An Australian Government Initiative

NATIONAL CONTROL PLAN

Northern Pacific seastar

Asterias amurensis

THE NATIONAL SYSTEM FOR THE PREVENTION AND MANAGEMENT OF MARINE PEST INCURSIONS

This collaborative effort is supported by the Australian Government, state and Northern Territory governments, marine industries, researchers and conservation groups.

Australian Government

National Control Plan for the Northern Pacific seastar *Asterias amurensis*

Prepared for the Australian Government by Aquenal Pty Ltd

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BACKGROUND

The National System for the Prevention and Management of Marine Pest Incursions (the National System) has been developed to deal with the marine pest problem in Australia. Under the National System, introduced marine pests that are established in Australia that are having a significant impact and are not amenable to eradication, will be addressed under the Ongoing Management and Control component. The key initiative under this component is the development and implementation of National Control Plans (NCPs), which reflect an agreed national response to reduce impacts and minimise spread of agreed pests of concern. The Australian, state and Northern Territory governments, through the National Introduced Marine Pests Coordination Group (NIMPCG), have determined that the following are agreed pests of concern, for which NCPs are required:

-Northern Pacific seastar (*Asterias amurensis*);
-European green crab (*Carcinus maenas*);
-Asian date mussel (*Musculista senhousia*);
-European fan worm (*Sabella spallanzanii*);
-Japanese seaweed (*Undaria pinnatifida*); and
-European clam (*Varicorbula gibba*).

The six NCPs for the above species are being developed in accordance with the Contents List that has been agreed by NIMPCG. The aims of the NCPs are to establish nationally agreed, species specific responses, secure their coordinated implementation across jurisdictions, and provide guidance on the development of future strategies to reduce impacts and minimise the spread of these pests.

This document outlines the NCP for the northern Pacific seastar (*Asterias amurensis*).

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LIST OF ACRONYMS

CCIMPE	Consultative Committee on Introduced Marine Pest Emergencies
CSIRO	Commonwealth Scientific and Research Organisation
DAFF	Department of Agriculture, Fisheries and Forestry
DEW	Department of the Environment, Water, Heritage and the Arts
EEOR	Emergency Eradication Operational Response
EMPPlan	Australian Emergency Marine Pest Plan
IMCRA	Interim Marine and Coastal Bioregionalisation for Australia
IMO	International Maritime Organisation
MPA	Marine Protected Area
NCPs	National Control Plans
NIMPCG	National Introduced Marine Pests Coordination Group
NIMPIS	National Introduced Marine Pest Information System
NMN	National Monitoring Network
R&D	Research and Development
RRM	Rapid Response Manual

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A. Vision statement and strategic overview

<u>Vision Statement:</u>

"To establish a nationally agreed response to *Asterias amurensis*, secure coordinated implementation across jurisdictions, and provide guidance on the development of future strategies to reduce impacts and minimise the spread of this pest."

<u>Strategic Overview:</u>

The National System for the Prevention and Management of Marine Pest Incursions (the National System) has been developed to deal with the marine pest problem in Australia. The objectives of the National System are to:

1. Prevent the introduction to Australia of exotic marine species;
2. Prevent the translocation within Australia of exotic marine species;
3. Provide emergency preparedness and response capacity to respond to and where feasible eradicate, outbreaks of exotic marine species; and
4. Manage and control exotic marine species where eradication is not feasible.

The National System has three major components:

1. Prevention: Prevention systems to reduce the risk of introduction and translocation of marine pests (including management arrangements for ballast water and biofouling);
2. Emergency Response: A coordinated emergency response to new incursions and translocations; and
3. Ongoing Management and Control: Managing introduced marine pests already in Australia.

The key initiative under the Ongoing Management and Control component of the National System is the development and implementation of National Control Plans (NCP's) for the following agreed pests of concern:

-Northern Pacific seastar (*Asterias amurensis*);
-European green crab (*Carcinus maenas*);
-Asian date mussel (*Musculista senhousia*);
-European fan worm (*Sabella spallanzanii*);
-Japanese seaweed (*Undaria pinnatifida*); and
-European clam (*Varicorbula gibba*).

Under the National System there is a process for identifying additional species for which development of NCPs may be required in the future. NCPs operate consistently with other elements of the National System, including ballast water management arrangements, biofouling guidelines, emergency management, communications and research and development. This document outlines the NCP for *Asterias amurensis* (hereafter referred to as *Asterias*) and includes:

- Practical management actions and cost effective approaches to improve any measures currently in place to prevent, control or manage the impacts of the this species.

- Contingency plans for new incursions, linking in with existing emergency arrangements, including those under development.
- Creation of links with the National System monitoring strategy and recommendations for monitoring in addition to locations in the National Monitoring Network.
- Recommendations for future research and development required to underpin the NCP.
- Recommendations for public awareness and education strategies in addition to those planned under the National System.
- Estimated budgets and resource requirements to implement the NCP.

Decision support frameworks (in the form of flow charts and decision trees) have been included in relevant sections of the NCP. The decision support frameworks have been adapted and developed from a previous study that developed similar frameworks for marine pest management[1]. Four decision support frameworks have been developed, including: (1) an overarching framework; (2) a pest prevention strategy; (3) a contingency plan for new introductions; and (4) an impact management framework. A monitoring decision support framework was not deemed necessary, since the need for additional monitoring was highlighted in each decision support framework. The decision support frameworks also provide the opportunity to highlight key Research and Development (R&D) issues (discussed in detail in section H) which should improve the decision-making process. It should also be recognised that to be effective in the long term the NCP should be viewed as a 'living' document that is reviewed and updated on a regular basis so that new information can be incorporated into the NCP. Development of new control technologies, for example, may influence the range of control options available to managers. Furthermore, management priorities may change with increasing knowledge of the spatial extent and impacts of *Asterias* within Australian environments.

The overarching decision support framework for *Asterias* management is shown in Figure 1. Managers should refer to individual sections of the NCP for further background information to assist the decision-making process.

It should be noted that the purpose of the NCP is to establish a nationally-agreed management response to *Asterias*, but it is not intended to represent a comprehensive field guide. In some circumstances managers will be required to refer to additional resources under the National System to implement particular sections of the NCP (e.g. biofouling guidelines, emergency response manuals). These additional resources are clearly outlined in the appropriate sections of the NCP and are listed in Appendix I.

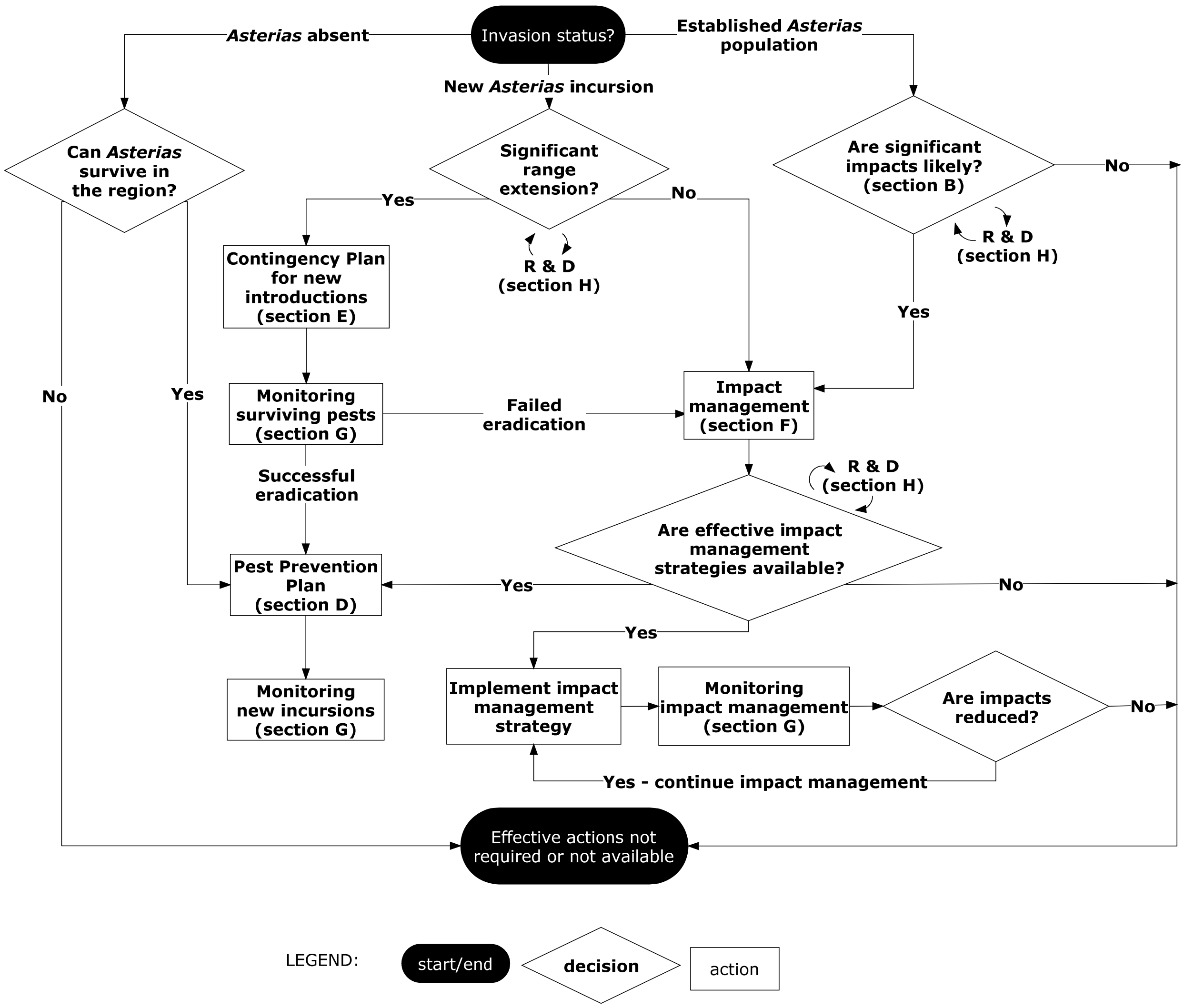

Figure 1. **Overarching decision support framework for *Asterias* management. There is inherent uncertainty associated with some questions (e.g. Can *Asterias* survive in the region?) so decisions must be made on the best available information (e.g. species range mapping data[2]). Note that if effective impact management strategies are available they will be integral to the "Impact management strategy", but they may also be considered under the "Pest prevention plan" if effective reproductive output and spread can be reduced from source populations.**

It is recognised that the number of pests and the likely impacts may vary substantially between jurisdictions so it will be essential to prioritise regional management activity. The purpose of the NCPs is to establish the ongoing control strategies that provide the best options for controlling the spread or impact of these species. It is beyond the scope of the NCPs to consider specific circumstances of each jurisdiction. Each jurisdiction needs to consider the costs and benefits of the proposed actions in relation to their specific circumstances and determine the ongoing control options that are most suitable for their jurisdiction. There are several tools available to assist managers to prioritise species for management purposes, such as the recommendations outlined in the Global Invasive Species Toolkit[3] (section 5.2 "Priorities for management"). As outlined in the Toolkit[3], a number of criteria should be considered when prioritising pest species including: (1) current and potential extent of the species on or near the site; (2) current and potential impacts of the species; (3) value of the habitats/areas that the species infests or may infest; and (4) difficulty of control.

