – increased frequency of antifouling protection.
- Increased frequency of in-water cleaning.

Impact Measurement Indicator (IMI): dollars

Fouling of industrial plant, power stations and desalination plants

IMI: dollars

Impacts on the environment

- Outcompeting native species
- Changes in water quality

IMI: Dollars – benefit transfer

Impacts on people

- Fouling recreational vessels

IMI: dollars

Impacts on human health

- High levels of accumulated toxins and heavy metals and linked to shellfish poisoning in humans (NIMPIS)

IMI: dollars

Impacts on infrastructure

- Fouling urban infrastructure including water inlets and water and sewage outlets
- Fouling navigation buoys

IMI: dollars

Positive impacts

- *P. viridis* is a cultivated aquaculture species in many parts of the world.

4. Predict the impacts over time.

- **Use available models to predict natural and anthropogenically-assisted spread of the pest**
- **Detail assumptions behind modelling**
- **Highlight key uncertainties in spread predictions**

Natural spread

Figure 8 shows the area north and south of Cairns and the nearest ports in each direction. It is anticipated that, in the event of an incursion being discovered by the planned survey in Cairns, this area will be at the most immediate risk from natural dispersion over a period of roughly one to five years.

Smart (2013) developed a simple spread model for Trinity Inlet based on flow rates of the tidal prism in the inlet. He concluded that:

> "It is likely that, following the spawning of mussel [*Mytilopsis sallei*] larvae within Trinity Inlet, some of them would reach the ocean before the end of the five day development period. In fact, it is quite possible some of them could reach the ocean on the first run-out tide following spawning, depending on the size of the tide, the location of the spawning event and the rate of influx of freshwater into the estuary." Smart (2013).

The 9am and 3pm wind speed vs direction plots ("wind roses") provide a graphical representation of wind direction and speed. Figure 9 shows 9 am and 3 pm wind roses for Cairns in January and July. From these it can be seen that the prevailing wind is from the south and south-east which will tend to push the surface waters, and any larvae entrained in the surface waters, northwards.

Figure 8. Regional map of Cairns. See below for an explanation of the 33 km radius.
Source: ABARES.

