COST BENEFIT ANALYSIS OF MANAGEMENT OPTIONS FOR DIDEMNUM VEXILLUM (CARPET SEA SQUIRT) IN SCOTLAND

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Report by Hambrey Consulting in Association with the Scottish Association for Marine Science and Poseidon Aquatic Resource Management to the Scottish Government TENDER REF: CR/2011/16

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REPORT BY HAMBREY CONSULTING IN ASSOCIATION WITH THE SCOTTISH ASSOCIATION FOR MARINE SCIENCE AND POSEIDON AQUATIC RESOURCE MANAGEMENT TO THE SCOTTISH GOVERNMENT TENDER REF: CR/2011/16

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EXECUTIVE SUMMARY

This report to the Scottish Government presents the basis for and results from an attempted cost-benefit comparison of three alternative management options considered as policy responses to the presence of *Didemnum vexillum* (Dv)in Scotland. It was based on a review of published literature and consultation with local stakeholders and global experts.

Dv is a non-native marine species of colonial sea squirt. It probably orginates from Japan but is distributed more widely, including in New Zealand, Canada, the USA, France, Ireland, the Netherlands plus more recently at several sites in England and at Holyhead in Wales.

Dv is a robust invasive species capable of surviving from rock pools to depths of 80m or more. It prefers hard substrates (not mud or sand) and is particularly at home on man-made structures and natural reefs. It can spread through both asexual budding/fragmentation and sexual reproduction, both of which involve a free floating planktonic phase. It is able to overwinter in a reduced form (unknown structure) in temperatures down to -2°C.

Dv was first detected in Scotland in 2009, with further monitoring during 2010 confirming its presence at three sites within the Firth of Clyde. Further spread is likely – locally within the Clyde area through its own dispersion mechanisms, and further afield, possibly through movements of boats and marine equipment/structures. Monitoring has not been undertaken in 2011 so the extent of spread is unknown.

Dv is tolerant of a range of environmental conditions in terms of water temperature, salinity and depth. Colonies are capable of rapid expansion, existing as either carpet-like or rope-like formations with growth fastest during summer months. Colonisation can occur sexually via larvae or asexually through translocation of viable colony fragments, for example as fouling on the hulls of boats or on relocated aquaculture equipment.*These characteristics mean that eradication will be extremely difficult and re-invasion likely. There are no examples of successful eradication to date.*

The *impacts* associated with the presence and spread of Dv may be summarized as follows:

- Displacement/smothering of native fouling species, and possibly wider but unknown effects on marine ecology and fisheries production
- Heavy fouling of man-made marine structures including pontoons, piles and moorings
- Fouling of shellfish farming equipment and growing substrate, and possibly smothering of growing stock
- Fouling of fish farm mooring and support structures and (where antifouling is not used regularly) fouling of nets
- Fouling of keep nets and other stationary equipment associated with creel fishing

The *costs* associated with these impacts are highly uncertain for several reasons:

- Great uncertainty associated with both the spread and severity of colonisation
- Great uncertainty associated with possible wider effects of Dv on the marine ecosystem, and the possible response of (for example) species that graze on sea squirts
- Great uncertainty associated with the marginal costs of increased fouling (native fouling of marine structures already represents a routine cost/management requirement for most maritime industries)

Such uncertainty hinders formal cost-benefit analysis of alternative policy responses in that quantification of relative effects is either highly dependent on assumptions rather than empirical evidence and/or not all elements can be quantified with equal robustness. Consequently, and *in-line with Green Book guidance*, speculative or overly complex analysis yielding spurious precision has been avoided here. Rather a cost-benefit framework has been used to identify impacts in a more qualitative manner, with no attempt at discounting over time but some discussion of likely relative magnitudes and outcomes. Evidence from invasion elsewhere in the world has been drawn upon through a literature review and consultation with leading global experts:

- In the US 473km2 of the Georges Bank is affected by Dv, with up to 75% coverage. No impact on fisheries has been detected to date.
- Dv has been present in Ireland since 2005. Standard management procedures have been implemented and it is now regarded as a small problem.
- In New Zealand eradication was attempted by the shellfish farming industry, but this failed. Losses to the mussel industry have been estimated at less than 5%. A number of cost benefit analyses have been undertaken for New Zealand Dv and these have been reviewed in detail.
- Wales undertook an eradication programme in 2009; however re-contamination occurred. CCW are currently seeking funds to undertake a second eradication attempt. Consultation and cost benefit analysis for Wales have been reviewed to inform this research.

Costs may arise due to the damage imposed by Dv on commercial and environmental interests, but also from efforts to avoid such damage. The policy objective is thus to minimise the sum of the two cost categories, with benefits equating to damage costs avoided. Hence mitigation effort may or may not be justified depending on how costly it is relative to the damage costs avoided. However, such judgements are clouded by uncertainties over the likelihood and timing of different costs, plus the distribution of costs and benefits across different stakeholder groups. Three options were considered.

Option 1: do nothing. This represents a baseline against which other options may be compared in that no government-sponsored management measures would be introduced to control Dv. Damage costs attributable to Dv would thus be expected to be at their highest under this approach. The costs under this option correspond to the costs associated with no action, and set the expected benefit of a successful eradication or management programme.

Unchecked, Dv has potentially significant impacts on food provisioning and wild species diversity. For the latter, the timing and magnitude of impact is difficult to quantify and may vary depending on the features of interest for which they have been designated, but the predicted distribution of Dv does not seem to threaten many designated conservation sites. For aquaculture, shellfish (particularly mussel) activities are most at risk, but available evidence suggests that yield losses and additional production costs are not necessarily excessive. On an annual basis, a 10% loss would equate to c.£0.7 million of turnover and c.£0.4 million Gross Value Added (GVA) for all of Scotland, or c.£0.2mturnover and c.£0.1m GVA if contamination were restricted to the Clyde, Minches & Malin Sea and Hebrides regions. Finfish activities might be affected through additional handling costs of fouled equipment, although the degree to which Dv would displace rather than add-to existing fouling levels is uncertain.

Dv is unlikely to have a significant effect on recreational and tourism values since activities on and above the waterline will not be affected; underwater activities might suffer marginally from overgrowth. Similarly, commercial navigation (i.e. ferries and shipping) and the use of water for industrial cooling (e.g. at

Hunterston) are unlikely to be affected since Dv fouling will be handled through existing cleaning procedures (the same applies to leisure boats). Water quality is not likely to be adversely affected.

Option 2: Attempt eradication of Dv at Largs/Fairlie. This would involve a complete eradication programme for all affected areas and would be expected to take place in January–April 2012, with follow-up monitoring for a minimum of 3 years and further eradication if needed.The costs associated with response option 2 (eradication) include:

- Direct costs associated with eradication by wrapping and treating infected structures
- Direct costs associated with eradication by cleaning and antifouling vessels
- Indirect costs associated with displaced vessels or restricted vessel movement
- Longer term impacts on marina and port business associated with disruption & inconvenience to clients

Eradication seeks to avoid all damage costs arising from Dv and is viewed as technically feasible within an enclosed area such as a marina. If successful, eradication from Scotland would avoid all of the costs identified under Option 1.

However, eradication has not been attempted in many locations and where it has (e.g., in New Zealand and Holyhead, Wales), it has not been successful (although efforts at Holyhead are on-going). Possible reasons for failure include re-contamination from elsewhere but also incomplete eradication at the selected sites due to, for example, phased rather than simultaneous treatment of all parts of the site and fragments escaping treatment as a result of practical difficulties with underwater manual operations.

If eradication were attempted using techniques and lessons-learnt from the New Zealand and Holyhead experiences (Coutts & Forest, 2007; Kleeman, 2009), the estimated process costs could amount to around £1.3m in year one. This reflects the large area to be treated (c.40,000m^2), the number of dive teams likely to be needed to complete the process relatively quickly and simultaneously plus the number of boats requiring treatment. Costs in years two and three, including on-going monitoring, may be lower depending on the level of successful eradication at the three sites.

However, the process of eradication would also impose costs on routine commercial activities at the affected sites since boat/ship movements can compromise the eradication process, for example by damaging encapsulation around piles and pontoons. The magnitude of business disruption costs is difficult to gauge but, for example, around 550 boats would be displaced from Largs Yacht Haven – representing a loss to LYH and allied marina businesses plus inconvenience to the boat owners. Equally, displacement of coal shipments from the Hunterston Coal Terminal could also represent a significant disruption cost if vessels could not port during wrapping procedures, due to risk of damaging plastic wrapping. If accelerant was used water quality could be adversely affected, necessitating a CAR license.

Option 3: Containment and management of Dv to limit detrimental impacts. This measure would be implemented from Winter 2011/12 and would, subject to ongoing review, continue indefinitely. This option would follow the recommendations laid out in the GB Non-native Species Secretariat's (GBNNSS) Pathway Management Plan.