B. Analysis of the level of threat posed by the species to national and regional environmental, social and economic values

This section of the NCP outlines the threat posed by *Asterias* to environmental, social and economic values should the species not be controlled. It is based upon an assessment of demonstrable and potential impacts of *Asterias* against the relevant CCIMPE criteria[4] (i.e. economy, environment, human health, amenity):

Economy:

Impacts in native range

In its native range, *Asterias* causes considerable damage to commercial shellfish fisheries[5-7] (e.g. oysters, cockles, scallops and clams).

Impacts in Australia

In Australia (refer to NIMPIS[8] for details on *Asterias* range), the economic impacts of *Asterias* are yet to be thoroughly examined, although it is widely recognised that *Asterias* causes impacts to scallop and mussel fisheries/aquaculture in Tasmanian waters (A. Morton, Tasmanian Department of Primary Industries and Water, pers. comm., October 2007). Of most concern is the influence of *Asterias* on scallop production in Australia (value $AUD 25M per year[9]) and in 2006, 25 tonnes of *Asterias* were caught as by-catch by commercial scallop fishermen on the east coast of Tasmania[10]. There have also been recent reports of 'very large numbers' of *Asterias* in scallop spat collector bags and suspended 'grow-out' cages on the east coast of Tasmania[11], resulting in ~ 1 million dollar loss to the industry in 2000[12].

Although predation rates on wild scallop populations remain unknown, a recent study examining the escape response of Australian scallops (*Pecten fumatus* and *Chlamys asperrima*) is cause for concern[13]. When exposed to native and introduced (i.e. *Asterias*) scallop predators, an almost immediate escape response by scallops was elicited in the presence of the native seastar *Coscinasterias muricata*. However, there was a low frequency of escape response exhibited by scallops after contact with *Asterias*. The absence of predator recognition in marine invertebrates may have serious implications for wild and farmed scallop populations in southern Australia where *Asterias* is prevalent.

The presence of *Asterias* also has the potential to impact clam and cockle fisheries such as those targeting *Katelysia* sp. and *Venerupis* sp. in sheltered bays on the east coast of Tasmania (combined average beach value of $AUD 234K per year, based on average earnings 2001-2005[14]). Experimental evidence has demonstrated significant predation impacts of *Asterias* on some of these commercial bivalve species in Tasmania, resulting in significant reductions in population density[15, 16]. Other cockle fisheries (e.g. Goolwa cockle *Donax deltoides*) that harvest animals from high energy surf zones are not likely to be affected by *Asterias*, due to a preference for low energy, sheltered habitats.

Asterias has the potential to impact abalone wild fisheries and aquaculture (value $AUD 225M per year[9]). However, significant impacts on the abalone fishery are considered unlikely, given that *Asterias* has a preference for sheltered habitats[8], while abalone are typically associated with high energy environments[17]. There have been no reported impacts of *Asterias* associated with abalone aquaculture[18].

Environment:

Impacts in native range

Predation by *Asterias* in its native range influences the abundance of a wide range of benthic infauna[5, 19, 20] including molluscs, ascidians, bryozoans, sponges, crustaceans, polychaetes, fish and echinoderms.

Impacts in Australia

The impact of *Asterias* on soft sediment habitats in Tasmania has been the subject of extensive research[15, 16, 21-23]. Results from experimental manipulations and detailed observations of feeding have demonstrated a large impact of *Asterias* on bivalve populations, particularly those species that live on or just under the sediment surface. *Asterias* appears to be a generalist predator with strong food preferences, but can readily switch to other prey species if the abundance of preferred prey becomes low. At high densities, *Asterias* has the potential to impact a large variety of taxa, with significant and broad effects on soft sediment communities. While *Asterias* also occurs on rocky reef in sheltered habitats, its impacts on these communities remain poorly understood.

Asterias has also been implicated as a contributing factor to the decline of the endangered spotted handfish in the Derwent River Estuary[24]. *Asterias* have been observed feeding on a stalked ascidian commonly used as a spawning substrate (*Sycozoa* sp.) and it is possible that predatory loss of the ascidian may impact spotted handfish by reducing the available spawning substrate[24]. The impact of *Asterias* on other rare echinoderm species in the Derwent River (e.g. small five-armed seastar *Marginaster littoralis*, holothurian *Psolidium ravum*) remains poorly known[25].

Asterias has the potential to spread along the Southern coast of Australia from Sydney to Perth out to a depth of at least 100m[2, 26] and is likely to represent a significant threat to the integrity of soft sediment communities if continued spread occurs.

Human health & Amenity:

If *Asterias* is used for consumption by humans or other species exploited by humans, there is a potential for impacts on human health because *Asterias* can accumulate toxins[27]. However, at this stage the risk of these effects is considered minimal.

The impacts of *Asterias* on biodiversity and the aesthetic values of the marine environment could potentially impact tourism and the recreational values of coastal areas.

C. The business case that led to the decision to establish a National Control Plan for the species

The business case that led to the decision to establish a NCP for *Asterias* was finalised in 2006[28]. The business case summarises the likely threat and impacts of *Asterias* and provides an outline of the likely benefits and costs of implementing the NCPs. A summary of key points arising from the business case is provided here:

Business case

NIMPCG considers that there is a business case for the development and implementation of a NCP for *Asterias*, given that implementation of the NCP will provide significantly improved coordination and management through nationally agreed responses.

The key information that informed NIMPCG is below:

Actual and potential impacts of Asterias

Asterias has been assessed by NIMPCG as having significant current and potential future impacts on Australia's marine environment, social uses of the marine environment and the economy. A summary of impacts known from existing infestations, which will occur at new sites if they are invaded, is as follows:

Asterias is a voracious predator on native species and commercially farmed shellfish causing loss of aquaculture, recreational, and commercial harvests. It dominates, out-competes and preys on native species. It is present in four out of 60 Australian marine bioregions (as defined in the Interim Marine and Coastal Bioregionalisation for Australia – IMCRA[29])

Potential for further introductions and spread of Asterias

Asterias can be transported in ballast water and via biofouling.

CSIRO has assessed the invasion potential of 53 introduced marine species, on the basis of: ballast water volumes discharged into Australian harbours and ports and the hull surface area of vessels that enter ports (which increases biofouling potential). *Asterias* has significant potential to invade additional places in IMCRA bioregions where the species are already present, as well as bioregions which have not yet been invaded.

Asterias has the potential to survive and complete its life cycle at places with suitable water depths along the southern Australian coast for at least some part of the year. Many other environmental factors affect the ability of *Asterias* to establish pest populations. On the basis of water temperature it has the potential to invade 28 bioregions (currently present in four).

Benefits of National Control Plans

NIMPCG considers that the implementation of a NCP for *Asterias* and the associated implementation of ballast water controls, inclusion of the species on the trigger species list under the Emergency management element, and inclusion as a target species for the National Monitoring Network will substantially reduce its spread in the short term.

In the long term a research and development program for *Asterias* designed to address the strategic needs of the NCP has the potential to provide more effective vector controls and means of addressing existing populations.

Costs of National Control Plans

Control measure	National System Component	Annual Cost
Operation of Ballast Water Framework	Prevention	$2.91 m
Ballast Water Exchanges and delays to shipping	Prevention	$6.99 m
National Monitoring network	Supporting arrangements	$0.96 m
Emergency management arrangements	Emergency management	$0.17m
Emergency responses - cost shared	Emergency management	Case-by case
Research and development	Supporting arrangements	Case-by case
Total (six species)		[At least] $10.96m

Cost - Benefit Analysis

Cost Benefit analysis for the implementation of NCPs cannot be precise as the losses to production values and the marine environment that would occur in the absence of control measures cannot be estimated. However consultants have estimated that, taking into account only the potential benefits to fisheries and aquaculture at only three sites where each of the species may have impacts, the benefit to cost ratio for a NCP for the six species ranges between 0 and 2.8. For *Asterias*, the benefit to cost ratio was 2.3 where eradication of the species was not considered possible and 1.5 where eradication of some incursions was considered possible. When the potential benefits for the marine environment are included, these ratios of benefits to cost will be exceeded.

Consultation

Consultation on the objectives and measures to be contained in NCPs and the business case for the initial six NCPs was conducted through NIMPCG.

D. A Pest Prevention Plan, which will refer to:

-National System ballast water management arrangements, where relevant to the species;

-National System best practice guidelines for management of biofouling; and

-Any other prevention strategies that are targeted specifically at the species or should be considered for the future.

Ballast water:

A generalised pest prevention framework that outlines the range of pest prevention strategies applicable to *Asterias*, including existing arrangements, is shown in Figure 2. Reducing the risk of ballast water – mediated translocation of *Asterias* within Australia will be addressed by new ballast water arrangements currently under development. NIMPCG has agreed that ships carrying high risk ballast water on domestic voyages may be required to exchange ballast water at least 12 nm from the Australian coast (with the exception of the Great Barrier Reef and Torres Strait which are still under consideration). It is expected that ballast water exchange in the Australian domestic ballast water arrangements will be consistent with International Maritime Organisation (IMO) regulations. This involves at least 95 % volumetric exchange conducted in water at least 200 m deep. The legislation for the Australian domestic ballast water arrangements is currently in the process of being developed and it is expected to come into affect by July 2009. *Asterias* has been nominated as one of the species for which ballast water management between Australian ports will be required.

While the new ballast water arrangements should reduce the risk of *Asterias* translocation, it must be recognised that it may not be sufficient to prevent spread of larvae, because *Asterias* has a long larval period (up to 120 days[30]). If *Asterias* larvae are entrained in ballast water, exchange or release of the ballast water close to the 12 nm limit could result in translocation to a new region given favourable currents.

Biofouling:

Hull fouling has been suspected to be a vector for translocating *Asterias*[31], a suspicion confirmed following testing of biofouling samples collected from vessel hulls using an *Asterias*-specific genetic probe[32]. An adult *Asterias* has also been reported from the sea chest of an ocean going vessel[33]. National best practice management guidelines for management of biofouling are currently being developed for various marine sectors[34] including domestic recreational vessels, aquaculture, commercial fishing and petroleum industries. Adherence to these guidelines should ensure that translocation risk is reduced.