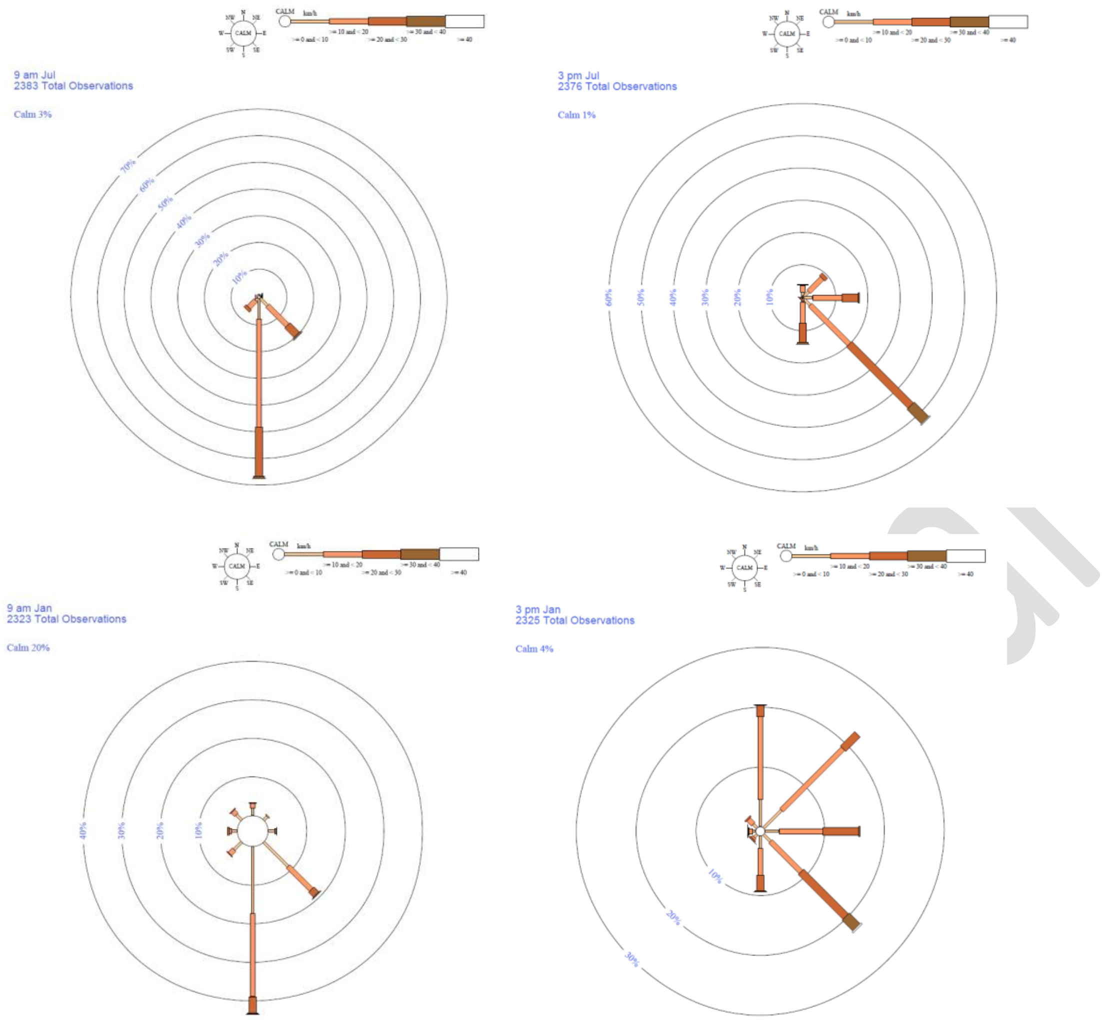

Figure 9. 9 am and 3 pm wind roses for Cairns in July (top) and January (bottom). Source: Bureau of Meteorology.

The larval duration (the period of time that the larval phase of *P. viridis* spends in the water column before settling and becoming an adult) is given as 2 – 3 weeks (Shanks, 2009) and 2 weeks (NIMPIS 2017). Shanks (2009) found that the dispersal distance of *P. viridis* is about 33 km. Figure 8 shows a distance of 33 km from Cairns. Assuming that sufficient larvae survived to form a new population at roughly the northern limit of the dispersal range and that the second generation was also dispersed northwards at the same rate the following year, it is feasible that it could reach Port Douglas, a distance of 60 km from Cairns, within two years. These are "heroic assumptions", not the least because of the questions raised by Heersink et al. (2015) and Wells (2017). It seems more likely that it would take an incursion at least five years to reach Port Douglas.

Anthropogenically-assisted spread

Commercial and non-trading vessels

Shipping traffic is one of the two principal vectors of invasive marine species, the other being recreational vessel traffic. Shipping traffic data are available from Lloyds List Intelligence; the Department has purchased data up to the end of 2016. Table 5 summarises shipping traffic from Cairns, Gladstone and Brisbane in 2016.

Table 5. Vessel traffic from Cairns, Gladstone and Brisbane in 2016. Only ports visited by two or more vessels have been included. (Lloyds Maritime Intelligence 2016).