This option would essentially accept the presence of Dv at the three known sites and thus avoid the costs of an eradication attempt, whilst seeking to reduce potential damage costs elsewhere by controlling the further spread of Dv in Scotland. Given the apparently limited negative impacts of the current Dv distribution, if effective, this option would also avoid most of the damage costs identified under Option 1 by preventing spread to other sites.

The costs associated with response option 3 (pathway management) depend critically on the stringency and extent of the measures taken. Two approaches are considered:

Rigorous. The greatest risk of spread is associated with yachts that have been moored and laid stagnant for a number of months. Rigorous pathway management would require that these boats be slipped, power washed and anti-fouled prior to departure, irrespective of treatment earlier in the year. Direct costs of this (to be borne either by the yachtsmen or through some form of government funded scheme) are estimated at approximately £600 per vessel. Rigorous pathway management would require this for all vessels leaving a marina known to have Dv colonisation, including English, Welsh, French and Irish marinas, as well as Largs Yacht Haven. These actions would have to be backed up by strict protocols/regulations for yachts using the marina and vessels visiting Hunterston Coal Terminal. Such an approach could well displace vessels to less onerous jurisdictions and/or simply reduce demand for recreational and commercial boating facilities.

Pragmatic. A perhaps more palatable, pragmatic approach would involve building on existing initiatives for invasive species, not necessarily with a species specific focus. Such local initiatives include the Clyde Forum Biosecurity Plan and the Green Blue Codes of Good Practise; national initiatives include general marina best practice, Codes of Good Practise for shellfish and fish farms including internal procedures and UK level invasives strategies. Key aspects of this approach will include: education and awareness, expanding codes of best practice to ensure adequate coverage of invasives and controls on vector movement. The costs of developing and enforcing such measures are difficult to estimate, but are likely to be less than an eradication programme – particularly if they build on existing information dissemination and training mechanisms. However, unless made mandatory, effectiveness will depend on high rates of information uptake and voluntary compliance with guidance amongst stakeholders – which in turn may rest on how well information reaches its target audience and/or how onerous/inconvenient adherence to guidance is. The latter represents a cost that should be accounted for.

In summary, although Dv represents a potentially significant invasive non-native species (INNS) problem, a lack of data and scientific understanding precludes a definitive, quantitative cost-benefit analysis of the situation and alternative policy responses. For example, the sources, rate and extent of further colonisation is uncertain, as are the consequences of colonisation. Equally, the costs and effectiveness of policy responses are somewhat speculative given the dynamic and stochastic nature of INNS and the practicalities of management actions.

Given these uncertainties, a single discounted cost benefit ratio would be inappropriate and of limited use in guiding decision making. Instead, the scale of costs and expected benefits has been summarized in Table 1 using a risk based assessment to determine both the severity of the impact and the uncertainty. On this basis, the most cost effective way forward appears to be **Option 3**, particularly given its applicability to wider biosecurity issues beyond simply Dv – provided that a pragmatic approach is adopted. Key policy points have emerged from the process of collating and reviewing available evidence and assessing the scale of costs and benefits. First, the damage costs of Dv do not appear to be excessive. Their likely irreversibility means that a precautionary principle approach could be justified if designated conservation sites or priority species and habitats are judged to be at risk of catastrophic loss. Indeed European and International obligations, such as the Marine Strategy Framework Directive (MSFD), Water Framework Directive (WFD) and the Habitat Directive may support this view with infraction penalties potentially being imposed if quality targets are not met. However, based on predicted spread of Dv across designated sites and the range of sites protecting reefs and lagoons, the overall risk is considered to be moderate and it is unlikely that entire features within a designated area would be impacted. Moreover, even if environmental damage was a serious concern, the management and disruption costs incurred in attempting to mitigate them would probably be accepted as disproportionate with low likelihood of success; no infraction penalties have been imposed yet on Member States experiencing Dv.

TABLE 1: SUMMARY OF OVERALL COSTS AND BENEFITS FOR EACH OPTION

		Option 1*	Option 2		Option 3	
Ecosystem Service	**Sector**	**Cost**	**Cost**	**Benefit**	**Cost**	**Benefit**
Food	Shellfish farming	Moderate		Moderate		Moderate
	Finfish farming	Low		Low		Low
	Capture fisheries	Low	Low	Low	Low	Low
Recreation and tourism	Marinas		Very High		Moderate	
	Yachts		Moderate		Moderate	
	Other recreation	Low		Low		Low
Navigation	Ferries				Low	
	Shipping		High		Moderate	
Wild species diversity	Marine protected areas	Moderate		Moderate		Low
Cooling water	Power plant	Low		Low		Low
Water quality regulation	CAR and MSFD & WFD	Low	Low			
Public sector	Eradication process		Very High	Low	Moderate	Low

* Since option 1 is the baseline it is not appropriate to assess benefits of costs avoided by not following other options

Second, if eradication is to be attempted, the likelihood of success will be enhanced if the entire affected area is treated simultaneously rather than in stages. This would necessitate deploying a relatively large number of divers and suspending other commercial and leisure activities at those sites for a period over the winter months with repeat treatments likely to be needed in subsequent years. Eradication costs, both in terms of the process itself and business disruption would be significant. Given the risk of re-contamination from elsewhere following eradication, Option 3 measures should accompany Option 2.

Third, unlike the discrete costs of eradication, an on-going programme of pathway management would have lower annual costs but several recurrent cost elements, such as information provision and monitoring. The design of such measures should consider the incentive structures and informational and institutional constraints facing different stakeholder groups, and thus variation in behaviour. For example, the influence of ignorance and/or compliance costs on voluntary uptake of best practice in biosecurity across different target audiences might merit further investigation, as would considering use of incentives to promote behavior change such as the idea being explored in New Zealand to reduce berthing fees for recreational boats that can demonstrate good anti-fouling practice.

Fourth, the range of pathways by which Dv can arrive, the existence of Dv in neighbouring countries and the variety of stakeholders involved all suggest that the effectiveness of policy responses could be enhanced through a co-ordinated approach, both in terms of inter-national management practices and consideration of all invasive species, to exploit biosecurity network effects.

1 INTRODUCTION

This report has been prepared as part of the Scottish Government contract for *an assessment of the options available for dealing with Didemnum vexillum (Carpet sea squirt) as a marine invasive non-native species (INNS)*. This work builds on the recent Scottish Natural Heritage (SNH) report '*Initial response to the invasive carpet sea squirt, Didemnum vexillum, in Scotland*' (Beveridge *et al*., 2011)but also draws on recent experience elsewhere in the UK and beyond. *Didemnum vexillum* will be referred to as Dv throughout the report.

The objective of the current assessment is to attempta cost-benefit analysis to inform the decision on the course of action to be taken in response to the detected presenceof Dv at Largs. The cost-benefit analysis considers the following three management options, pre-specified by the Scottish Government:

> **Option 1**–Do nothing; this is the default option against which each of the other options should be compared. Under this approach, no government-sponsored management measures would be introduced to control Dv.
>
> **Option 2**–Attempt eradication of Dv at Largs/Fairlie. This would involve a complete eradication programme for all affected areas, based on the techniques used at Holyhead, and involve, for example encapsulation, air drying, and/or biocides. This eradication would be expected to take place in January–April 2012, with follow-up monitoring for a minimum of 3 years and further eradication if needed.
>
> **Option 3**–Containment and management of Dv to limit detrimental impacts. This measure would be implemented from Winter 2011/12 and would, subject to ongoing review, continue indefinitely. This option would follow the recommendations laid out in the GB Non-native Species Secretariat's (GBNNSS) Pathway Management Plan. The key aspects of this will include: education and awareness, developing codes of best practice, controls on vector movement, quarantine practices, etc.

2 METHODOLOGY

2.1 Approach

This report provides an overview of the biology of Dv, its global occurrence and current Scottish status and potential spread. The potential biodiversity and socio-economic impacts are reviewed, together with an outline of the available options for eradication and management of Dv. UK and international experience of managing Dvis explored in some detail, including outcomes of treatment processes and consequences of living with the presence of Dv.

Evidence reviewed includes literature – both academic and grey – plus stakeholder and expert views sought via consultation within and outwith Scotland (notably England, Wales and New Zealand).

This report reviews the existing ecosystem services to establish the extent of the possible impact and risks of Dv. The ecosystem services included within the report were agreed with the steering group as follows:

- Food: shellfish farming, finfish farming and capture fisheries;
- Recreation and tourism: marinas, yachts and other recreation (diving etc);
- Navigation: ferries and shipping;
- Wild species diversity: marine protected areas;
- Cooling water: power stations; and

- Water quality regulation: Controlled Activities Regulation.

Costs and benefits are then analysed for each of the ecosystem services and sectors, including process costs of implementing the management option. The literature review and consultation has been key to informing thecost benefits analysis and highlight relevant recommendations to support the options and strategy being assessed.