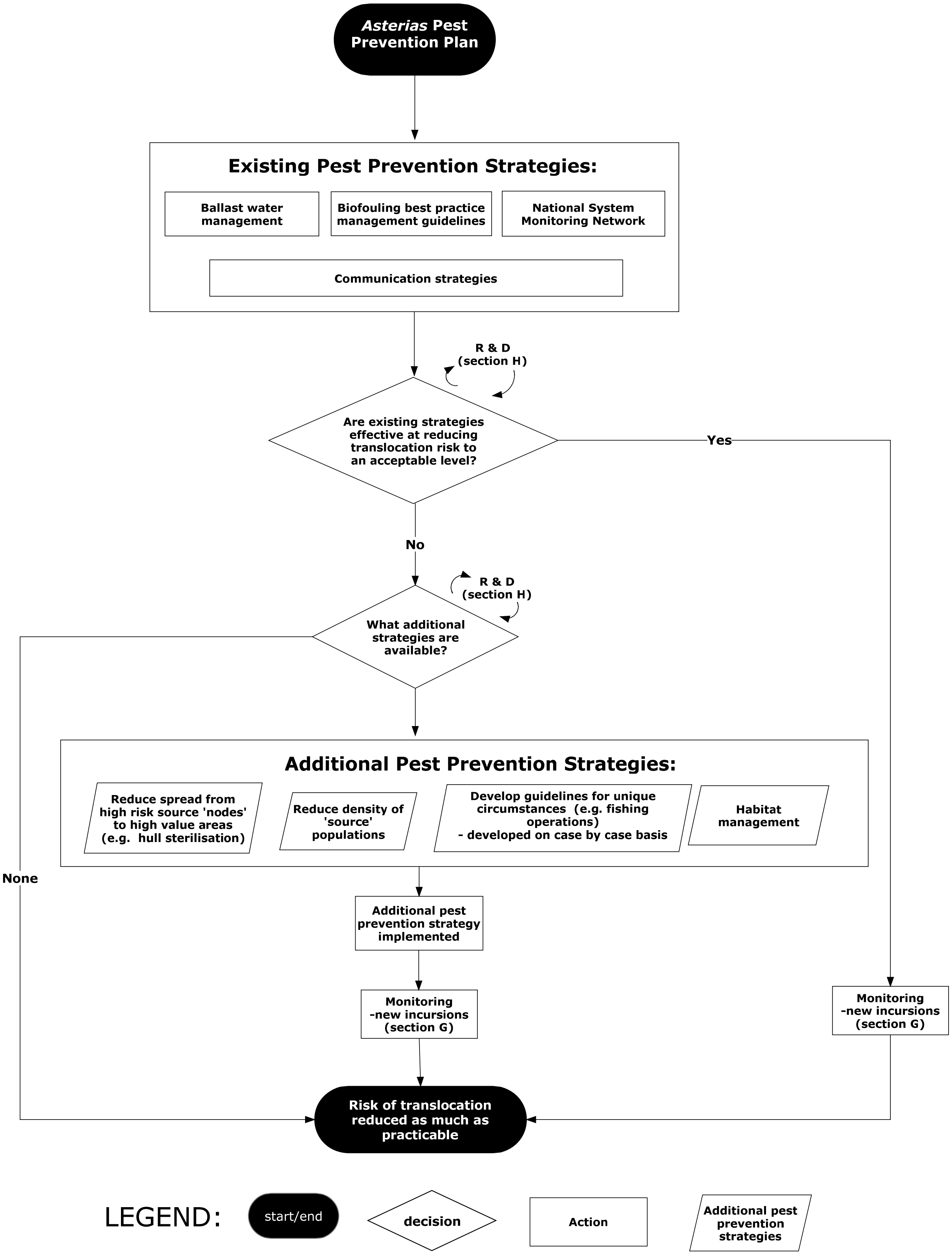

Figure 2. **Pest prevention plan and decision support framework applicable to *Asterias*.**

Commercial fishing and aquaculture activities are thought to pose the greatest risk with respect to translocation of *Asterias*[12], so it is particularly important that measures are taken to reduce the risk of translocation via these vectors. In relation to commercial fishing activities, translocation of *Asterias* may occur via biofouling (e.g. hull fouling, sea chests) and/or in association with vessel operations (e.g. deck fittings, mooring lines) and fishing activities (e.g. entrainment in fishing gear, live tanks and wells). A number of measures are available to reduce translocation risk associated with hull fouling including: regular slipping and dry-docking of the vessel to enable inspection; repair or renewal of the anti-fouling coating; in-water inspection by divers, and undertaking in-water clean (note that prior approval to undertake in-water cleaning is required from the relevant state/territory authority) or dry-docking as necessary, inspecting internal seawater systems, cleaning strainer boxes, and dosing or flushing of these systems. Translocation risk in association with vessel operations and fishing gear should be reduced by cleaning and drying equipment (including refuge areas) and ensuring unwanted biological material is either returned to the sea as close as possible to the point of capture, or disposed at a land based facility.

Transfer of aquaculture equipment and seedstock is considered a high-risk vector for entraining *Asterias* because of the propensity for seastars to congregate at farms[18]. Oyster and scallop farming activities are most likely to entrain *Asterias*[18]. Currently there are no significant stock or gear movements associated with the scallop industry until stock go to market. However, oysters are routinely moved within and between states and it is important that biofouling guidelines for the aquaculture industry are effective in eliminating *Asterias* from stock and/or equipment. A range of techniques are available[35] including a number of simple and environmentally friendly methods (e.g. freshwater immersion, air drying) that have been trialled against *Undaria*[35]. The efficacy of potential treatments to reduce translocation of *Asterias* associated with aquaculture activities remains unknown (section H).

<u>Additional Pest Prevention Strategies:</u>

- Transfer of *Asterias* from high risk nodes (e.g. infested ports, marinas) to high value areas (e.g. MPAs, important aquaculture regions) may warrant additional pest prevention measures. For example, sterilisation of hull and internal seawater systems might be recommended for vessels travelling to high value areas. Effective public awareness and communication campaigns will be an integral component of this strategy.
- A potential management option to prevent further spread is to reduce the density of the ‘source’ *Asterias* population[12, 36]. Since *Asterias* is an externally fertilised broadcast spawner, the density of reproductively mature adults is critical in determining the proportion of eggs fertilised. Consequently, reduced adult density should result in reduced abundance of larvae for entrainment in human mediated vectors and reduced capacity for natural spread, with the added benefit of a localised reduction of impacts. This approach would sensibly focus on removal activities prior to spawning (May-December[18]) and should target high density *Asterias* populations associated with artificial wharf structures. Currently available options for reducing *Asterias* density are detailed in section F. It is recommended that before such a strategy is implemented, the current distribution patterns and likely benefits of successful management of source populations are taken into account. The success of this strategy also relies on some key assumptions surrounding the links between *Asterias* larval supply and recruitment (see section H).
- Other pest prevention strategies may arise on a case-by-case basis. A good example of an additional pest prevention strategy is the recent development of protocols designed to

prevent translocation of *Asterias* by scallop fishers in a high risk area on the east coast of Tasmania[37]. Fishers have been provided with a clear set of guidelines that outline cleaning procedures to prevent translocation between fishing grounds, along with clear instructions on how to store *Asterias* that have been caught in their fishing gear (e.g. non-draining bins).

- While it has not been rigorously tested, anecdotal evidence suggests that *Asterias* is associated with disturbed habitats[44]. If links between invasion success and human-mediated disturbance can be demonstrated, managing human-mediated disturbance to increase the resilience of native systems should be viewed as an indirect method of preventing continued *Asterias* spread.

E. A contingency plan for responses to new introductions and translocations, including reference to National System emergency management arrangements

A framework for responding to new introductions and translocations of *Asterias* is provided in Figure 3. The decision on a national response to eradicate new introductions or range extensions of *Asterias* is dependent on whether or not a 'significant range extension' has occurred. As defined in the CCIMPE Standard Operating Guidelines[4], a significant range extension is considered to have occurred when the secondary introduction of an exotic marine pest species, that is limited in its known distribution within Australia, is detected that is deemed:

1. *to meet the EMPPlan criteria for a marine pest emergency alert;*
2. *is unlikely to be due to spread by natural means;*

and either:

3(a). *is likely to have considerable direct impacts on the economy, environment, public health, and/or amenity in the affected region;*

or

3(b). *is likely to considerably increase the indirect risk to assets (economic, environmental, public health, and/or amenity) in other regions.*

If a significant range extension has occurred and it is deemed feasible to eradicate the new incursion, an Emergency Eradication Operational Response (EEOR) may be instigated, pending approval of the National Management Group. A detailed breakdown of the EEOR and the procedures to be followed in the case of a marine pest emergency can be found in the Australian Emergency Marine Pest Plan (EMPPlan)[38].

A key component of the EEOR involves implementation of measures to eradicate the pest species from infested sites. Rapid Response Manuals (RRMs) are currently under development (commissioned by the Australian Government Department of Agriculture Fisheries and Forestry (DAFF)) that will specifically deal with eradication options for new *Asterias* incursions. The National Introduced Marine Pest Information System (NIMPIS) rapid response toolbox[39] also provides a range of physical, chemical and biological eradication options that should be consulted in the case of a marine pest emergency, while a recent review of currently available technology commissioned by DAFF provides an up-to-date assessment of emergency eradication options including novel treatment methods[40]. Another recently commissioned DAFF study provides tools to estimate the cost involved in emergency eradication or response based on the biology of the pest species and environmental conditions of the infected site[41].

The range of treatment options available for a marine pest emergency involving *Asterias* depends on the area of infestation and the environmental circumstances associated with the incursion. As applies to all marine pest emergencies, the most effective way to deal with a new *Asterias* incursion is to detect it early and eradicate or contain the population before further spread occurs.

There are two examples of successful *Asterias* eradications in Australia demonstrating the significance of containment and early detection in the success of eradication programs. The first involved a population of *Asterias* in Henderson's Lagoon on the east coast of Tasmania that was discovered in February 2001[11]. Community dives were organised in an attempt to eradicate *Asterias* from the lagoon (639 *Asterias* removed), however, these were unsuccessful in removing all

Asterias[42]. Somewhat fortuitously, the lagoon became isolated from the sea only a few weeks after the initial *Asterias* discovery, due to formation of a sand bar, created by a large swell. It was initially thought freshwater input from the many creeks feeding into the lagoon and the subsequent reduction in salinity of the lagoon waters would result in the demise of the contained *Asterias* population. However, *Asterias* defied predictions and proved it could survive at salinities well below levels reported from the literature. On August 31st 2001 the lagoon mouth was opened by a local farmer using a bulldozer. While this act caused considerable acrimony, particularly amongst local residents opposed to any human interference in the lagoon's natural processes, it resulted in death of all *Asterias* within the lagoon. It is thought that the *Asterias* were probably killed by a sudden salinity change - either a sharp increase in salinity with the renewed tidal exchange post-opening, or a sharp decrease in salinity on the lagoon bottom with a breakdown of the stratification that existed pre-opening[42].