Cairns		Gladstone		Brisbane	
Next port	Vessel count	Next port	Vessel count	Next port	Vessel count
Horn Is.	125	Brisbane	350	Port Kembla	310
Thursday Is.	83	Weipa	188	Gladstone	286
Townsville	54	Newcastle	61	Botany Bay	185
Cooktown	31	Townsville	42	Sydney	96
Darwin	24	Gove	42	Newcastle	78
Brisbane	22	Mackay	37	Townsville	49
Weipa	12	Hay Point	28	Weipa	43
Newcastle	8	Sydney	22	Cairns	28
Gladstone	7	Port Kembla	17	Mackay	26
Sydney	6	Cairns	10	Melbourne	25
Port Kembla	5	Launceston	9	Kurnell	17
Airlie Beach	4	Bell Bay	7	Airlie Beach	15
Broome	3	Abbot Point	6	Whitsunday Is.	15
Hay Point	2	Melbourne	5	Geelong	14
Hobart	2	Port Alma	4	Thevenard	13
Melbourne	2	Botany Bay	4	Port Alma	10
Milner Bay	2	Hobart	4	Adelaide	10
Port Douglas	2	Geraldton	2	Gove	9
		Bundaberg	2	Dampier	7
		Burnie	2	Hobart	7
		Geelong	2	Thursday Is.	5
		Hastings	2	Fremantle	5
				Bundaberg	5
				Tangalooma	4
				Kwinana	3
				Hastings	3
				Darwin	3
				Nganhurra Terminal	3
				Montara Field	3
				Vincent Field	2
				Hay Point	2
				Exmouth(AUS)	2
				Burnie	2
				Port Pirie	2
				Devonport	2
				Portland	2
				Pyrenees Field	2
				Pyrenees SPM	2
				Abbot Point	2

Source: Lloyds Maritime Intelligence.

Pathways

There are two main pathways for IMS in shipping:

- Ballast water
- Biofouling

Ballast water

Virtually all modern ships use ballast water for purposes of stability and trim. The large volumes of water carried, particularly by bulk carriers, have been implicated in to translocation of many invasive species (Bailey, 2015).

The larval duration of *P. viridis* is two to three weeks. The marine area potentially suitable for *P. viridis* to become established is from Shark Bay (WA) to Coffs Harbour (NSW) (Figure 1), a distance, following the main shipping routes, of 3674 nm (6804 km). A bulk carrier travelling at 13 knots would cover this distance in about 12 days. *P. viridis* larvae taken up in ballast water in any location between these two points could be discharged as viable larvae at any port within this area.

Table 6. Representative port distances and voyage durations

From port	To port	Distance	Voyage duration[1]
Cairns	Horn Is/Thursday Is	469 nm	2-3 days[2]
Gladstone	Brisbane	321 nm	1 day
Brisbane	Port Kembla	566 nm	2 days

Notes:

1. Based on a speed of 13 knots, which is typical for a bulk carrier.
2. From Sea Swift voyage schedule (https://www.seaswift.com.au/our-services/general-cargo/schedules/qld-schedules)
3. Port Kembla is outside the *P. viridis* area of establishment.

The consequence of this is that all ballast water from a port with a confirmed infestation of *P. viridis* would have to be managed, either by oceanic exchange outside 12 nautical miles from the coast and in 200 m water depth or by treatment with a ballast water treatment system. The cost implications of this are examined in Section 5.

Biofouling

P. viridis is a known fouling organism that has been detected in Australia on at least 49 occasions since 1999 (Heersink et al., 2015 and more recent information), mostly on arriving vessels. Protection against biofouling on vessels is achieved with an antifouling coating (AFC), a specialist paint, usually with a built-in biocide or designed to prevent biota becoming attached to the hull.

Managing biofouling risk is difficult as identifying the risk requires a physical inspection of the vessel’s hull which can only be effectively done with a diver, which is an expensive operation if it is to be carried out routinely. Current thinking is that the best way to manage biofouling risks is to ensure that each vessel is protected with the appropriate AFC for its mode of operation, including its niche areas, and that it is replaced within its service life.

The cost implications of managing risks of translocations of IMS as biofouling are examined in Section 5.