ASSESSMENT OF COSTS

Monetisation of costs/benefits for the three options has been undertaken with care. While it is recognized that sophisticated methodologies exist to apply monetary values to almost any form of cost or benefit, some of these are both costly and of questionable validity, and may not offer a robust or accessible underpinning to inclusive or participatory decision making. Direct monetisation has therefore not been possible for all ecosystem services identified. As a result of this and to allow objective comparison across the three options under assessment, the severity of costs resulting from the impacts of each option have been assessed on a scale of: major, high, considerable, minor and slight based on boundaries presented in Table 2. The likelihood of occurrence that each impact will occur has been assessed on a scale of: certain, probable, possible, uncertain and highly uncertain (Table 3). The severity and uncertainty levels have then been combined to give an overall risk rating on a scale of: very high, high, moderate and low as presented in Table 4.

TABLE 2: BOUNDARIES FOR SEVERITY / IMPACT LEVEL

			Cost to Industry	Cost to Environment
Severity / Impact Level	**5**	Major	Unlikely to reduce Gross Value Added (GVA) by more than 40%	Long-term, extensive environmental damage
	4	High	Unlikely to reduce GVA by more than 25%	Severe national environmental damage
	3	Considerable	Unlikely to reduce GVA by more than 10%	Regional environmental effect
	2	Minor / Limited	Unlikely to reduce GVA by more than 5%	Local environmental effect
	1	Slight	Unlikely to reduce GVA by more than 2%	Limited environmental impact

TABLE 3: BOUNDARIES FOR UNCERTAINTY LEVELS

		Keyword	Uncertainty Guidance
Uncertainty/ confidence of occurence	**5**	**Certain**	90% probability of occurrence i.e. expected to happen with certainty
	4	**Probable**	70% probability of occurrence i.e. more likely to happen than not
	3	**Possible**	50% probability of occurrence i.e. may happen
	2	**Uncertain**	30% probability of occurrence i.e. uncertain whether it will happen
	1	**Highly uncertain**	10% probability of occurrence i.e. extremely uncertain whether it will happen

TABLE 4: OVERALL RISK RATING BASED ON SEVERITY OF IMPACT AND UNCERTAINTY THAT THIS IMPACT WILL OCCUR

Severity / impact level		Uncertainty				
		1	2	3	4	5
		Highly uncertain	Uncertain	Possible	Probable	Certain
5	Major	High	High	High	High	High
4	High	Moderate	Moderate	High	High	High
3	Considerable	Low	Moderate	Moderate	Moderate	High
2	Minor / Limited	Low	Low	Low	Moderate	Moderate
1	Slight	Low	Low	Low	Low	Low

2.2 Consultation

Consultation has provided important insight into this cost benefit analysis and also acted to disseminate information on Dv to wider stakeholders. Two fact sheets produced by the GB Non-Native Species Secretariat(2011)were used in the wider dissemination, one to outline potential impacts and a second that aidsidentification of Dv.

The stakeholders consulted during this project are presented in Table 5.

TABLE 5: LIST OF STAKEHOLDERS CONSULTED

Sector	Location	Stakeholder company/association	Contact person	Contact
UK and International Dv experts	Wales	CCW	Rohan Holt	Email communication
	England	Cefas	Ian Laing	Email communication
	UK	MBA	John Bishop	Email contact
	New Zealand	Marine Biosecurity Scientist, Cawthorn Institute	Barrie Forrest	Email and Skype communication
	New Zealand	Senior Scientist, Aquenal Ply Ltd	Ashley Coutts	Email communication
	New Zealand	Research Manager, Malborough Mussel Company	Aaron Pannell	Email contact
	USA	U.S. Geological Survey	Page Valentine	Email communication
	Canada	Fisheries and Oceans Canada	Marie-Claude Fortin	Email communication
Aquaculture industry	Loch Fyne	Scottish Salmon Farms/ Lighthouse of Scotland / Lighthouse Caledonia	Rebecca Dean and Sean Pyne	Met at Clyde Biosecurity workshop and follow up telephone call and email communication
		Loch Fyne Oysters	David Attwood	Email contact
	Loch Striven	Scottish Salmon Company	Mr Peter Roy	Email contact
	Arran	Scottish Salmon Farms	Rebecca Dean and Sean Pyne	Met at Clyde Biosecurity workshop and follow up telephone call and email communication
		Marine Harvest (Scotland) Ltd	Helen Aitken	Email contact
	Largs	Cumbrae Oysters	Alan Forbes	Email and telephone

Sector	Location	Stakeholder company/association	Contact person	Contact
	Mull	Mussel farm	Douglas Wilson	Met at ASSG conference
	Scottish wide	Scottish Shellfish Marketing Group	Stephen Cameron	Email contact
		Association of Scottish Shellfish Growers	Walter Speirs (Chairman)	Met at ASSG conf and email sent
		Association of Scottish Shellfish Growers	John and Nicki Holmyard	Met at ASSG conf
		Scottish Salmon Producers Organisation SSPO	John Webster	Email contact
Harbours, Marinas, Piers	Largs	Fairlie Quay Marina	Stuart Chalmers	Face to face meeting
		Largs Yacht Haven	Carolyn Elder	Face to face meeting
	Cumbrae	Cumbrae Water Sports	Chris Nichol	Email communication
	Wider Clyde	Holyloch Marina	Marina Manager	Email contact
		Kip Marina	Brian Rowley	Email communication
		Clyde Cruising Club	Club Administrator: Jennifer Rolland; Commodore: John Watson	Email communication
Other		Clyde SSMEI / Clyde Forum	Project Manager for Clyde Forum	Met at Clyde Biosecurity workshop
		The Green Blue	Sarah Brown	Met at Clyde Biosecurity workshop and follow up telephone call and email communication
		Hunterston Power Station, British Energy	Michael Campbell	Email communication
		Clyde Inshore Fisheries Group	Alex Watson Crook	Email communication

Stakeholders were identified from discussions with the project steering group, existing professional contacts of the research team and relevant literature.

3 *DIDEMNUM VEXILLUM* BIOLOGY & ECOLOGY

3.1 Taxonomy

Didemnum vexillum(Kott, 2002) is an invasive non-native marine species of colonial sea squirt. Uncertainties in the past over its taxonomy have led it to it being previously described as *D. vestum*, *Didemnum* sp. and *Didemnum* sp. A., however, recent genetic analysis of these *Didemnum* species has concluded they were indeed Dv and that it potentially originates from Japan (Lambert, 2009; Stefaniak*et al.*, 2009).

3.2 Appearance

Didemnum vexillum can exhibit a wide variety of growth forms, including mat- or sheet-like colonies with short lobe-like structures and rope or beard-like colonies which can extend to up to 2m in length (Kleeman, 2009). Colony colour can vary from pink to pale yellow or orange and the surface appearance can be smooth and/or covered with 'warty' protruberances, together with highly visible cloacal canals (Valentine*et al.*, 2007a).The colony is composed of many small individuals or 'zooids' that filter seawater for food particles. Each zooid is approximately 1 mm long and 0.2 mm wide (Kott, 2002).

FIGURE 1: *DIDEMNUM VEXILLUM* COLONIES GROWING ON A SUBMERGED ROPE AT LARGS MARINA, FIRTH OF CLYDE IN FEBRUARY 2010 (© C. BEVERIDGE)

3.3 Habitat Preference

This species can over-grow a wide variety of structures including; natural 'hard' substrata such as pebble, gravel, cobble and bedrock (Valentine, 2007); plants, algae and sessile invertebrates (Valentine*et al.*, 2007b;Kleeman, 2009; Beveridge*et al.*, 2011;Gittenberger, 2007), sea grasses (Carman and Grunden, 2010) and artificial 'hard' structures such as boat hulls, marina pontoons, dock pilings (Bullard*et al.* 2007), ropes, shellfish creels, plastic creels and tyres (Beveridge *et al.*, 2011), mussel longlines, oyster trestles and salmon cage netting (Kleeman, 2009). No artificial structure to date has been known to repel this species (Valentine*et al.*, 2007b).

Didemnum vexillum can tolerate depths from inter-tidal rock pools (Valentine*et al.*, 2007b), shallow estuaries and lagoons (Morris *et al.*, 2009);Carman and Grunden, 2010) to offshore gravel banks at a depth greater than 80 metres (Valentine*et al.*, 2007a; Lengyel*et al.*, 2009). However, it appears that this species is unable to tolerate surfaces composed predominantly of sand or mud and may be vulnerable to smothering by fine grained sediment (Valentineet *al*., 2007b;Coutts, 2002).