The second example of a successful *Asterias* eradication involved a population discovered in January 2004 in Anderson Inlet, near Inverloch on the south coast of Victoria[43]. This population was the focus of eradication efforts managed by the Victorian Government's Department of Sustainability and Environment (DSE) and involved Victorian government agencies, a large range of volunteer organisations and many volunteer divers. Throughout 2004, a number of surveys and collection dives (20 days in total) were conducted and it is believed that the *Asterias* population has been eradicated, with surveys in 2007 failing to locate any *Asterias* (M. Holloway, DSE, pers. comm., January 08). There seems little doubt that the success of this eradication effort was due to the early detection and rapid response to the introduction. The importance of ongoing removal and monitoring efforts is another key factor contributing to the success of the Inverloch eradication. For detailed discussion of the management response at Inverloch, including issues related to use of volunteers and potential future improvements, refer to Holliday (2005)[43].

A key question for managers when responding to new *Asterias* translocations is whether or not the introduction is deemed "unlikely to be due to spread by natural means". This necessitates an understanding of the capacity for natural spread, which depends on the interaction between larval life history and local environment[30]. Recent modelling studies have examined the potential for natural *Asterias* dispersal on the south coast of Australia[30]. While some of the model assumptions in this recent work require validation (e.g. are there density dependent effects on larval mortality and recruitment?), the range of natural spread over the next 50-100 years was estimated to be restricted to populations in Bass Strait and the Victorian coastline[30]. While movement of larvae up the east coast of Australia was not considered in the model, it is suggested that the southward flowing East Australian current may limit *Asterias* spread in a northerly direction.

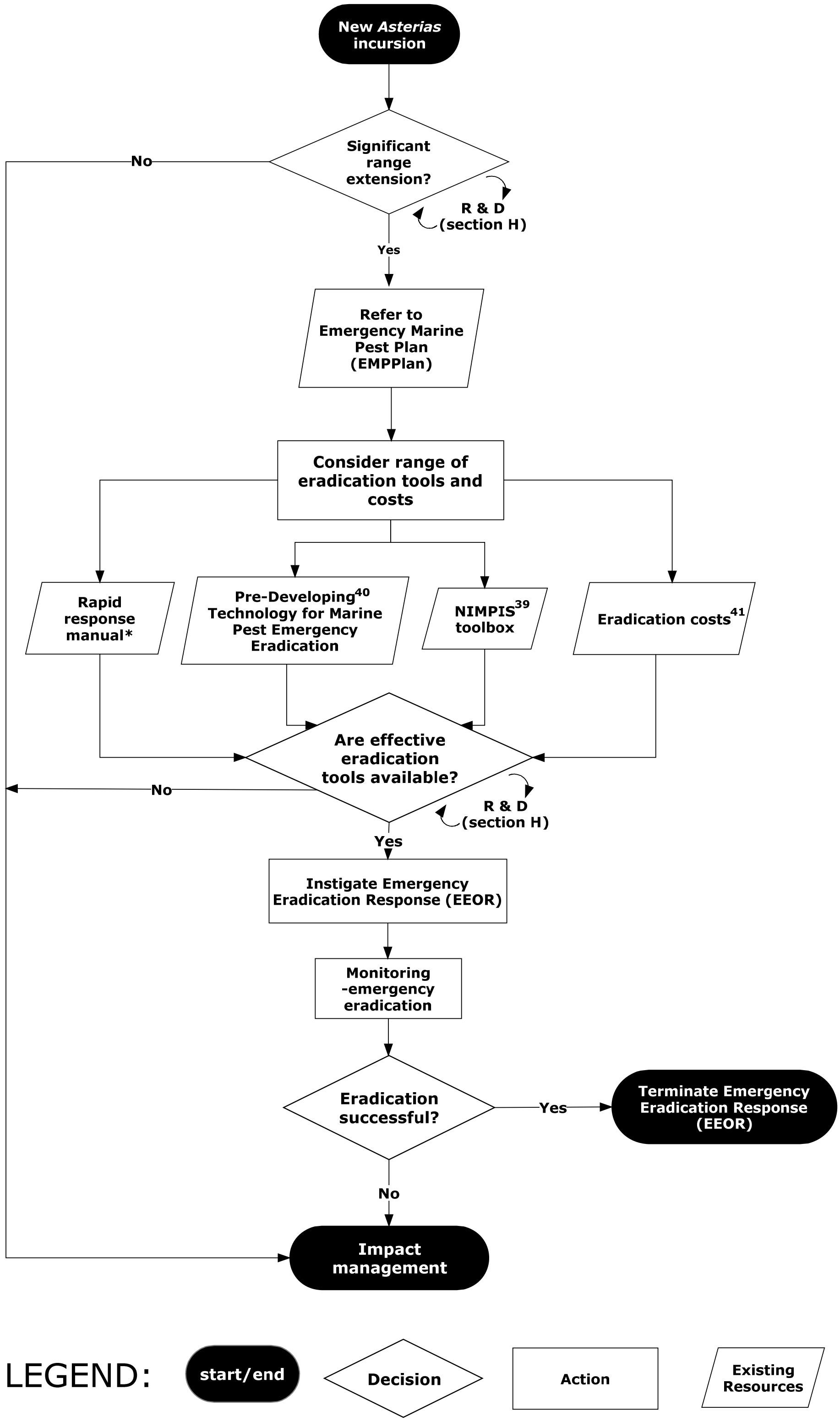

Figure 3. **Decision support framework for new introductions of *Asterias* highlighting the currently available resources to assist the decision-making process. *Resources currently under development.**

F. A plan for species impact management i.e. physical, chemical and biological measures to attack existing populations if feasible; and habitat management

A generalised decision support framework applicable for *Asterias* impact management is outlined in Figure 4. Assessing impacts is the first stage in the decision-making process. It is not appropriate to assign *Asterias* to impact categories across all jurisdictions since the extent of impacts will depend upon the industries operating within a jurisdiction, the nature of biological communities and habitats present, and other values of the region. Prioritisation for management purposes will also be based on relative impacts and the presence of other pest species within a particular jurisdiction. Notwithstanding these issues, in most jurisdictions *Asterias* impact is likely to be in the 'moderate to high' categories for economic and environmental impact based upon the threat analysis (section B) and the scheme proposed in Figure 4.

Before potential impact management options are identified, it is important to establish clear objectives which can be used to measure the subsequent success of management actions. As part of the decision-making process it is also vital to assess the likely benefits of impact management and the costs involved in implementing the impact management strategy. To justify investment in on-going control, it is essential that likely benefits exceed management costs. In most circumstances it will not be possible to control all populations, so it will be at the discretion of each jurisdiction to identify high value areas (e.g. MPAs, fisheries, key aquaculture areas) where there is greatest need to reduce impact. In relation to determining environmental values, resources such as 'The Interim Marine and Coastal Regionalisation of Australia (IMCRA)[29]' should be consulted to identify areas of biological significance.

<u>Currently available impact management options:</u>
Impact management options are defined under three broad categories; (1) direct targeting of *Asterias*; (2) habitat management; and (3) impact mitigation. A summary of the efficacy and feasibility of currently available options is provided in Table 1. It should be recognised that the various impact management options are not mutually exclusive and multiple methodologies may be incorporated into an integrated management strategy. The range of available impact management options will largely depend on the management objectives. The likely effectiveness and feasibility of impact management will also depend on the spatial extent and density of the target population which will require assessment on a case-by-case basis. For a detailed review of potential *Asterias* control options refer to Goggin (1998)[44]. It is worth noting that since completion of the review in 1998, there has been minimal progress or reported developments in this field, consequently the range of available impact management options remain largely unchanged (but see Ling 2000[36]).

(1) Direct targeting of Asterias:
<u>Physical removal</u>
Physical removal of *Asterias* by divers or trapping is the only currently available option considered suitable for reducing *Asterias* numbers. Dredging is a potential physical removal method that has been used in Japan to reduce seastar densities around fish farm operations[45]. However, as an impact management measure its environmental impacts are considered unacceptable, especially in locations such as the Derwent River where resuspension of heavy metals would be a serious concern.

Diver removals have so far been largely ineffective as an impact management strategy, although to date they have only been tested on an experimental scale. In July 1993, more than 6000 *Asterias* were collected from the port of Hobart by 22 divers from a 300 x 20 m area as part of a community cleanup. Another community cleanup conducted in August 1993 removed approximately 24 000 *Asterias* from Hobart's wharves. Both of these dives were judged to have negligible effects on *Asterias* densities[46]. In May 2000, an *Asterias* removal by community divers was conducted, but on this occasion, before and after sampling was carried out to assess the effectiveness of the trial. More than 21 000 *Asterias* were collected over two days from two wharves in the Hobart area[47]. Surveys conducted immediately after the removal showed significant reductions in *Asterias* density at both wharf sites. However, two months after removal densities had recovered to pre-removal densities at one of the wharf sites, while at the other wharf site, densities had increased but were still slightly lower compared to 'pre-removal' surveys[47].

The effectiveness of *Asterias* trapping was tested by the Tasmanian Department of Primary Industries and Fisheries[48]. Intensive trapping trials were completed at both a 'high density' and 'low/moderate density' site. Trapping reduced populations of *Asterias* at the high density site, but had no effect at the low density site. At both sites *Asterias* immigrated rapidly into the trapping area. Trapping was shown to be ineffective in controlling migrating *Asterias*, even when traps were placed closely together (2.5 m apart). Subsequent work has shown that the effectiveness of trapping declines when *Asterias* are actively moving through an area or where food is readily available[49].

The comparative effectiveness and cost efficiency of trapping and diver removal was also considered as part of the aforementioned trapping study[48]. Trapping was more cost effective than diving to control chronic infestations, regardless of density or depth. For *Asterias* infestations that are sporadic over time and when densities are below 1.5 m^{-2}, diver control appears more appropriate. Diver control was also preferred in low density situations because intensive trapping may attract *Asterias* into an area. At depths greater than 12 m, diver control was considered prohibitively expensive[48].

Recent work examining the reproductive ecology of *Asterias* in the Derwent River estuary provides some valuable outcomes in relation to impact management options and the overall effectiveness of physical removal[36]. *Asterias* near wharf structures (where food is abundant) are present in higher densities, have larger gonads and potentially far greater reproductive potential compared to *Asterias* occurring on natural substrates throughout the Derwent River. Modelling suggests that this ≈ 10% of the population occurring at the wharves (which cover ≈ 0.1% of the total area of the Derwent estuary) contributes 80-90 % of its reproductive output. Consequently localised removal of populations of *Asterias* around wharf structures prior to spawning (May-December[18]) has been suggested as a potential approach to reducing reproductive output and overall abundance of *Asterias*[36].