Recreational vessels

There are large numbers of recreational vessels in use on the east coast of Queensland – both privately owned and chartered. Marlin Marina in Cairns has berths for 261 vessels, Yorkey's Knob Marina, about 15 km north of the city has berths for 197 vessels and Bluewater Marina, 1 km to the west of Yorkey's Knob Marina, has berths for 108 vessels. In addition, there are moorings for at least 150 recreational craft in Trinity Inlet and additional space for anchorages. There is therefore accommodation for over 700 privately-owned recreational vessels in Cairns.

Cairns is also the hub of a fleet of vessels that operate tours of all types on the Great Barrier Reef. 12 tourism companies are registered as operating from the Reef Fleet Terminal in Cairns. Activities offered include fishing, diving, sight-seeing and cruises and they visit numerous locations on the Great Barrier Reef, including a number of fixed pontoons (Figure 10).

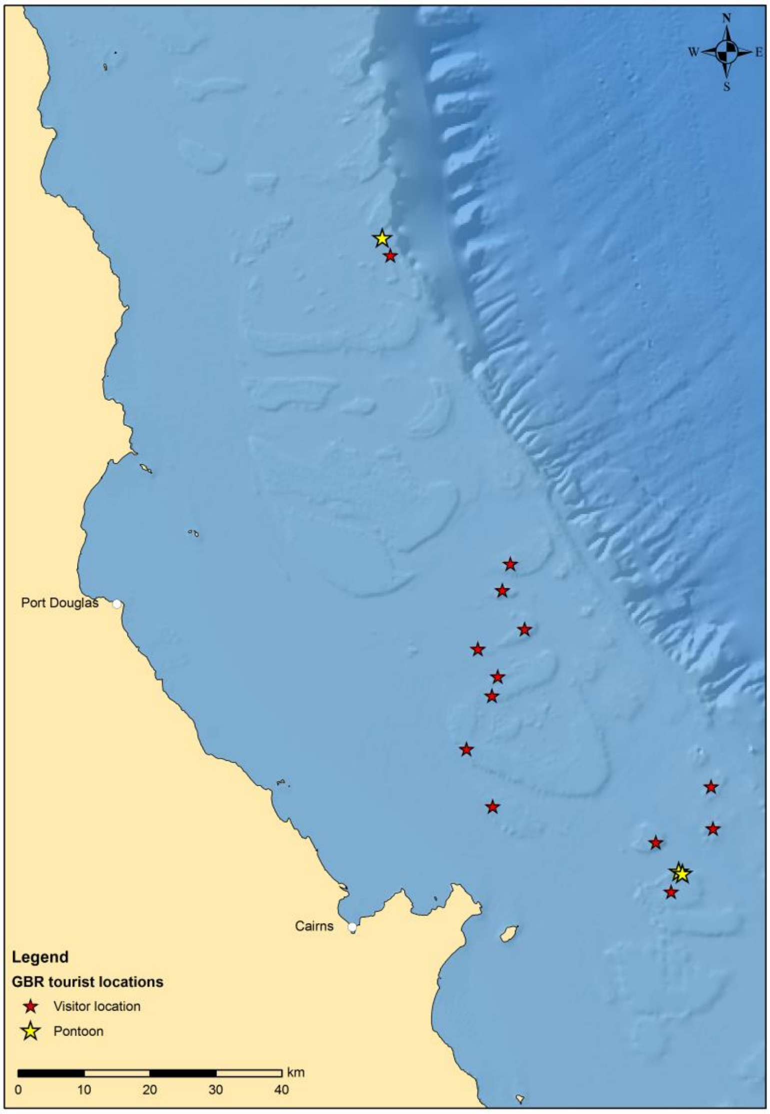

Figure 10. Locations on the Great Barrier Reef visited by vessels operating out of Cairns.

Source: Reef dive/fish/tour operators' web sites.

Cairns is also home to fishing vessels in the northern sector of the Eastern Tuna and Billfish Fishery, the Coral Sea Fishery and Queensland state fisheries.