3.4 Reproduction and recruitment

This species can reproduce extremely rapidly, both sexually and asexually (Lambert, 2009) and increases in mean biomass of 60% in two weeks at a depth of 2.5 m have been reported on the northeast coast of the US at temperatures between ~20 and 25.6 °C (Bullard and Whitlatch, 2009). Colonies formed through fragmentation (asexual) and subsequent re-attachment have exhibited a 11 - 19 fold increase in colony size within the first 30 days in tidal pools in northeastern U.S. (Valentineet *al*., 2007b). In New Zealand, colonies have reached 30 cm in diameter within 21 days following larval settlement (Kleeman, 2009). Massive colonies of Dv can occur within a few years after the initial introduction and the carpet-like growth form now occupies a total of473 km^2 of seabed on the Georges Bank fishing grounds, northeastern U.S. (Valentineet al., 2007a). Despite this no effects on the scallop fishery in this area have been reported (see Section 5: Impacts).

Dv can tolerate a wide temperature range from -2 to > 26 °C in tidal pools on the northeast coast of the U.S. (Valentineet al., 2007b) and it is highly likely that temperature is an important factor in controlling the seasonal cycle of growth and degeneration that has been observed in shallow water habitats (Valentineet al., 2007b). Typically, the asexual growth phase is initiated when water temperatures reach 8 to 12 °C, along the NE coast of the U.S. this equates to a growing period between May and December in near-shore environments (Valentineet al., 2007b). In The Netherlands, the optimal growing temperature for Didemnum sp. appears to be 14–18 °C (Gittenberger, 2007). Asexual growth occurs through the rapid 'budding' of zooids embedded in the outer covering or tunic of the colony and can enable this species to spread via fragmentation. Carman (2008) found that these fragments could not only survive suspension for upto 30 days (15 % survival), but that they could change their gross morphology into spheres thus making them more easily dispersed. In addition, fragments of Dv are able to re-attach within six hours of making contact with a hard substrate (Bullardet al., 2007).

The sexual phase tends to occur during the summer months when growth rates and water temperatures are at their highest. Valentine et al. (2009) suggest that the release of larvae and subsequent recruitment typically occurs at water temperatures between 14 and 20°C, but this can be highly dependent on local conditions. In the UK, new colonies of Dv occurred on experimental panels in a marina in south-west Scotland in August 2009, when the water temperature ranged from 15 to 16 °C (Cook, unpub.) and in Holyhead marina, Wales recruitment was observed between August and December when water temperatures ranged from 16 to 9 °C, respectively (Jenkins et al. 2010). During the sexual reproductive phase, embryos are brooded within the tunic of the colony and can take several weeks to mature (Lambert, 2009). Free-swimming 'tadpole' larvae (~1.4mm in length) are then released gradually over 3 to 5 months (Valentine et al. 2009; Jenkins et al. 2010), although little is known regarding larval development and release cues (Lambert, 2009). The larvae are only competent to settle for a few hours following release (Kott, 2002). In the early stages following release the larvae are positively phototatic, however, after 24 – 48 hours in laboratory conditions, the larvae exhibited greater settlement success under shaded conditions (Fletcher and Forrest, 2011).

Colonies have then been observed to rapidly decline in size and degenerate from October onwards on the NE coast of the U.S., as temperatures decreased below 15 °C. These colonies typically appeared to have dark patches across their surface, which related to trapped faecal pellets in the cloacal canals and cavities near the surface of the tunic (Valentineet al., 2007a). Dv can then survive in an unidentified over-wintering (resting) stage at temperatures below zero until the following spring (Valentineet al., 2007a;Daley and Scavia, 2008). This seasonal growth cycle of Didemnum sp. has been observed in many other ascidian species and has been described in detail in (Berrill, 1951).In contrast, it has been suggested that this seasonal cycle is not occurring in colonies inhabiting offshore deep water environments (> 40 m), where the temperature range and daily fluctuations are much smaller compared to tide pool or near shore habitats (Valentineet al., 2007b). On the Georges Bank, no signs of deterioration in the colonies have been observed and larvae were found in November, suggesting that these colonies are able to survive and reproduce within a temperature range of 4 to 15 °C (Valentineet al., 2007a). Established colonies have also recently been found both intertidally and subtidally to a depth of 16 m on the west coast of Alaska, where the temperature range is 3.7 to 15.1 °C (Cohen et al., 201).

3.5 Environmental tolerances

Tolerance to salinities below 20 ppt is minimal for Dv[1],greatest growth in a short term *in situ* experiment on the northeast coast of the U.S. was between 26-30 ppt (Bullard and Whitlatch, 2009). However, positive growth was observed, albeit significantly reduced compared to the colonies held at 26-30 ppt, in colonies held for 2 weeks in an upstream site in the Thames River estuary (NE U.S.), where salinity ranged from 10 – 26 ppt (Bullard and Whitlatch, 2009) and Dv has been reported from the Kiso River estuary, Japan (Lambert 2009)suggesting that this species can withstand short term significant reductions in salinity. This is supported by a recent laboratory study, which demonstrated that Dv still exhibited positive growth rates and a 40% survival rate at a salinitiy of 20 ppt over a two week period, although growth rates were significantly reduced compared to the 104% increase in colony surface area within one week when Dv was held at 34 ppt (ambient) (Gröner *et al.* in press). *Didemnum vexillum* is able to survive upto one-hour immersed in freshwater, but freshwater baths lasting between 3 to 24 hours and freshwater sprays for 10 minutes were effective against Dv covering wild, blue mussel *Mytilus edulis* seed (Carman *et al.* 2010).

Dv is also tolerant of short periods of emersion. Valentine *et al.* (2007b) found colonies able to withstand short periods of exposure to air at low tide during the main growing season (July to September) on the NE coast of the U.S. High mortality is experienced, however, with prolonged exposure for more than 3 hours per day for 28 consecutive days (Valentine *et al.*, 2005), but it was highlighted that this time period would be highly dependent on air temperature and humidity at a particular site. Carman *et al.*(2010) also found that Dv, colonizing wild mussel seed in aquaculture bags, could withstand up to six hours of exposure to sun and air, whereas noticeable mortality was recorded for the mussel seed after five hours.

3.6 Biological Control

Grazing by gastropod snails, including *Littorina littorea*(Valentine*et al.*, 2007a), *Trivia arctica* and *Lamellaria* sp. (Gittenberger, 2007), sea urchins and sea stars and overgrowth by the invasive colonial tunicate *Botrylloides violaceus* has been observed on degenerating colonies of Dv (Bullard and Whitlatch, 2007). Actively growing colonies were thought to be resistant to predation, overgrowth or colonization by other organisms, potentially through the production of anti-fouling chemicals, as seen in the didemnids *Didemnum candidum*(Pisut and Pawlik, 2002) and *Polysyncraton lacazei*(Wahl and Banaigs, 1991).However, recent studies in New Zealand have shown that the cushion sea star *Patiriella* sp. and sea urchin *Evechinus* sp. are highly effective at removing 'healthy' colonies of Dv from the seabed (B. Forrest, pers. comm.).

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[1] Note that if salinity could be reduced to at least 10ppt for a few days this could potential act as a control measure for Dv.

4 OCCURANCE

4.1 Current status

Didemnum vexillum has become established worldwide (see Lambert, 2009 for review)and has been recorded from cool temperate regions in both the northern and southern hemispheres; including the north-east coast of the United States (U.S.) in 1970s, the north-west coast of the U.S. in 1993, New Zealand in 2001and British Columbia in 2003 (Lambert, 2009). It was first identified in Europe in The Netherlands in 1991(Ates, 1998) and has since been recorded in France in 1998 (Lambert, 2009), Ireland in 2005 (Minchin& Sides, 2006), Spain (El Nagar*et al.*, 2010) and the United Kingdom (Griffith*et al.*, 2009) in 2008 and the west coast of Alaska in 2010 (Cohen*et al.*, 2011).

In the UK, Dv was first recorded in Holyhead marina, north Wales (Griffith*et al.*, 2009) and in Plymouth, south coast of England in 2008 (Bishop, pers. comm.). This species was then reported in two further sites on the south coast of England (Dart Estuary, Devon and the Solent, Hampshire, Isle of Wight)(Bishop*et al.*, 2010) and for the first time in Scotland (Firth of Clyde) in 2009 (Beveridge *et al.*, 2011). The most recent confirmed sighting of Dv is from the north coast of Kent in July 2011, where it was recorded for the first time in the UK on 'natural' substratum (i.e. boulders and macroalgae) on the lower shore at Seasalter, near Whitstable (McKnight, 2011) (Fig. 2)