While this management approach is appealing, there are significant uncertainties and key assumptions surrounding the method that may limit its effectiveness. For example, *Asterias* immigration from surrounding lower density areas is likely to occur[48] and unless the food supply associated with the wharves can be reduced (see below, habitat management), it is likely that high density *Asterias* populations would re-establish once removal activities cease. It should also be acknowledged that the effectiveness of this management approach relies on some key assumptions that require validation. Firstly, there is no proven link between larval abundance and recruitment of *Asterias*. Consequently, we do not know whether effective recruitment can be reduced by reducing adult density, nor the extent to which *Asterias* density should be reduced if such a link exists. Secondly, it remains unknown whether or not density dependent mortality of *Asterias* larvae occurs and this will have a major influence on the success of this strategy (see section H). Thirdly, the benefits of reducing the reproductive output from within a high density infestation are yet to be assessed. It is possible that recruitment from remaining low density *Asterias* populations may be more than enough to completely replace all those removed from high density locations, while also enabling natural range expansion on the margin of the population. It also must be recognised that even if this management approach successfully reduces *Asterias* recruitment levels, it would require ongoing effort and its effectiveness would be gauged by long term decline in *Asterias* abundance rather than immediate results.

Biological control

Biological control has been considered as a control option for *Asterias*[44] and the ciliate *Orchitophyra stellarum* is the most likely candidate for biological control of the species. However, its capacity to control *Asterias* populations remains doubtful. In addition, its ability to infect other asteroid genera raise serious concerns in relation to potential impacts on non-target species[50].

Another possible biological control option with close links to 'habitat management' (see below) involves native predators. There are a number of recent examples that demonstrate the negative influence of native predators on introduced marine species and their role in conferring invasion resistance[51]. Rehabilitating or enhancing populations of native predators therefore represents a potential control option for *Asterias*. The seastar *Coscinasterias muricata* has previously been suggested as most likely to influence *Asterias* populations. *C. muricata* have been observed predating *Asterias* adults[44] and it is also likely they compete with *Asterias* for food. Further research efforts in an Australian context are required to determine the significance of native predators in controlling *Asterias* populations (see section H).

Genetic manipulation of pest species is the subject of ongoing research efforts at CSIRO. Modelling studies show that it could be an effective control strategy to reduce or eradicate pest populations[26]. While such techniques have potential (e.g. sonless/daughterless offspring), public concern and legislative restrictions associated with release of genetically manipulated organisms would need to be overcome before they could be applied in the marine environment.

Chemical control

Chemical control including broadcast application of chemicals, direct injection and application of chemicals that interfere with reproduction have been considered to reduce *Asterias* populations[44]. However, these methods are not likely to be considered environmentally acceptable for large-scale management of established *Asterias* populations (refer to Goggin (1998)[44] for discussion of chemical control options).

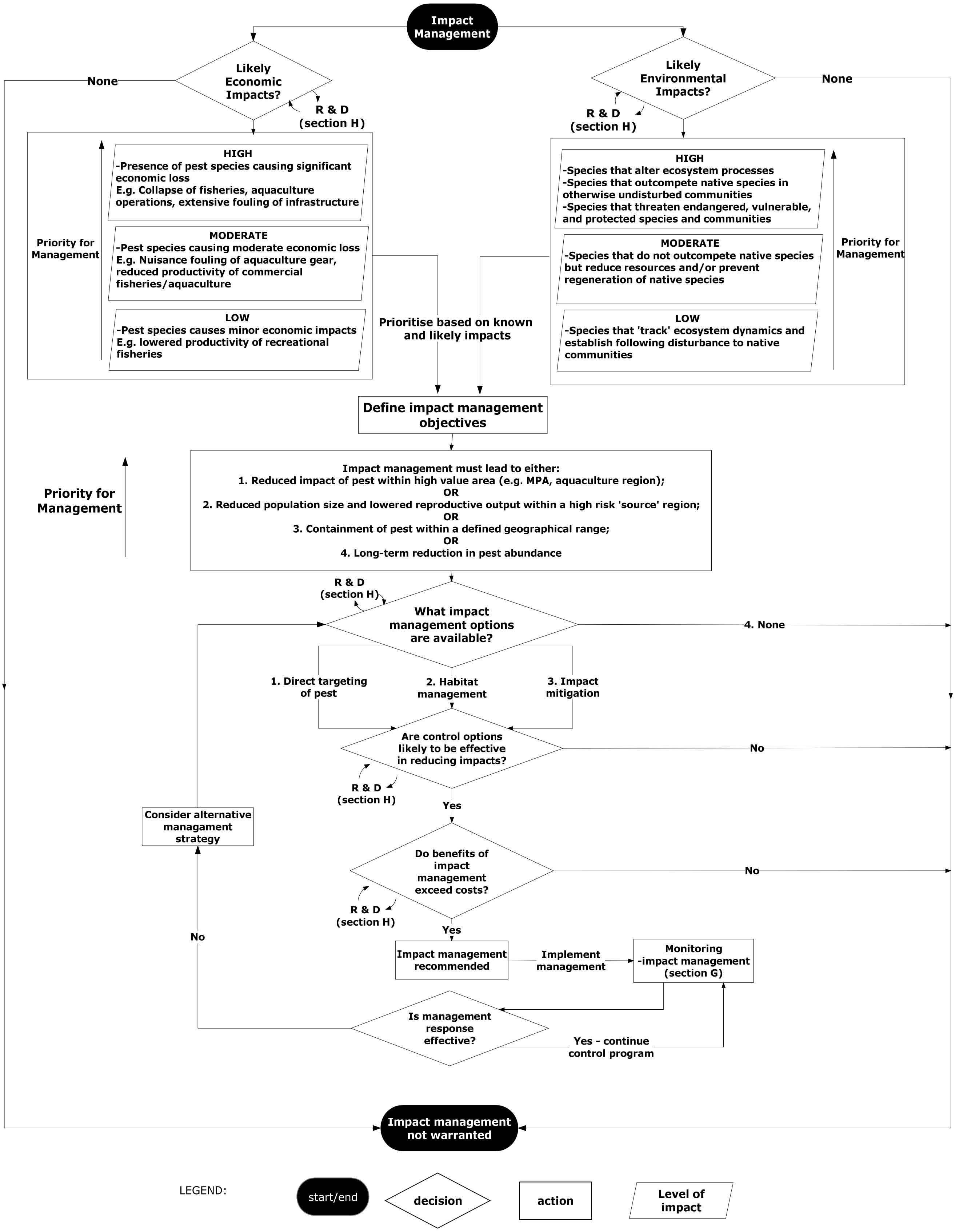

Figure 4. **Impact management decision support framework applicable to *Asterias*.**

(2) Habitat management:
In the Derwent River estuary, dense populations of *Asterias* are associated with wharf structures that provide an abundant source of food[36]. Removing the food source (primarily mussels) may be an indirect way of reducing reproductive output and abundance of *Asterias* in the long-term. While this approach has merit, the practicalities and consequences of removing mussels from artificial structures are yet to be considered (see section H).

Where invasion success can be linked to human activity, managing the human-mediated activities represents an indirect method of controlling *Asterias* and may be more cost-effective than targeting them directly. However, it remains unclear whether *Asterias* is a driver or tracker of system dynamics (see section H).

Habitat management may be targeted or it may be of a more general nature that aims to improve ecosystem health. Locations in Australia where *Asterias* is most abundant (i.e. Derwent River, Port Phillip Bay) have been subject to significant inputs from urban and industrial effluent, resulting in habitat degradation. Rehabilitation of these habitats may lead to increased resistance to invasion and reduced impacts of existing *Asterias* populations[46].

(3) Impact mitigation:
Impacts of *Asterias* on commercial operations are currently poorly understood, hence there is limited scope for recommending impact mitigation strategies. Nevertheless, impact mitigation is a potentially promising management strategy against the impacts of *Asterias* if significant impacts are identified in the future. Barriers (e.g. Nets with nylon lips) have been successful in containing adult *Asterias* in research experiments[44] and similar principles could be applied to prevent adult *Asterias* from entering aquaculture areas. In circumstances where negative interactions are caused by *Asterias* recruitment events (e.g. *Asterias* recruitment onto scallop growout baskets in Tasmania[11]), cost effective strategies that prevent *Asterias* recruitment would require significant research and development. The simplest strategy involves timing operations to avoid interactions with settling *Asterias* larvae. For example, where possible, operators should retrieve stock before peak *Asterias* settlement (late summer/autumn)[18].

Table 1. Currently available impact management options considered suitable for *Asterias*. (Note that potential control options such as genetic control that are under development or are considered environmentally unacceptable are not included).

Method	Likely Efficacy	Feasibility	Environmental/public concerns
1. Directly targeting *Asterias*			
Diver removal	Potentially effective given adequate intensity of diving effort. Likely to require ongoing removal to maintain low *Asterias* densities.	Feasible at shallow depths (< 12 m) at small-moderate spatial scales* (e.g. aquaculture leases, localised high density populations associated with wharf structures). Initial and ongoing efforts will require significant expenditure.	Minimal environmental concerns.
Trapping	Partially effective for high density populations. Likely to require ongoing removal to maintain effectiveness.	Feasible at all depths. Initial and ongoing efforts will require significant expenditure.	Minimal environmental concerns. By-catch release unharmed.
Biological control *-Enhancement of native predator populations*	Requires understanding of native predators of *Asterias*. Likely efficacy remains unknown.	Practical application remains unknown.	Would require research to ensure impacts on non-target species are minimal.
2. Habitat management			
Food supply *-reduce abundance of mussels associated with artificial structures*	Likely to be effective in reducing formation of high density *Asterias* aggregations and subsequent reproductive output.	Feasibility remains unknown. Unlikely to be a practical, readily available method of removing food organisms (e.g. mussels).	'Cleared' pylons could provide habitat for other pest species.
Environmental rehabilitation	Efficacy remains unknown. Efficacy depends on the link between human mediated activity and *Asterias* invasion success.	Feasibility will depend upon the human activities concerned and remains unknown an.	Minimal environmental concerns.
3. Impact Mitigation			
Barriers for aquaculture	Potentially effective method to exclude adult *Asterias* from aquaculture areas.	Only likely to be feasible on small spatial scales*. Would require significant investment to build and maintain barriers.	Minimal environmental concerns.
Modify aquaculture practices -e.g. Modify timing of commercial operations to minimise interaction between *Asterias* larvae stock/equipment.	Likely to be effective.	Requires understanding of the abundance and distribution of *Asterias* larvae. Likely to incur labour costs and result in lost productivity.	Minimal environmental concerns.