5. Attach dollar values to impacts.

- **Place dollar values on the benefits of management action (=avoided losses)**
- **Place dollar values to the costs of management action**
- **Non-market environmental values do not always need to be estimated to determine whether the benefits of actions overweights the cost. Benefits to industries may already be higher than the response cost which gives mandate to act.**

Impacts on business activity

<u>Fouling vessels</u>

- Direct impacts on vessel performance (fuel consumption) and handling

In 2016 23 cruise ships made 136 visits to Cairns. The deadweight tonnages of these vessels varied between 50 and 11,928 with an average DWT of 1848. It is not possible to calculate the fuel consumption of every vessel but as a rule of thumb, cruise ships burn about 150 tonnes of fuel per day (https://www.cruise1st.co.uk). Assuming cruise ships in the Great Barrier Reef Marine Park are using the lighter and potentially less polluting MGO (marine gasoline oil), the current (16 November 2017) average Singapore bunker price (https://shipandbunker.com/prices) is US$485.50/tonne. Cruise ships therefore burn, on average, US$72,825 of fuel per day per vessel. Schultz et al. (2011) estimated that a biofouled hull increases fuel consumption by 10 – 20%. Assuming that a population of *P. viridis* in Cairns infests the hulls of 1 in 5 vessels, say 5 vessels, as a result of aging antifouling coatings and results in a 10% increase in fuel consumption. The total cost of the additional fuel consumption for these five vessels combined over a period of one year before they go into dry dock would be AU$17.49 M (at US$0.76). Even if these vessels were already fouled and that *P. viridis* contributed 1% extra fuel cost that is $174,875 for these 23 ships alone.

Additional fuel costs for fouling by *P. viridis* incurred by cruise ships only, in Cairns only, are a minimum of $174,875

- Costs of antifouling protection (already being done) – increased frequency of antifouling protection.

Not assessed

- Increased frequency of in-water cleaning.

The costs of in-water cleaning of a 120 m vessel in Fremantle in 2013 were calculated as $53,000 (Franmarine Underwater Services Pty Ltd, 2013). For reference, the average length of bulk carriers travelling between Gladstone and Weipa is 225 m. Franmarine uses the Envirocart in-water hull system; there are several other similar systems on the market, including Brush Kart, Ship Wiper and Fleet Cleaner. Assuming a present day price of $50,000 for a 120 m vessel in Gladstone, this equates to $416/m. In the event of a marine pest incursion, such as by *P. viridis*, vessels with extended periods in the infected port are at risk of the invasive species recruiting onto their hulls. In 2016, 11 vessels spent more than 10 days in Gladstone harbour. Data for 2017 are not yet available but a similar pattern of activity is assumed. Of these vessels, three were destined for ports outside the area at risk of establishment. It is likely that vessels that had remained in an infected port would be required

to have their hulls cleaned before departing. The seven remaining vessels have a total length of 652 m, which means that the total costs of cleaning them would be in the order of $270,000.

The assumed in-water cleaning costs of vessels at risk of becoming fouled with *P. viridis* in Gladstone is therefore $270,000. Similar costs would have to be calculated in Cairns and Brisbane.

<u>Fouling of industrial plant, power stations and desalination plants</u>

Gladstone Power Station, which is Queensland's largest power station, uses sea water for cooling. Sea water is drawn from a channel off Auckland Inlet that connects with Gladstone Boat Harbour. The cooling water is then discharged into Calliope River. To date there has been no experience with the impacts of invasive mussels on power generating facilities in Australia but there has been extensive experience in the US with impacts from zebra mussel (*Dreissena polymorpha*). Connelly et al. (2007) calculated the impacts of zebra on power generating facilities from information provided by the facility operators. It is unclear in the paper whether the values are presented are in real (adjusted for inflation) or nominal (not adjusted for inflation) terms. If in nominal terms (from 1995) the current (2017/2018) real value would be $108,975 (US$83,786). If in real values (from 2004) the current 2017/2018 current real value would be $87,917 (US$67,595). These figures are per annum.