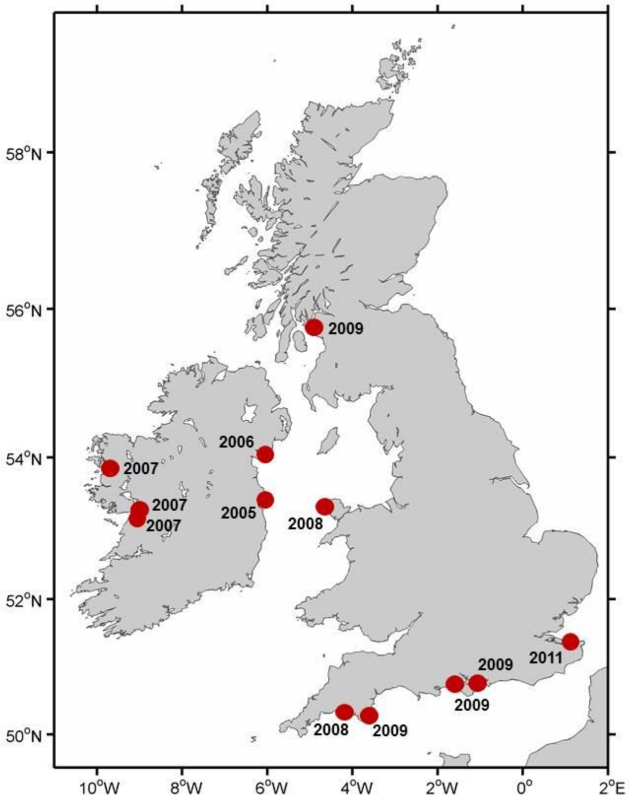

FIGURE 2: MAP SHOWING DISTRIBUTION AND DATE OF FIRST RECORD OF *DIDEMNUM VEXILLUM IN THE UK AND IRELAND*

In Scotland, the first record of Dv was confirmed in November 2009 in Largs Yacht Haven located in the Firth of Clyde during a routine non-native species survey of marinas by researchers from the Scottish Association for Marine Science (SAMS). This survey had also been conducted by SAMS at two other marinas; Clyde Ardrossan and Troon and no sign of Dv had been found. Previous surveys for non-native species in the 10 largest marinas in Scotland in August 2006 (Ashton*et al.*, 2006), 2007 and 2008 (Cook, unpublished data) did not find any sign of Dv, suggesting that this introduction in Largs Yacht Haven (LYH) occurred in 2009. Subsequently, additional surveys were conducted to determine the extent of the infestation in Scotland. In February 2010, twelve locations, including ten marinas and two harbours in south-west Scotland were surveyed, from Dunstaffnage marina near Oban in the north to Portpatrick, Mull of Galloway in the south. Only LYH was found to contain Dv (Beveridge*et al.*, 2011). In April 2010, a further twelve locations including two marinas, eight piers and two areas of swinging moorings were surveyed in the vicinity of LYH. *Didemnum vexillum* was found at three locations outside LYH including; a rope and ~70% of the pilings at Fairlie Quay Jetty, a rope on a small marker buoy at Fairlie Moorings and two pilings and a ladder at Clydeport Jetty (Beveridge *et al.*, 2011). Eleven survey dives using a camera mounted in a remotely operated vehicle (ROV) were also undertaken in July 2010 on ‘hard ground’. The maximum depth recorded on these dives was 14.6 m and Dv was not found on the seabed, but was present on the heavily fouled chain of a navigation buoy mooring chain,situated in the vicinity of LYH and Clydeport Jetty(Beveridge *et al.*, 2011). No further targeted surveys have taken placeor confirmed sightings have been reported for Dv since July 2010 (F. Manson, pers. comm.).

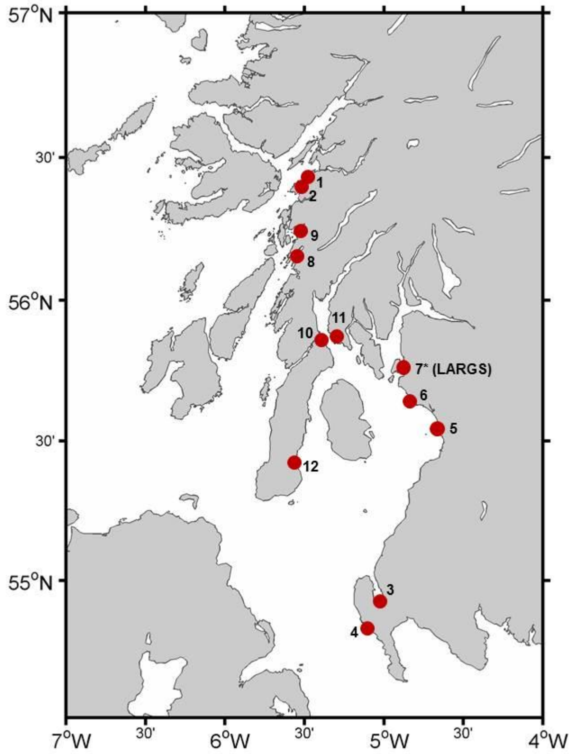

FIGURE 3: MAP SHOWING LOCATION OF 12 SITES IN SOUTH-WEST SCOTLAND SURVEYED IN FEBRUARY 2010; 1. DUNSTAFFNAGE, 2.OBAN, 3.STRANRAER, 4.PORTPATRICK, 5.TROON, 6.CLYDE ARDROSSAN, 7*. LARGS YACHT HAVEN (D.VEXILLUM PREVIOUSLY IDENTIFIED AT THIS SITE IN NOVEMBER 2009), 8. ARDFERN, 9.CRAOBH HAVEN, 10.TARBERT, 11.PORTAVADIE, 12. CAMPBELTOWN.(SOURCE: BEVERIDGE *ET AL*. 2010)

4.2 Potential spread

Didemnum vexillum has most likely been spread globally by shipping, either as hull fouling or within sea chests (ballast water intake chambers) on commercial vessels (Lambert, 2009). In New Zealand, the dispersal of this species was linked to the movement of a slow-moving commercial barge (Coutts, 2002) and subsequent spread linked to the movement of an infected salmon farm pontoon (Coutts*et al*., 2007). In Ireland, it has been linked to leisure craft and in France to commercial shipping (Minchin& Sides, 2006). In addition, subsequent localised dispersal has been associated with small craft, fouled aquaculture stock and equipment, and drifting and reattachment of dislodged fragments (Lambert, 2009). The natural dispersal of Dv, however, either through the passive movement of detached fragments and larvae via currents or wind drift or via the attachment to mobile, hard shelled species is poorly understood and requires further investigation.

To predict the potential spread of Dv in the UK, modeling studies have been undertaken for England (Laing*et al*., 2010) and Scotland (Somerwill, 2010) adapting the model by Herborg *et al*. (2009). These models have shown that suitable areas for colonization of this species exist all around the UK coastline, that these areas are typically associated with increased recreational boating activity and that they include regions of both commercial and biodiversity interests (Laing*et al*., 2010;Somerwill, 2010). In Scotland, the model predicted that the west coast was the most likely region to be colonised, since Dv is already established in south-west Scotland and that Tarbert, Dunstaffnage, Troon and Clyde marinas were classified as ‘high risk’ (Somerwill, 2010). It was also stated that both models were limited by a lack of quantitative data and still required ground truthing (Somerwill, 2010;Laing*et al*., 2010).

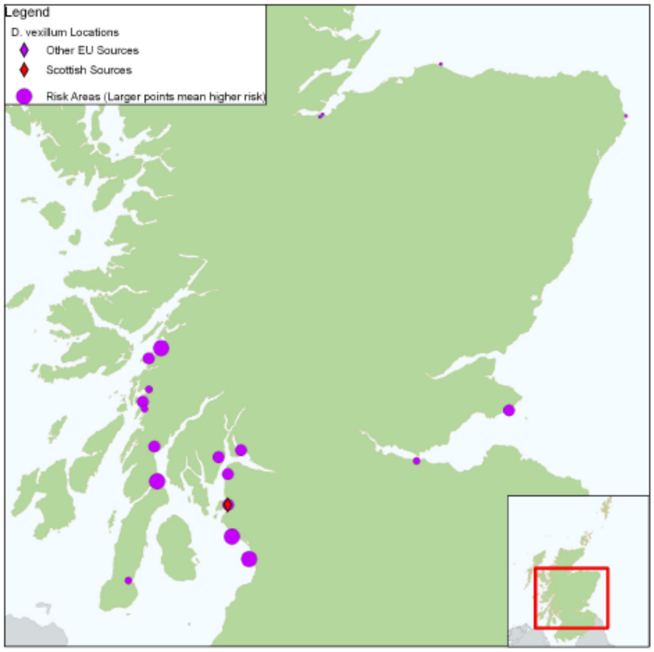

FIGURE 4: PREDICTED SPREAD OF D.IDEMNUM VEXILLUM FROM ALL KNOWN COLONIES OF THE SPECIES TO ALL AREAS OF THE SCOTTISH COASTLINE (SOURCE: SOMERWILL 2010)

5 IMPACTS

5.1 Biodiversity

The '*potential*' ecological impacts of this species are significant, including the overgrowth of fish spawning grounds (Valentine *et al*., 2007a), the prevention of demersal fish species foraging on benthic prey (USGS, 2010) and the competitive exclusion of native species (Gittenberger, 2007).