*Small spatial scale = < 1000 m^2; moderate spatial scale = 1000 – 10 000 m^2; large spatial scale = > 10 000 m^2.

Overall recommendations:

- If practical, impact management strategies should focus on reducing *Asterias* abundance and/or impact mitigation in high value areas (e.g. aquaculture regions, MPAs, regions where threatened species or communities are present).
- Physical removal of high density *Asterias* populations associated with artificial structures is a potentially effective control method for reducing adult abundance and subsequent reproductive success. However, further research is required to address some of the key assumptions that underpin the effectiveness of this control strategy.
- Where invasion success can be linked to human activity, managing the human-mediated activities represents an indirect method of controlling *Asterias* and may be more cost-effective than targeting them directly.
- Removing the key food source (primarily mussels) associated with high density populations may be an indirect way of reducing reproductive output and abundance of *Asterias* in the long-term, however, further research is required to investigate the practicalities and consequences of removing mussels from artificial structures.

G. A monitoring strategy for the species, including the National System Monitoring Network and Monitoring Guidelines

Monitoring of *Asterias* is included in the National Monitoring Network (NMN), which is comprised of 18 locations across Australia[52]. Guidelines for monitoring *Asterias* within the NMN are included in the Marine Pest Monitoring Manual[53]. The primary objectives of the network are: (1) to detect new incursions of established target species at a given location i.e. species already established elsewhere in Australia but not recorded at that location; and (2) to detect target species not previously recorded in Australia that are known to be pests elsewhere.

<u>Additional Monitoring:</u>
The requirements for additional monitoring will be governed by the status of the pest within a particular jurisdiction and the components of the NCP that are relevant at the time. The preceding decision support frameworks (Figures 1-4) can be used to determine whether additional monitoring is required. Additional monitoring to be considered for the *Asterias* NCP (summarised in Table 2) comprises three broad categories:

1. *Pest Prevention*
In relation to new incursions, additional monitoring sites may be recommended based on known vectors and transport pathways. Based on environmental tolerance information[2, 54], only five of the 18 NMN locations are of relevance to *Asterias* and two of these locations already have established populations. Consequently, additional monitoring sites should be considered by local jurisdictions on a case-by-case basis, considering transport pathways not considered in the NMN (e.g. recreational vessels, transfer of aquaculture gear etc.). When considering additional monitoring sites, priority should be given to sites in high value areas, particularly if strategies are in place to prevent translocation of *Asterias* from a high risk source node to these high value areas. Given the apparent preference of *Asterias* for shallow sheltered estuaries and bays[55], additional monitoring sites should focus on these habitats, particularly those locations where a high level of larval retention is likely due to local hydrodynamic conditions[30].

2. *Contingency Plan for new introductions*
Monitoring new incursions will involve surveys that determine the spatial extent of the new incursion, including monitoring of suitable habitats in areas adjacent to the known population of *Asterias*. If an eradication attempt is initiated, monitoring will form a core component of the eradication program. Monitoring will involve quantifying *Asterias* abundance and is likely to be required on an ongoing basis to ensure eradication success.

3. *Impact management*
If an impact management strategy is implemented a range of monitoring strategies should be considered depending on the management objectives (see Figure 4). If the objective of the control strategy is to reduce abundance of *Asterias* within a high value area, for example, estimating the abundance of *Asterias* should form a core component of the monitoring strategy. Monitoring of the impact itself is also recommended in these circumstances so the success of impact management can be assessed. If the high value area is based on the presence of an industry (e.g. aquaculture, fishery), monitoring should also include estimates of abundance for the species that the industry is based upon. Alternatively, if the high value area is based on environmental values, monitoring should involve quantifying the diversity and abundance of species of environmental value. Where possible,

incorporating 'treatment' and 'control' areas is recommended so the effectiveness of management activities can be critically evaluated. Monitoring the rate of spread of *Asterias* should also be considered within the 'Impact Management' category because the spatial extent of the pest is an important component of overall impact. It is also important when determining whether or not a significant range extension has occurred and consequently, whether or not an eradication attempt should proceed.

Incorporating results from other monitoring programs into NIMPIS[56]:

In many states there are programs in place involving monitoring of marine communities (e.g. community-based surveys, MPA surveys) and in some instances these programs collect information on the distribution and abundance of marine pests. Given the significant costs involved with monitoring programs, in circumstances where the surveys are appropriate for *Asterias* it would be of considerable benefit if a mechanism was in place to incorporate this data into NIMPIS. Incorporating such data into NIMPIS may at least partly alleviate the need to carry out additional monitoring that may be recommended in the NCP and could represent a considerable cost saving. It would also be invaluable if NIMPIS includes results associated with control/eradication attempts.

Another potential data source lies with relevant government authorities. Approval of developments in the coastal zone may include biological surveys as part of environmental impact assessments. Information collected as part of these surveys could be relevant to *Asterias* and it is recommended that results from these surveys should also be incorporated into NIMPIS. There are also opportunities to incorporate industry based monitoring into NIMPIS. For example, aquaculture operations may monitor marine pests and in some jurisdictions this is a legislative requirement. In Tasmania one of the conditions of a marine farming licence is that: "The licence holder must notify the Department of Primary Industries and Water of the presence of any introduced marine pests within the lease area". Similarly, in Victorian waters, aquaculture licence holders operating in marine waters are required to report the presence of suspected new incursions of exotic marine organisms at the specified site to the Secretary (or delegate), Department of Sustainability and Environment, within 24 hours of detection. It is recommended that this type of information should also be incorporated into NIMPIS. The information supplied not only provides potential information on distribution and abundance of *Asterias*, but may also provide observations in relation to impacts. Where possible, state jurisdictions should engage industry to ensure collection of *Asterias* data that will be of most benefit to management agencies. Providing quality information requires goodwill on the part of industry. Consequently it is very important that industry participants understand the value of the information they collect and are provided with adequate feedback to encourage continued cooperation. An efficient mechanism of extracting the relevant industry data compiled by state and territory governments and inputting it into NIMPIS is also needed.

While results from other monitoring programs are a potentially valuable resource, it should be noted that such data must meet minimum quality assurance standards before it is incorporated into NIMPIS. Alternatively, its use in a decision-making framework should be guided by an assessment of data quality.

Table 2. **Additional monitoring strategies that may be required for *Asterias*.**

NCP Section & Monitoring objectives	Additional monitoring locations	Nature of data
1. Pest Prevention		
- To detect new incursions	Select additional sites based on transport pathways and environmental conditions at recipient locations	Presence/absence
- To detect new incursions in high value areas	Selected high value areas (e.g. aquaculture areas, Marine Protected Areas)	Presence/absence
2. Contingency Plan for new introductions		
- To determine spatial extent of new incursion and whether additional populations exist	Site of infestation along with adjacent suitable habitats	Presence/absence
- To assess the effectiveness of eradication attempts	Eradication site(s)	Abundance
3. Impact Management		
- To assess effectiveness of impact management strategies	Monitor in locations with/without impact management strategies.	Abundance; Population estimates may require mark-recapture studies and monitoring of tagged *Asterias*; Monitoring of specific impacts (e.g. impacted industries or biota)
- To monitor the rate of spread	Various locations to establish the range of *Asterias*	Presence/absence

H. A research and development strategy to improve vector controls, techniques for control and eradication of existing populations and detection and monitoring

A National strategy (2006-2016) for marine pest Research & Development has been completed[57] and includes a variety of research areas that should contribute to improved management of marine pests (including *Asterias*) within Australia. The purpose of the R&D outlined in the *Asterias* NCP is to highlight key R&D areas that will specifically enhance the performance of the plan, rather than presenting a comprehensive list of potential research areas. Most of the key R&D areas (summarised in Table 3) have been highlighted previously in the relevant decision support frameworks (Figures 1-4). In the long-term the proposed R&D will reduce uncertainty associated with the decision-making process and lead to more efficient investment of resources. Table 3 also includes a scheme for prioritising the proposed R&D based upon the importance of the research area to the NCP, its cost effectiveness and feasibility. It must be emphasised that the R&D areas and their relative priority is likely to change through time, so it is vital that a flexible approach is maintained.

A brief justification of the inclusion of the proposed R&D areas is provided for the relevant sections of the *Asterias* NCP:

Pest Prevention

Understanding the effectiveness of existing management arrangements (i.e. ballast water, biofouling) is an important component of the R&D strategy, since the requirement for additional pest prevention measures will be largely determined by the success of these strategies. Given the potential importance of aquaculture activities as a vector for *Asterias* spread, it is particularly important that an assessment of the likely efficacy of the proposed guidelines be conducted (Table 3; PP1).

Contingency Plan for new introductions

While a range of resources are available to managers to assist in dealing with new introductions, publicly acceptable methods generally have a low probability of success against established pests[58]. Development of innovative tools to eradicate *Asterias* populations should therefore be an on-going research priority, despite the technical challenges associated with eradicating a mobile species in an open marine environment (Table 3; CP1).

Table 3. Summary of R&D strategy including a relative ranking system for prioritising research efforts. Scores for a range of assessment categories were summed to provide the overall priority score and allow a relative priority ranking to be assigned to each R&D area. Scores 0 = low, 5 = high, for assessment categories and relative priority ranking. Where appropriate, the relevant decision support framework figures are referenced to demonstrate how the proposed R&D areas will aid the decision-making process. Estimated indicative costs to complete each R&D section are also provided under the 'cost effectiveness' category. Since it is not possible to quantify benefits of each R&D area, cost effectiveness cannot be determined in quantitative terms. Instead, research areas requiring less expenditure have been prioritised at a higher level to reflect the likelihood that research funding will be limited.