The assumed annual impact of an incursion of *P. viridis* on Gladstone Power Station would be initially be between about $90,000 - $110,000 deceasing with time as the investment in filtering and antifouling technology paid off.

<u>Aquaculture</u>

There are aquaculture facilities near Cairns Some farms intake seawater for filling and top-up of ponds with varying degrees of treatment at intake. In the event that the prawn/barramundi farm does eventually become infested with *P. viridis*, the costs of fouling prevention would be substantial for the farm.

Impacts on the environment

Cairns and Gladstone are both situated within the Great Barrier Reef Marine Park, an iconic coral reef system that is renowned worldwide and has been placed on the World Heritage List. Healthy coral reefs have been found to be resilient to many invasive marine species, partly because healthy ecosystems are difficult to become established in as physical space has already been colonised, and partly because the nutrient levels on coral reefs are low, which limits the food available for filter feeders like many bivalve molluscs.

The coral reef bleaching event of 2017 left swathes of the northern Great Barrier Reef (GBR) severely damaged (http://www.gbrmpa.gov.au/about-the-reef/reef-health). Healthy coral reefs are usually able to withstand incursions by invasive marine species but in its weakened state, the reef has allowed the incursion of Asian green mussel (*Perna viridis*) from a population that has recently become established in Cairns. The mussels were discovered on both of the pontoons anchored on Moore Reef (**Error! Reference source not found.**), 50 km from Cairns, and have spread onto the reef itself. It is believed that the mussels were translocated on the hull of a tourist boat that had been moored in Cairns during last winter and had been scraped off when moored alongside the pontoons. The mussels had then reattached

themselves to the pontoons and had spawned some months ago. Plumes of nutrient-rich waters from rivers on the mainland have provided food for the mussels to grow. Another smaller population has recently been discovered on Green Island 30 km to the north-west but it is not clear whether this is from the postulated spawning event at Moore Reef or from the same vessel that also regularly visits Moore Reef.

Benefit transfer was used to estimate the non-market value for the benefits (avoided losses) of eradication or prevention of potential losses to a part of the GBR. The benefit transfer method is used to estimate non-market values of the environment by transferring available information from studies already completed.

For this exercise, willingness to pay values from the Rolfe and Windle (2010) study were used. Rolfe and Windle (2010) estimated values for the improvements of the quality of the GBR.

Due to unviability of non-market values for avoided loss to the GBR the values for the improvement of the quality of the GBR from Rolfe and Windle (2010) were used as proxies under the assumption that the values for the improvements are valued the same as the losses. This is a conservative approach as the losses are generally valued higher than the gains (willingness to pay versus willingness to accept) therefore the estimates obtained from this exercise are likely to underestimate the non-market value of the potential losses to the GBR. While this approach is conservative, the non-market values of the avoided environmental losses to the GBR can be compared with the cost of eradication or prevention. If the benefits (avoided losses) are higher than the cost of prevention or eradications actions are socially desired.

The assumed area affected by *P. viridis* is 8,275 km^2 (**Error! Reference source not found.**); the willingness to pay per 1000 km^2 estimated by Rolfe and Windle (2010) was $5.22 per household for 5 years. If all Australian households would have the same value, the estimated non-market value (avoided losses) are $79.5 million per year for 5 years ($94.18 million in 2017/18 terms) or $397.40 million in total ($470.91 million in 2017/18 terms). However, it is unknown whether all of the household would share these values. Therefore, conservatively assuming that only 30 percent (2.76 million) of the total Australian households (9.2 million) share these values and the willingness to pay of the rest of the population is zero the total value (avoided losses in other words benefits of actions such as prevention or eradication) of the potential impact occurring to the 8.275 km^2 was estimated at $23.8 million per annum ($28.3 million in 2017/18 terms) or $119.2 million in total ($141.27 million in 2017/18 terms). These non-market values are estimated under an assumption that there is 100 percent chance the impact will occur. However, if the probability of the impact is lower the communities' willingness to pay (for these environmental values) may be lower.