The impacts on fish spawning grounds and the prevention of foraging by demersal fish species are still to be scientifically proven with robust experimental design. The long term impacts on biodiversity of Dv in invaded regions are yet to be examined as most introductions are relatively recent. However, Dvhas been shown to have a negative impact on species diversity and abundance on the Georges Bank, northeast U.S. (Lengyel*et al*., 2009) and in The Netherlands (Gittenberger, 2007). Lengyel *et al*. (2009) found that the number of benthic macrofauna significantly declined with an increase in the abundance of Dv and that benthic species composition was significantly altered after the appearance of this species on the Georges Bank. This change was predominantly caused by a significant increase in two burrowing polychaete species; *Nereis zonata* and *Harmothoe extenuata* underneath the Dv colonies compared with the reference sites (Lengyel*et al*., 2009). In The Netherlands, species diversity also decreased significantly, following the rapid increase in Dv colonies, which can locally cover > 95% of the hard bottom in the regions of Oosterschelde and Grevelingen (Gittenberger, 2007).

In The Netherlands, Dv has been observed overgrowing a wide variety of species, including the sponge *Clione celata;* sea anemone *Diadumene cincta;* and bivalves, including the blue mussel *Mytilus edulis* and the oysters *Crassostrea gigas* and *Ostrea edulis* (Gittenberger, 2007).The latter native oyster species is highlighted by the Scottish Natural Heritage as a 'threatened species of socio-economic value' in their Five Year Species Action Framework Plan(SNH, 2007). Other species include a variety of hydroids, colonial ascidians *Aplidium glabrun* and *Diplosoma listeranum* and solitary ascidians *Styela clava* (non-native) and *Ascidiella aspersa*(Gittenberger, 2007). The majority of species that are overgrown by Dv appear to die upon contact, with the exception of the solitary ascidians which survive as long as their siphons remain uncovered. Species able to prevent overgrowth by Dv in The Netherlands are the tube-worm *Sabella pavonina*, sea anemone *Sagartia elegans* and the invasive non-native colonial ascidian *Botrylloides violaceus*(Gittenberger, 2007).

Kleeman (2009) and Laing *et al*. (2010) consider 'reefs' and 'lagoons', designated as priority habitats under the EC Habitats Directive, as particularly vulnerable to colonization by Dv. These reef habitats include; rocky intertidal and subtidal reefs and biogenic reefs, such as those formed by the horse mussel *Modiolus modiolus*, blue mussel *Mytilus edulis*, honeycomb worm *Sabellaria alveolata* and mearl beds. The lagoon habitat includes the eelgrass beds (*Zostera* spp.), which Dv has been shown to overgrow in Lake Tashmoo, Massachusetts, U.S.(Carman*et al*., 2010). In Scotland, the Priority Marine Features (PMFs) on the draft list that could be affected by Dv include: blue mussel beds, flame shell beds, horse mussel beds, mearl beds, native oysters, seagrass beds and serpulid aggregations (SNH, 2011).

5.2 Socio-economic

5.2.1 Aquaculture

Dvis documented to impact shellfish and finfish aquaculture by fouling cultured bivalves and cultivation gear for both shellfish and finfish farms (Coutts, 2007; Lambert, 2009), impeding water exchange, increasing operating costs (Carman *et al*., 2010) and reducing the reproductive output of bivalves, thus potentially impacting spat collection (Auker and Harris, 2010). Suspended bivalve and finfish aquaculture infrastructure provides suitable substratum for sessile organisms to settle, including Dv.

A recent study in New Zealand has found that Dv displaced significantly greater numbers of small mussels (10 – 20 mm shell length) from long lines compared with larger mussels leading to concern over the potential impacts of Dv on the collection of wild mussel spat for the aquaculture industry (B. Forrest, pers. comm.).Lines and cages weighed down by ascidians also require cleaning before they can be retrieved, and ascidians need to be removed from shellfish species before they are marketable.Furthermore, in the case of bottom cultivated mussels presence near spat and immature seeding mussels is a potential problem as it may force the need to eradicate Dv before mussels can be transported to other locations for growing and harvest (Kleeman, 2009). Presence of Dv may also – depending on policy responses - restrict aquaculture related vessel movements to and from non-infested locations.

The aquaculture industry has to manage fouling and predatory organism as part of their normal management practices. Fouling by algae can reduce water flow and increase siltation in both finfish and shellfish aquaculture, while epibiontic filter feeders can be effective competitors for resources and predatory organisms can destroy the cultivated products in the case of shellfish aquaculture (Switzer *et al.*, 2011). Details of practices to manage such fouling are included within *A Code of Good Practice for Scottish Finfish Aquaculture*[2] (2011) and the *Association of Scottish Shellfish Growers Code of Good Practice*[3] (2005).

Despite these codes of practice, mitigating the impacts associated with invasive tunicate fouling is relatively new and no clearcost-effective, environmentally-friendly methods for controlling tunicates have been documented to date (Switzer *et al.*, 2011). Moreover, quantification of impacts is rare: they are different on a case by case and country by country basis based on the proximity and type of aquaculture in the affected and wider region; this is also the case for the management measures adopted, which will be discussed in the UK and International experience of implemented management sections.

In New Zealand, Dv readily attaches itself to the lines on which green-lipped mussel *Perna canaliculus* are also growing, smothering the mussels and also competing for space and resources. Sinner and Coutts (2003) undertook a cost-benefit analysis of Dvmanagement in Shakespeare Bay, New Zealand and suggestedthat 10% ofthe green-lipped mussel lines would be impacted to a point where treatment would be necessary or compete loss occurred, assuming a spread of Dvinto the Marlborough Sound area.

Nationally significant bottom cultivation of blue mussels *Mytilus edulis* occurs in Welsh waters and a feasibility study into eradication or control of Dv (Kleeman, 2009)suggesteda potential 40% coverage of mussel beds by Dv and a 25% loss in production due to poor growth or mortality due to smothering.

Likewise in Canada, heavy infestations of ascidians (understood to be *Styela clava)* in aquaculture operations have increased handling and processing costs (Daley and Scavia, 2008).

5.2.2 Inshore capture fisheries

Dvcan affect capture fisheries by fouling gear (namely creels or pots), smothering seabed habitats associated with commercially important shellfish species and increasing the vulnerability to predation of the shellfish species themselves (Dijkstra & Nolan, 2011).

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[2] Specifically Sections 5.1, 5.2, 5.25 and 5.5

[3] Specifically Section 18 and Appendix A

In New England, USA, the expansion of Dvinto valuable sea scallop fishing grounds has led to concern about the impact of this tunicate on economically important sea scallop habitat (Valentine*et al.*, 2007a). One study by Morris *et al*. (2009) found that Dv inhibits the settlement of the bay scallop (*Argopecten irradians irradians)*, and therefore, will likely prevent the settlement of sea scallop spat.

Pots and creels are used throughout the UK inshore fleet to target lobster, crabs and *Nephrops*. Routinely recycling pots to allow air drying allows effective control of Dvand it is therefore not expected to be an issue, nor have any adverse affects of creel fouling been reported to date (Laing *et al*., 2010).

5.2.3 Power stations

Dvhas the potential to foul intakes for power station cooling water. Power plants experience fouling in their cooling systems as part of normal operations. Fouling organisms are removed through normal management practices and disposed of according to biological waste guidelines. Dvis thought to be no more of an impact to cooling water systems than other fouling organisms.

5.2.4 Yachts and marinas

Fouling of Dvon yacht and boat hulls and marina and harbour infrastructure is considered to be a nuisance, but no more hazardous than other foulers. The risk lies with transport to aquaculture and other industries and therefore any impact to yachts and marinas is focused on the management adopted to limit spread. If legislation or codes of conduct require marinas and boats to be cleaned there will be ongoing costs to achieve pest free status.

Kleeman (2009) reports on discussions with Biosecurity New Zealand which revealed movement towards international hull fouling regulations are presently being discussed with the International Maritime Organisation (IMO) in London (N. Parker, pers. comm., as cited in Kleeman, 2009). These are now in draft stage and constitute a voluntary code for recreational vessels. The IMO, with MAF Biosecurity's leadership have initiated a biofouling correspondence group to try to fast-track international measures for biofouling.

5.2.5 Shipping

As with fouling of yachts, fouling of commercial shipping is considered a nuisance, but no more hazardous that other foulers. Again, the risk lies with transportation and the management adopted to limit spread.

6 MANAGEMENT OPTIONS

There are several options that are available for the management of Dv on artificial structures in marinas and aquaculture operations, as well as yacht and boat hauls. Many of these approaches are considered less effective or unsuitable to control populations of Dv that have spread outside a moderately accessible and manageable area.

A number of research papers and reports are available on the options for management of Dv, those that have been specifically drawn upon to inform this review include (Kleeman, 2009; Carma *et al*, 2010; Denny, 2008; Laing *et al*, 2010, Coutts and Forrest, 2005; Holt and Cordingley, 2011, Pannel & Coutts, 2007).