NCP section	**R&D area** ***(Relevant decision support framework)***	**Relative importance to NCP**	**Cost effectiveness (indicative costs $'000)**	**Technical Feasibility**	**Priority score**	**Relative priority**
Pest Prevention	PP1. How effective are the aquaculture best practice guidelines for biofouling in reducing translocation risk? *(Figure 2)*	4	4 (75)	4	12	**5**
Contingency Plan for new introductions	CP1. Development and testing of novel eradication/control options *(Figures 3,4)*	5	2 (200)	1	8	**1**
Impact management	IM1. What are the impacts of *Asterias* on commercial scallop industries in Australia? *(Figure 4)*	5	2 (200)	4	11	**4**
	IM2. What are the impacts of *Asterias* on deep water, open coast soft sediment communities? *(Figure 4)*	4	3 (100)	4	11	**4**
	IM3. What are the environmental impacts of *Asterias* on rocky reef habitats? *(Figure 4)*	3	3 (100)	4	10	**3**
	IM4. Improved understanding of the role of human-mediated disturbance in the invasion process for *Asterias* *(Figure 4)*	4	2 (200)	3	9	**2**
	IM5. Improved understanding of processes between fertilisation and recruitment *(Figure 4)*	4	2 (200)	3	9	**2**
	IM6. Investigation of the potential of native predators for *Asterias* control. *(Figure 4)*	2	3 (100)	3	8	**1**
	IM7. .Practicalities of food removal from artificial structures as a control method. *(Figure 4)*	3	3 (100)	3	9	**2**

Impact management

Understanding the economic and environmental impact of *Asterias* is vital because it plays a pivotal role in determining whether or not control actions should be pursued (Figure 4). While there has been much speculation regarding the impacts of *Asterias* on fishing and aquaculture industries, it is apparent that the most significant impacts are likely to be associated with the scallop wild fishery and aquaculture industries. While impacts on scallop aquaculture industries have been reported[12], interactions between *Asterias* and wild scallop fisheries have only recently been observed and the extent of impacts remain largely unknown. Improved understanding of current and potential impacts on the scallop industry is therefore recommended as a priority research area (Table 3; IM1). This research should define the current spatial extent and nature of *Asterias*-scallop interactions and examine whether interactions are occurring in particular environmental conditions. Research outcomes should not only provide improved understanding of impacts, but may also provide potential options for *Asterias* impact management.

The recently reported interaction between *Asterias* and scallops on the east coast of Tasmania is cause for concern. Interactions were observed in soft sediment communities on an open coastline in relatively deep water (30 - 40 m). Prior to these reports, high density *Asterias* populations have been typically associated with shallow (< 25 m) sheltered bays and inlets[8]. It is recommended that future R&D examine the environmental impact of these *Asterias* populations (Table 3; IM2). This should also include surveys of *Asterias* in adjacent deep water habitats. If *Asterias* can colonise and form high density populations in deep water habitats (note that in Japan it is recorded down to 200 m deep[8]), the threat to environmental and economic values may be greater than previously thought. Addressing this research area would sensibly be incorporated into research area IM1 (described above), since sampling to examine impacts on benthic communities could be conducted in the same geographic region with minimal additional costs.

While the impacts of *Asterias* on soft-sediment habitats are well known[15, 21-23], its impacts on rocky reef communities have not been examined and is recommended as an important area for future research (Table 3; IM3).

Improved understanding of the role of human-mediated disturbance in the invasion process for *Asterias* is crucial for assessing impact and prioritising management activity (Table 3; IM4). Until this information is known, it is not clear where impact management funds should be best spent[44]. For example, if *Asterias* ‘tracks’ ecosystem dynamics by colonising disturbed habitats, funds may be best spend rehabilitating the environment. In contrast, if *Asterias* ‘drives’ ecosystem dynamics and can invade in the absence of disturbance, management funds would sensibly focus on direct control of the pest.

While the link between *Asterias* density and fertilisation success is well understood[59], the processes that occur between fertilisation and recruitment to the adult population remain poorly known[26] and are recommended as a priority research area (Table 3; IM5). Key aspects that need to be addressed include (1) whether there are density dependent effects on larval mortality and (2) what factors influence recruitment success. Addressing these questions will provide significant benefits to the *Asterias* NCP. For example, the ‘Management Strategy Evaluation’ framework developed by CSIRO[26] is a valuable tool for predicting the outcome of different management strategies for *Asterias*, but assumptions in relation to the above key questions lead to high levels of uncertainty in the modelling process. Similarly, the effectiveness of localised reduction of *Asterias* populations around wharves as a management response is reliant upon the direct link between larval abundance and recruitment. If this link does not exist or is weak, this management approach would be futile.

Rehabilitating or enhancing populations of native predators is a potential control option for *Asterias*. While predators of adult *Asterias* have been reported[44], further research is required to determine the most significant *Asterias* predators (including predators of juveniles) and whether they have the potential to influence *Asterias* population density (Table 3; IM6).

Removal of food associated with wharf structures has been suggested as a potential 'habitat management' option to control source *Asterias* populations[12, 36]. While this approach has merit, the practicalities of mechanical removal and effectiveness of the technique in reducing *Asterias* density requires critical evaluation (Table 3; IM7).

I. Public awareness and education strategies for the species

The Communications and Awareness Strategy for the National System is currently under development. While the activities planned are not species-specific, their implementation should generally be effective in meeting a number of the objectives of the *Asterias* NCP. For example public awareness and education strategies aimed at reducing the spread of marine pests through management of biofouling will be applicable to *Asterias*. Additional strategies which should be considered to enhance the effectiveness of the *Asterias* NCP include:

Additional strategies – Pest prevention

Additional public awareness strategies may include targeted public awareness campaigns directed at high risk nodes where *Asterias* is already established (e.g. ports, marinas and boat launching facilities) to reduce the risk of further translocation events. The proximity of transport vectors to high value locations such as aquaculture areas, important fisheries habitats and conservation areas may also warrant additional targeted public awareness strategies at the local level. Of the potential transport vectors, aquaculture and fishing (commercial and recreational) activities probably represent the greatest risk for translocation of *Asterias*. If additional public awareness strategies are developed, it is vital that these sectors are targeted.

Additional strategies – Contingency plan for new introductions

Early detection of new incursions is a critical factor in the success of eradication programs and the public can play a key role in this regard. Detection of new *Asterias* incursions is reliant upon an understanding of current distribution patterns and whether or not a 'significant range extension' has occurred. This is a complex issue when considering public awareness, for two main reasons. Firstly, spatial extent and spread is subject to change so public awareness strategies need to reflect this dynamic situation. Secondly, an improved understanding of likely natural spread is required to determine whether a 'significant range extension' has occurred. As outlined previously scientists and managers need to clearly define what constitutes a 'significant range extension' for *Asterias* so the public can be properly educated/informed.

Due to the potentially dynamic nature of the spread and spatial extent of *Asterias*, monitoring results will be incorporated into a new web-based system (i.e. via NIMPIS), including locations that would be considered a 'significant range extension'. Clearly for this to be effective, the marine pest monitoring database under the National System must include the most up-to-date information available.

With regard to new *Asterias* incursions, public awareness strategies in relation to emergency response are covered in the Australian Emergency Marine Pest Plan[38] (EMPPlan).

Additional strategies – Impact management

Additional public awareness and education strategies will require development on a case-by-case basis depending on the jurisdiction and impact management activities that are implemented. Information to be disseminated should highlight the threat posed by *Asterias*, the control approach (e.g. trapping) and the likely benefits of impact management (e.g. biodiversity, commercial activities).

J. *Agreed funding mechanisms*

The Intergovernmental Agreement (IGA) on a National System for the Prevention and Management of Marine Pest Incursions addresses the agreed funding mechanisms for implementing National Control Plans. In particular, Section 24.1 states that:

‘The Parties agree that funding for the ongoing management and control measures of the National System will need to be provided by the Parties in accordance with the shared and co-operative measures agreed through National Control Plans on a case by case basis. That Parties acknowledge that, where relevant, Partnership Agreements should be developed to provide funding support for ongoing management and control measures based on the level of benefit of the arrangement to stakeholders and government.’

Within the IGA a “Partnership Agreement means the agreement by that name (including any attachments or annexes to that agreement) between a stakeholder organisation and governments with respect to implementing and/or funding the National System”.

K. A multi-year budget

Providing accurate budget estimates is problematic because costs will depend on the management actions that are conducted by the relevant jurisdictions. There are also significant uncertainties associated with budget estimates for each section of the NCP. For example, costs associated with monitoring will depend on the need for additional monitoring sites and whether or not impact management activities are required. Providing a budget for impact management (e.g. physical removal) is complex because costs will depend upon numerous factors such as the spatial extent of the population, the location (i.e. accessible versus remote) and depth (e.g. is diving feasible?). The ability to utilise volunteers also has a strong influence on the budget required to implement NCP activities (see Table 4, Impact management) but it should be noted that there are potentially significant occupational health and safety issues associated with use of volunteers (refer to Holliday (2005)[43]).

Despite the uncertainties associated with provision of budgets, indicative costs for management activity within the relevant NCP sections have been provided in Table 4. These are intended as a rough guide for managers to assess the cost of implementing the various management activities outlined in the plan. The costs involved in habitat management were not included in the indicative budget for a number of reasons. Firstly, there is a significant level of uncertainty associated with cost estimates for habitat management (e.g. reducing food supply, environmental rehabilitation) and the capacity to implement such management depends on the jurisdiction concerned. Secondly, including habitat management within a *Asterias* budget is not considered appropriate, because it is unlikely that habitat management would be the carried out for the sole purpose of controlling *Asterias* populations (as discussed in section F).

Two case studies for impact management have been included in the budget including (1) localised reduction of high density 'source' *Asterias* populations associated with wharf structures; and (2) localised impact reduction. The case studies and assumptions underpinning the suggested management approaches are briefly described below. Refer to section F for discussion outlining the likely effectiveness and feasibility of physical removal as a management strategy.

Case study 1 - Localised reduction of high density 'source' Asterias populations

This case study is based upon reduction of *Asterias* population densities associated with wharf structures in the Derwent River, Tasmania. It has been estimate that approximately 260 000 (based on information collected in October 1999[36]) *Asterias* are associated with wharf structures in the Derwent River at an average density of 2 m^{-2}. A reduction in density of 90 % has been arbitrarily chosen as a target for the case study (it should be emphasised that although it is likely reduced larval production associated with *Asterias* removal will lead to decreased recruitment, this has not been explicitly tested). Immigration rates represent a significant source of uncertainty in relation to the effort required and it is ultimately difficult to predict[48]. An immigration rate of 50 % (over an estimated three month removal period) has been incorporated into calculations, resulting in an overall removal target of 351 000 *Asterias*.

Physical removal by diving is proposed as the preferred method of *Asterias* removal. A previous study that examined the cost-effectiveness of trapping and diving concluded that trapping was more cost effective for seastar densities above 1.5 m^{-2}, but diving was more appropriate below these densities[48]. It is envisaged that *Asterias* densities would be reduced to below 1.5 m^{-2} in the early stages of the removal program and therefore diver removal would be more cost effective in the long-term. The efficiency of trapping has also been reported to be reduced when there is an abundant food supply, so it is expected to be an inefficient method around wharf structures. It is assumed that most of the diving would be conducted at depths < 12 m, since diving becomes prohibitively expensive beyond this depth[48].

Two budgets are provided, based on commercial (1a) and volunteer (1b) divers. There is limited available information regarding the efficiency of diver removal, particularly as densities change. For commercial divers, it is estimated that an average catch rate of 200 *Asterias* per diver hour is feasible (total of 900 *Asterias* per person per day based on 4.5 dive hours per day). In the early stages of removal program, catch rates may be significantly higher, but are likely to drop as densities decline. For volunteer divers, calculations are based upon a previous community based dive, where 6000 individuals were removed by 22 divers[60].