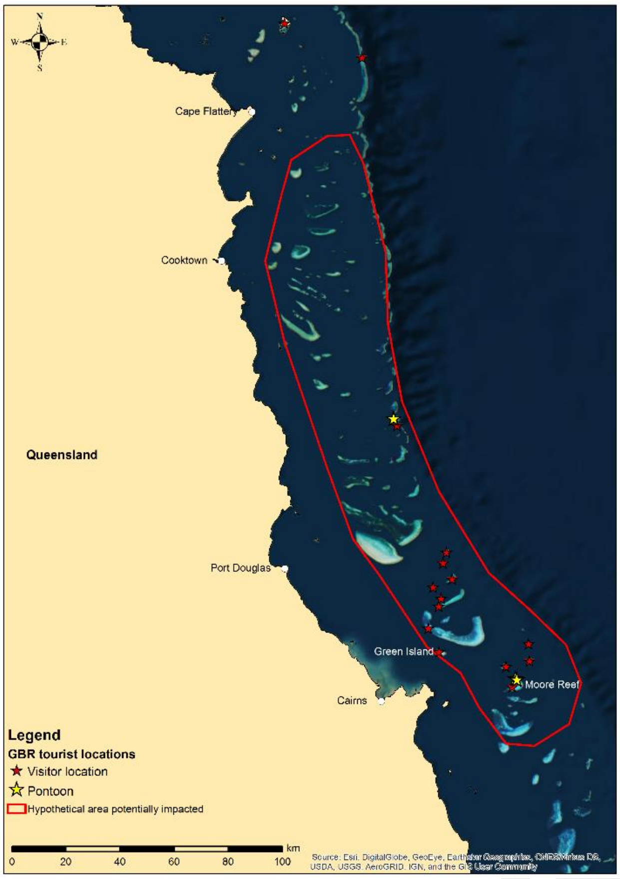

Figure 11. Hypothetical area potentially at risk over 30 years from a hypothetical incursion of *P. viridis* established on the Great Barrier Reef.

- Outcompeting native species

Not assessed

- Changes in water quality

Not assessed

Impacts on people

- Fouling recreational vessels

Not assessed

Impacts on human health

- High levels of accumulated toxins and heavy metals and linked to shellfish poisoning in humans (NIMPIS)

Not assessed

Impacts on infrastructure

- Fouling urban infrastructure including water inlets and water and sewage outlets

Not assessed

- Fouling navigation buoys

Not assessed

Prevention of spread

If it was found that there had been not just a transfer of *P. viridis* from Vessel X to Vessel Y but that a population had become established in Gladstone, it is likely that it would be mandated that ballast water taken up in Gladstone would have to be treated before it could be discharged in other ports.

One of the busiest routes for bulk carriers in Australia is from Gladstone to Weipa to collect bauxite for smelting in Gladstone. In 2016 188 bulk carriers navigated this route carrying a total of 5,394,786 m3 of ballast water. Summerson et al. (2017) found that 42% of vessels visiting Australia were fitted with ballast water treatment systems (BWTS) that use chlorination. The costs of running a chlorination system have been found to be US$0.08/m3 (AU$0.11/m3) for the precursor chemicals alone .

The cost of treating ballast water between Gladstone and Weipa alone is therefore a minimum of AU$249,239.

6. Discount future costs and benefits to obtain present values.

- **Select an appropriate discount rate**
- **Calculate a discount factor for each year in the future and apply to net benefits**

Response costs

1. The total combined response costs in Cairns, Gladstone and Brisbane are estimated as **$137,500**.

Impact costs

1. Additional fuel costs for fouling by *P. viridis* incurred by cruise ships only, in Cairns only, are a minimum of $174,875.