6.1 Eradication

If *D.vexillum*is found in the early stages of establishment in an accessible and confined area, then eradication may be a viable option in practical terms. Various methods have been trialed as detailed below.

6.1.1 Encapsulation/ wrapping

Encapsulation/wrapping of marina pontoons, mooring buoys, pilings and chains with plastic film/bags prevents supply of clean water to the Dv and smothers it through lack of oxygen. An accelerant can be added to reduce the application time such as sodium hypochlorite (bleach), acetic acid, chlorine or freshwater (Kleeman, 2009; Carma *et al*, 2010; Denny, 2008; Laing *et al*, 2010). The freshwater method is considered particularly effective (Laing *et al*., 2010) and undoubtedly reduces any risk of spillage and effect on the environment.

For marina pontoons, specially manufactured plastic bags would be put in place by dive teams and left in situ for a period of time. A detailed description of set-n-forget methodology, with no accelerant, is provided in Box 1. Accelerants may be added for pontoons in particular high demand or requiring rapid treatment. After accelerant is added covers may be removed after 48 hours, although this depends on the accelerant.

Box 1 "Set-n-forget"encapsulation using tarpaulins or plastic silage covers (Kleeman, 2009)

- *PVC Truck Tarpaulins (see www.allplas.co.uk) could be used as covers to encapsulate pontoons of various sizes and similar to methods described by Coutts and Forrest (2005).*
- *At least 2 above water personnel would be required to fix the plastic to the smaller pontoons and for the larger pontoons, possibly 4 personnel in addition to two divers would be required to deploy the covers underneath the structures.*
- *Topside operators would be involved in pulling one side of the cover above the water line and securing it to the pontoon using either PVC cellotape, ropes or a staple gun.*
- *Divers would displace as much of the water between the covers and the pontoons as topside operators secured all remaining sides.*
- *Covers would be removed after one month.*
- *Defouled material would be released to the surrounding environment to break down naturally or sent to landfill (depending on assessment of risk), while covers would be recycled to treat subsequent pontoons or where damaged, removed to landfill.*
- *Recycled covers would be used to treat subsequent "sweeps" of pontoons.*

Piling can also be treated by plastic wrapping, but rather than a bag, a plastic sheet can be wrapped around the piling, overlapping each successive wrap and securing with a joining material such as PVC tape (Figure 2).

Chains and moorings can also be treated by wrapping in plastic and securing with cable ties.

In all cases, once the plastic wrapping is removed the defouled material would be released to the surrounding environment to break down naturally or sent to landfill (depending on assessment of risk).

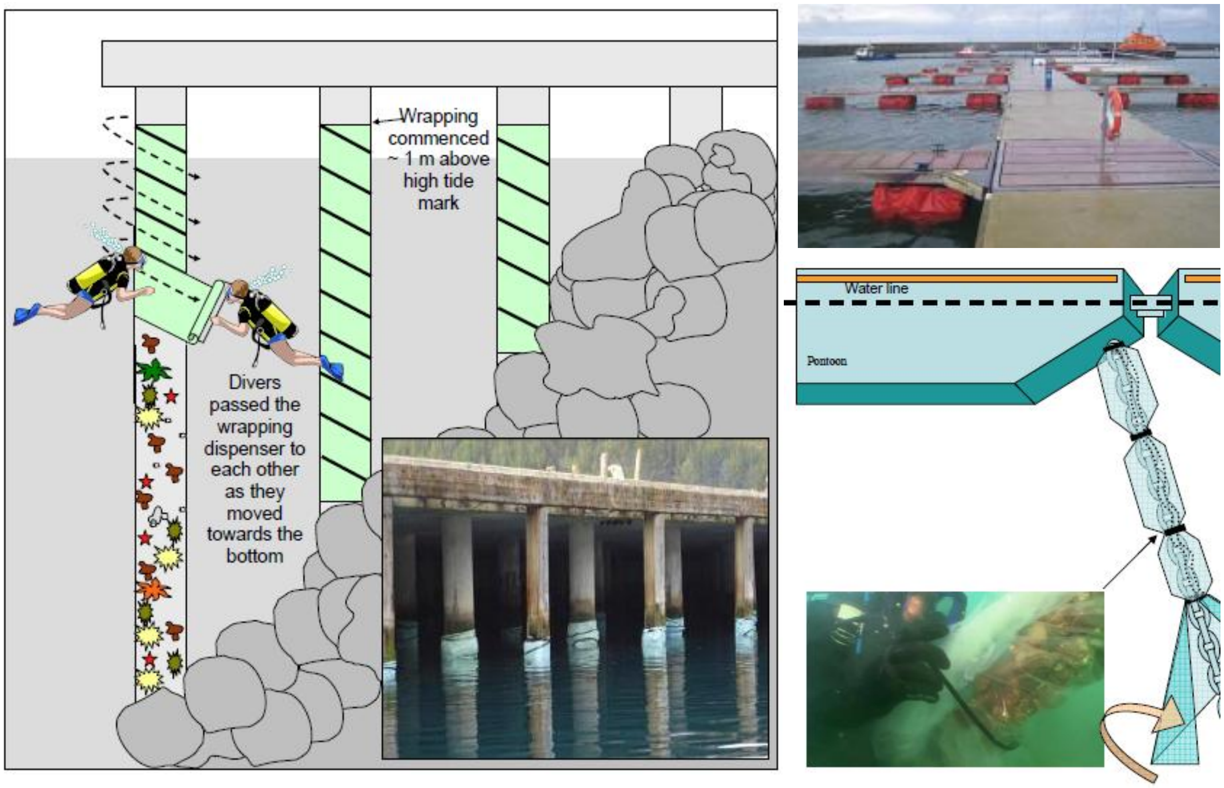

FIGURE 2: LEFT: A SCHEMATIC DIAGRAM OF THE METHOD USED TO TREAT AFFECTED WHARF PILES AND A PICTURE OF THE COMPLETED WRAPPED WHARF PILES AT WAIMAHARA WHARF, SHAKESPEARE BAY (PANNEL & COUTTS, 2007). RIGHT: ERADICATION IN HOLYHEAD HARBOUR, WALES. SHOWING WRAPPED PONTOONS (TOP) AND CABLES (BOTTOM) *HOLT AND CORDINGLEY, 2011)

Boat hulls may also be treated by encapsulation. Boats or yachts that have remained moored for considerable time are at risk of hull fouling including considerable growth of Dv. Depending on the size of the boat plastic covers could be specifically manufactured and put in place in a similar manner to pontoon wrapping.

Applying this encapsulation/wrapping method to is relatively straightforward, although can be labour intensive, particularly in terms of divers. If applied correctly it is considered to be 100% effective in terms of killing Dv on the treated structures. However, if some populations are missed then the possibility remains that Dv would 're-seed' from these missed occurrences and the process would need to be repeated. <u>This method is also unsuitable for treating natural structures should Dv be found in 'wild' populations</u>.

Most attempts to eradicate Dv to date have employed this method both in Wales (Kleeman, 2009;Holt& Cordingley, 2011) and New Zealand (Coutts& Forrest, 2007). In particular a number of lessons have been learnt from the eradication undertaken at Holyhead, Wales, which will be discussed further later in the report, but can be summarised as follows:

- Only carry out the eradication when seawater temperatures are at their lowest
- Continue regular monitoring for larval settlement and reproductive potential.
- Treated surfaces must not be left uncovered adjacent to unwrapped untreated surfaces.
- Investigate removing sections for air drying as the first line of 'attack' as this wouldreduce the need for expensive in-situ treatment (see below).
- Opt for simpler, cheaper plastic bag designs without floatation chambers but with greater freeboard (i.e.sufficient material to draw the bags up the level of the walkways), and plenty of attachment pointsfor hooking the bag to the pontoon superstructure.

6.1.2 Air drying

When structures are modular and can be more easily removed for maintenance then air drying is an attractive option for eradication of Dv. Under appropriate tidal conditions, pontoons could be held clear of the water for sufficient time to dry out to kill Dv. Alternatively, sections of marina could be towed and beached and allowed to dry out. This approach may not be possible in reality (dependant on whether pontoons could be lifted safely from the water), would entail inconvenience to marina operators and would require a carefully planned and coordinated operation. However, it may present a cheaper option than encapsulation if divers are not required.

Air drying is also an option for aquaculture facilities, although less attractive for unharvested mussel ropes. Carman *et al* (2010) studies survival rates of Dvand found it survives up to 6 hours of exposure to air, however significant mussel loss began at 5 hours.

Air drying can also be used to treat yacht and boat hauls, when boats are removed from the water and allowed to air dry.

6.1.3 Biocides

Recent testing of the 'BioBullet', a biocide added to the water which is filtered out and ingested by Dvleading to death, have been undertaken in New Zealand and found to be effective at killing Dvin large numbers, as well as other invasive ascidians (Laing *et al.,* 2010).