Case study 2 Localised impact reduction.
Localised impact reduction is a potential option to protect high value areas such as an aquaculture area, MPAs, or habitats containing rare or threatened species. Indicative costs associated with diver removal of *Asterias* from a small (5000 m^2) area are presented. Immigrating *Asterias* again present uncertainty in relation to the effort required to reduce impacts in this scenario. In this particular case study, regular ongoing removals are proposed to reduce *Asterias* impacts. Budget estimates are provided for commercial (2a) and volunteer (2b) divers.

While the use of volunteer divers represents a significant cost saving, it is recommended that an operation of the magnitude proposed for *Case study 1* is far more likely to succeed using commercial divers. Maintaining enthusiasm at the intensity required (20 days over a three month period; 66 divers/day) is considered beyond the scope of a community based approach. Consideration could be given to using a combined approach, where a limited number of community dives are held in addition to the commercial component of the program. This approach would also have merit in terms of raising public awareness to the *Asterias* problem. Using volunteer divers for local impact reduction in *Case study 2* is considered more appropriate, because the intensity and frequency of diving required is considerably less.

Note that salary for a project officer at a nominal level of 0.5 FTE included to co-ordinate management activities outlined in the plan. It is envisaged that a full time position would incorporate management of other marine pest species at a national level – allocation of effort for each particular species would be based on the funding made available for each species.

Table 4. **Indicative budget for *Asterias* National Control Plan (as at January 2008).**

NCP section	Budget items	Likely Costs ($AUD)	Funding arrangements/ expected financier
Pest prevention	No applicable budget items	NA	**NA**
Contingency plan for new introductions	Eradication of new incursion (including on-going monitoring)	$860 000 – 263 million per incursion[2]	Interim cost-sharing arrangements are in place
Impact management	Case study example 1a. Physical removal of 'source' *Asterias* population[a] – fully funded. Staff ($195 000[b]), Boat Hire ($39 000[c]), Car hire ($7800[d]), Tank fills ($9360[e]), Consumables ($2000[f]), Waste management ($3000[g]).	$256 160 per year	State/territory governments
	Case study example 1b. Physical removal of 'source' *Asterias* population[a] – volunteer based. Boat fuel ($6000[h]), Tank fills (10 560[e]), Consumables ($2000[f]), Waste management ($3000[g]).	$21 560 per year	State/territory governments
	Case study example 2a. Local impact reduction[i] – fully funded. Staff ($30 000[b]), Boat hire ($6000[c]), Car hire ($1200[d]), Tank fills ($1440[e]), Consumables ($500[f]).	$39 140 per year	State/territory governments
	Case study example 2b. Local impact reduction[i] – volunteer based. Boat fuel ($600[j]), Tank fills ($1440[e]), Consumables ($500[f]).	$2540 per year	State/territory governments
	Habitat management (e.g. rehabilitation of environment)	Uncertain	State/territory governments
Monitoring	Additional monitoring sites to detect new incursions. -Requirement for additional monitoring sites will depend on jurisdiction and vectors operating.	$10 000- $20 000[k] per site per year	State/territory governments
	Monitoring: Case study 1 E.g. Monitoring effectiveness of *Asterias* removal and subsequent larval recruitment[l]. Staff ($18 000[b]), Boat hire ($6000[c]), Car hire ($1200[d]), Tank fills ($864[e]), Settlement collectors ($500[m]), Data analysis and write-up ($30 000[n]), Consumables ($500[f]).	$57 064 per year	State/territory governments
	Monitoring: Case study 2 E.g. Quarterly sampling of control and impact sites[o]. Staff ($12 000[b]), Boat hire ($4000[c]), Car hire ($800[d]), Data analysis and write-up ($10 000[n]) Car hire ($1600[e]), Consumables ($500[f]).	$28 900 per year	State/territory governments

[a] Based on 2 x 5 person dive teams, 9000 *Asterias* removed/day, total of 39 days; [b] Divers cost $500/day (salary plus per diem); [c] Boat hire $500/day; [d] Car hire $100/day; [e] Tank fills based on 1170 fills @ $8 per fill; [f] Consumables including catch bags, gloves, waterproof paper, slates, stationary; [g] based on hire of waste carts and skip bin [g] Cost effectiveness could be improved by surveying multiple pest species; [h] Fuel vouchers ($50), 20 days, 6 vouchers/day; [i] Based on 1 x 5 person dive team, monthly *Asterias* removals, 1 day/month; [j] Fuel vouchers ($50), 1 voucher/month; [k] Cost effectiveness could be improved by surveying multiple pest species; [l] Based on monthly dive surveys (1 x 3 person dive team) & annual retrieval of settlement collectors; total of 12 days; [m] 50 settlement collectors @ $10/collector; [n] Data analysis and write-up by suitably qualified scientist; [o] Based on 4 sites, 'impact' site and three control sites (1 x 3 person dive team), 2 days/quarter, total of 8 days.

Table 5 (continued). Indicative budget for *Asterias* National Control Plan (as at January 2008).

NCP section	Budget items	Likely Costs ($AUD)	Funding arrangements/ expected financier
	Monitoring rate of spread	$10 000 per year	To be advised
R&D	Various R&D areas (see Table 3)	1.275 million[p] over 3 years	Commonwealth & State/territory governments
Communications strategy	Depends on the impact management measures implemented	Uncertain	
Overall co-ordination	Salary for project officer (0.5 FTE)	$50 000 per year	To be advised

[p] Assumes all priority R&D areas are addressed.

L. A mechanism for monitoring of implementation of the National Control Plan and ongoing evaluation

An important component of the NCP involves monitoring implementation of the plan and critical evaluation of its effectiveness. Proposed performance indicators have been identified and these are provided in Table 5.

Table 6. **Potential performance indicators for the *Asterias* National Control Plan. Note that monitoring was not included as a criterion in its own right because the proposed performance indicators are inextricably linked to monitoring (e.g. Pest prevention - number of new populations; Emergency response - detection of new invasions; Impact Management – change in abundance over time).**

Criteria	Objectives	Performance Indicators
Pest prevention	(i) Prevent significant range extensions	Number of significant range extensions
	(ii) Prevent new populations establishing within current range of natural spread	Number of new self sustaining populations minimised, especially in high value areas
	(iii) Reduce translocation risk by improved vector management	Uptake of existing or proposed guidelines
	(iv) Development of additional strategies as required	Number of additional pest prevention measures developed
Contingency plan for new introductions	(i) Detect new invasions early enough to enable rapid response	Proportion of invasions detected in time for rapid response
	(ii) Eradication of new incursions	Eradication of new populations prior to spawning
	(iii) Increase range of effective eradication techniques	Number of effective eradication tools evaluated and available
Impact Management	(i) Prioritise *Asterias* impact management relative to other threats	*Asterias* impact management prioritised based on known and likely impacts
	(ii) Reduce impacts in high value areas	Detectable reduction in impacts
	(iii) Reduced population size & lowered reproductive output within high risk source regions	Detectable reduction in reproductive output in high risk source regions
	(iv) Long-term reduction in *Asterias* abundance	Decrease in abundance over time (e.g. 10 years)
R&D	(i) Implement priority R&D areas highlighted in plan	Number of priority R&D areas completed
	(ii) Re-evaluate R&D in response to research outcomes	Regular assessment and prioritisation of R&D activities
Public education	(i) Increased public awareness	Increased community knowledge of risk, impact & prevention/control measures
	(ii) Increase effective community involvement	Increased community involvement in detection and impact management activities; Increase in proportion of informative reports (e.g. correct ID's)

M. Stated commitments of relevant parties, including Australian Government, State/Territory governments, local government, industry and NGOs

The Intergovernmental Agreement on a National System for the Prevention and Management of Marine Pest Incursions (IGA) addresses the stated commitments of the Australian Government and the State and Northern Territory Governments in implementing the National Control Plans. In particular, Section 16a-16c states that:

The Parties will implement the ongoing management and control component of the National System as follows:

(a) each Party accepts responsibility for ongoing management and control activities for agreed pests of concern within waters under its control;

(b) National Control Plans, reflecting an agreed national response, will be developed to reduce, eliminate or prevent the impacts (including translocation) of agreed pests of concern;

(c) each Party will use reasonable endeavours to develop and implement the relevant National Control Plans;

(Currently, all States and the Northern Territory, with the exception of NSW, have signed the IGA. NSW have, however, agreed to intent of the IGA and are only concerned about the funding model in regards to a marine pest outbreak. This situation may change in the future.)

Agreements to implement a control plan by a jurisdiction may involve consultation and cooperation with other relevant jurisdictions (i.e., other State and Territory Governments) and with relevant local government, industry and the non-government organisations. These arrangements will depend on the nature of the particular control operation and will vary between operations.

Agreed Control Plan actions by the Australian Government, State and Territory Governments and stakeholder agencies will be identified as part of a National Implementation Strategy. The National Implementation Strategy document will be maintained independently of the National Control Plan documents, and updated to reflect current and proposed commitments.

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APPENDIX I – List of available resources to assist with implementation of NCP

Pest Prevention

- Australian domestic ballast water arrangements (under development)
- Biofouling Guidelines (guidelines for many sectors still under development)
  - National Biofouling Management Guidelines for Non-trading Vessels
  - National Biofouling Management Guidelines for the Petroleum Production and Exploration Industry
  - National Best Practice Management Biofouling Guidelines for the Aquaculture Industry
  - Best Practice Guidelines for Domestic Commercial Fishing Vessels
  - National Best Practice Management Guidelines for the Prevention of Biofouling on Commercial Vessels
  - National Biofouling Management Guidelines for Domestic Recreational Vessels
  - National Best Management Practice Biofouling Guidelines for Nodes- Commercial Trading Ports
  - National Best Management Practice Guidelines for Abandoned, Unseaworthy and Poorly Maintained Vessels
  - National Best Practice Management Biofouling Guidelines for Nodes- Boat Harbours, Marinas and Boat Maintenance Facilities

Contingency Plan for New Introductions

- National Introduced Marine Pest Information System[8] http://crimp.marine.csiro.au/nimpis
- The Web-Based Rapid Response Toolbox[39] http://crimp.marine.csiro.au/NIMPIS/controls.htm
- Pre-Developing Technology for Marine Pest Emergency Eradication Response[40] (in review)
- Rapid Response Manual – *Asterias amurensis* (under development)
- Australian Emergency Marine Pest Plan[38] (EMPPlan)
- National System Marine Pest Identification Card – *Asterias amurensis* (under development)

Monitoring

- Australian Marine Pest Monitoring Guidelines: Version 1 (December 2006)[52]
- Marine Pest Monitoring Manual: Version 1 (December 2006)[53]