2. The assumed in-water cleaning costs of vessels at risk of becoming fouled with *P. viridis* in Gladstone is $270,000. Similar costs would have to be calculated in Cairns and Brisbane.

3. The assumed annual impact of an incursion of *P. viridis* on Gladstone Power Station would be initially be between about $90,000 - $110,000 decreasing with time as the investment in filtering and antifouling technology paid off.

4. Willingness to pay for protection to the area of the Great Barrier Reef potentially at risk from a hypothetical incursion: $23.8 million per annum

5. The cost of treating ballast water between Gladstone and Weipa alone is a minimum of AU$249,239.

The costs are summarised in Table 7.

Table 7. Summary of impact costs

Cost type	**Costs**	**Impact on**	**Period**
Additional fuel costs	$174,875	Cruise ships, Cairns	Annual
In-water cleaning costs	$270,000	Ships in Gladstone > 10 days	Annual
Biofouling prevention	$100,000	Gladstone Power Station	Annual - decreasing
Non-market values	$23.8 M	Protection GBR	
Ballast water treatment	$249,239	Gladstone – Weipa bulk carriers	Annual
Total direct impacts	$794,114		
Total non-market values	$23.8 M		
TOTAL	$24,594,114		

7. Compare the costs and benefits using net present value

- **Net present value (NPV) is the present value of benefits minus the present value of (response) costs**.

The present value of benefits, i.e. the estimated costs of impacts, which will be avoided if the response is successful, total $24.59 M (Step 5). The total combined response costs in Cairns, Gladstone and Brisbane are estimated as $137,500. It was unnecessary to discount either the impact or response costs as they are both in present day values. The net present value of the biosecurity response is therefore $24.45 M. If non-market values were excluded and only direct impacts on market values were estimated, the net present value of the biosecurity response would be $656,614. And it should be noted that not all direct impacts were estimated.

8. Perform sensitivity analysis.

- **Re-run BCA for worst and best case values of uncertain variables**

A sensitivity analysis was not carried out as part of the test case due to the limited time available.

9. Reach a conclusion.

With the information obtained it is clear that eradication would be the preferred option as impacts from *Perna viridis,* if it became established, would likely be severe. This is the advice that would be transmitted to CCIMPE.

Discussion and conclusions from the case study

The response costs seem lower than expected but is probably because of the way the incursion scenario was described. Of the three localities (in Queensland) that were described as being potentially infected with *P. viridis*, two only required surveys, although these could be extensive, and the "isolated population" in Brisbane seemed to only require a limited response. It is also important to bear in mind that by the time the BCA is required in a real life incursion, a response plan would have been prepared so that instead of guessing what the response plan might be, the BCA compiler would have been told explicitly.

In the limited time available (this BCA was completed in 10 working days), it was not possible to calculate all the impact costs. In this BCA four representative direct impact costs have been calculated plus a non-market valuation that was compiled using benefit transfer from another study. The representative direct impact costs were to two single vessel sectors in one port each, vessels resident in one port for a period that incurs a risk of infection and one power station. These four impact "scenarios" together accounted for nearly six times the response costs, which should easily justify the latter, without the need for incorporating non-market values. When time is of the essence it makes little sense to spend time over-justifying the response.

The BCA above has been compiled using the OBPR guidelines (Office of Best Practice Regulation, 2016) which have been found to be reasonably efficient for this purpose as the structure is logical and easy to follow.

Acknowledgments

The authors wish to thank the following for their invaluable contributions: Dr Paul Goldsworthy for information on representative costs of divers. Dr Justin McDonald, WA Department of Fisheries, for advice on the costs of settlement plate arrays. Dr Ashley Williams, ABARES, for advice on the plausibility, or otherwise, of *P. viridis* becoming established on the Great Barrier Reef. Dr Kasia Mazur for help with non-market valuation and calculation of other economic costs.

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