This method is only possible when an area, such as a marina, can be isolated from the wider environment and the BioBullet added to the marina. This is not fully tested and also all flora and fauna are likely to be killed within the area being treated. In the UK for dosing within open water, it is not considered that this method of eradication would be deployed without rigorous testing.

Biocides may be useful, however, in situations where fouled structures can be removed from the water and dipped in biocide, before being rinsed and returned to the water. For example Denny (2008) showed that dipping *Didemnum* spp. in a 0.5% solution of bleach for 2 min was a 100% effective method of treatment and also left seed-mussels relatively unaffected.

6.1.4 Jet washing and antifouling paint

Yacht and boat hulls may be jet washed, having been removed from the water. Ensuring treatment is in an appropriate enclosed area where there is no risk of runoff reaching the sea and that all debris is safely disposed according to guidelines for biological waste[4]. Hulls can then be treated with anti-fouling paint.

6.2 Management and Control

Once an introduced marine invasive non-native species (INNS) has become established in an inaccessible or unmanageable area the species has to be addressed through on-going management and control procedures.

6.2.1 GB Invasive Non-Native Species Framework Strategy

In the UK, the GB Non-native Species Secretariat (GBNNSS) has developed the 'Invasive Non-native species Framework Strategy for Great Britain' (GB NNSS 2008). This strategy takes a three-tiered hierarchical approach adopted by the Convention of Biological Diversity (CBD), which includes three main ways of dealing with invasive species including; prevention, detection/surveillance and control/eradication.

(i) Prevention

Preventing the establishment of an INNS requires a range of tools and measures, which can includeinformation and public education campaigns, promotion of high biosecurity standards, and risk assessment/ analysis techniques.

Following the first UK sighting of Dv, a number of public information and education campaigns were launched, providing information to both experts and general public through the production of press releases, factsheets, YouTube videos, posters and presentations by organisations such as GB NNSS, Countryside Council for Wales (CCW), Scottish Natural Heritage (SNH), Marine Life Information Network (MarLIN), the Royal Yachting Association (RYA), Bangor University and the Scottish Association for Marine Science. These campaigns have been supported by an additional campaign launched recently, 'Check, Clean, Dry' by Richard Benyon, Minister for the Natural Environment and Fisheries, which should help to raise the profile of INNS in general throughout the UK and by a website maintained by the US Geological Survey, which provides an excellent source of information on the worldwide spread and impacts of *Dv* (http://woodshole.er.usgs.gov/project-pages/stellwagen/didemnum/).

A Pathway Management Plan (PMP) for Dv has also been finalised in March 2011 by the GB Dv Working Group. This plan provided recommendations to reduce the rate of spread and potential for re-invasion by this species, although it was recognized that these could be applicable to a much broader range of marine INNS. The plan considered five potential pathways for the movement of this species including recreational boating, fisheries/ aquaculture, ship recycling, marine industries such as oil and gas, renewables, aggregates and dredging, and commercial shipping. For each industry, current control measures, regarding the spread/ introduction of Dv were assessed and recommendations were provided for improvement, if necessary. Voluntary codes of good practice for the various industries deemed to be high risk pathways for the spread of INNS, including Dv have been developed in other countries, such as Ireland (Kelly & Maguire, 2008), Wales (Wilson & Smith, 2008; Holt & Cordingley, 2011) and New Zealand (Biosecurity New Zealand, 2011). These codes typically provide information about best practice in removing INNS from vessels, fishing equipment, marina pontoons and reducing the spread of INNS via the movement of seed (in the case of the mussel industry).

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[4] As noted within The Green Blue factsheet on Antifouling and the Marine Environment "*any waste material collected from boat wash down and maintenance is classified as a hazardous material and will require disposal under the Hazardous Waste Regulations in an appropriate manner.*"

In Scotland, this GB PMP has been taken a step further by the Firth of Clyde Forum, which is currently preparing a Biosecurity Plan for the region following the three tiered approach used by the GB NNSS. In addition, a code of practice is currently being produced for *Mytilus trossulus*, in association with the Scottish aquaculture industry (SARF project 064), which could also be expanded to incorporate Dv and a monitoring strategy, produced by the Fish Health Inspectorate following the outbreak of infectious salmon anaemia, could possibly be used as a model for developing a code of practice for Dv.

Finally, arisk assessment for *Dv*was produced in 2011 by the GB NNSS and it concluded that this species presents a 'high risk' to GB, with potential negative consequences on the local economy and the environment requiring some form of government action(GB NNSS 2011). Modelling studies for England (Laing et al. 2010) and Scotland (Somerwill, 2010) have also been recently published and provide guidance on the likely spread and potential 'high risk' sites for future colonisation by Dv.

(ii) Detection/ Surveillance Systems

These systems are not management tools in themselves, but they are necessary to inform a management strategy and would constitute an on-going cost that would have to be considered as part of any cost-benefit analysis. A standardized monitoring procedure, using trained observers, has been successfully used to survey marinas and harbours for Dv in the UK (Bishop, Wood & Yunnie, 2010b; Beveridge et al. 2011). Regular monitoringusing SCUBA or snorkeling has also been shown to be effective at detecting recently established colonies (< 4 weeks) of Dv on marina pontoons in Wales (Holt & Cordingley, 2011).In addition, settlement panels, deployed during the main growing and reproductive months (August to September) in marinas throughout the UK were successful in detecting colonies of Dv less than 2 weeks old (J. Bishop, pers. comm.).

(iii) Control

Once Dv has become established at a particular location and it is deemed either too costly or impractical to eradicate, then measures to control its spread need to be employed. These control measures tend to be industry specific and are detailed in Section 6.3. A summary of these measures is provided in Box 2.

Box 2: Summary of potential control measures used for Dv

Recreational Boating/ Fishing vessels

- ***Regular treatment with anti-fouling paint, ideally once a year.***
- ***If cleaning required, then all fouling material collected and disposed on at land-based refuse sites.***
- ***For trailer boats, drain or thoroughly rinse all areas and where possible, allow to air dry for several days before using in new location.***

Aquaculture/ Fishing gear

- ***For marine equipment (e.g. ropes, buoys, cage netting and lobster creels), remove if unused and either thoroughly air dry or soak in freshwater for 72 hours. Avoid moving between locations.***
- ***For mussel spat, spray with freshwater for a minimum of 10 minutes or immerse in a water bath for > 3 hours.***
- ***For mussel lines, strip, grade and re-stock lines 6 – 12 months after deployment and for oyster bag, regular turning reduces the build-up of unwanted fouling.***
- ***If possible, consider the use of native grazers (e.g. sea urchins) to reduce fouling impact.***
- ***Dispose of all debris in an approved landfill site.***

6.3 Experience of management implemented elsewhere

6.3.1 UK

WALES

A rapid response eradication programme led by the Countryside Council for Wales (CCW) began in October 2009 in Holyhead Harbour. Initially plastic wrappings were used to isolate, smother and kill *Dv*, however, later that year, permission was granted to use an accelerant, calcium hypochlorite. This process was extremely labour intensive, but by May 2010 the entire marina was cleared of obvious colonies of this species. In late August 2010, small colonies of *Dv* were detected in the marina during a routine survey, which formed part of the quality assurance measures implemented during the rapid response phase. Re-settlement of larvae released during the treatment procedure and difficulties experienced in sealing the bags around the numerous chains and ropes securing the pontoons to the seabed were considered the most likely reason for this re-colonisation of *Dv* around the marina, rather than via a new 'invasion' from an infected yacht or adjacent site. A second course of treatment of these colonies was planned, but in October 2010 a further survey revealed a larger area of re-infection throughout the marina. In January 2011, sufficient funds and time were unavailable to re-run an improved eradication programme (Holt and Cordingley, 2011). However, CCW are still trying to secure funding from the Welsh Government for another attempt at eradication in Holyhead marina this winter. This attempt would include; (i) increased labour to ensure that at least 60% of the submerged structures (i.e. pontoon and chains) in the marina and swinging moorings in the vicinity of the marina are 'wrapped' and treated rather than treating a smaller 'block' of pontoons at one time, (ii) treatment during the coldest water temperatures to avoid larval dispersal, (iii) removal of as many 'structures' as possible for air-drying or bleach spraying and (iv) establishment of a detailed surveillance programme for at least 2 years following treatment to detect any re-infection of the marina. This is estimated to cost ~£400,000. CCW are also progressing the building of a trial decontamination berth and self-antifouling pontoon at Holyhead marina (R. Holt, pers. comm.).

ENGLAND

At present, the strategy in England is to continue with the surveillance, particularly at sites that are deemed to be most at risk, or are sensitive for biodiversity or shellfish aquaculture to invasion by *Dv*. To date, no attempts have been made to eradicate this species from infected sites in England due to a number of factors including high cost and requirement for significant manpower, high risk of re-infection due to unmanaged populations of *Dv* in France and the possibility of undetected sites in England. Laing *et al* (2010), however, did conclude that eradication should be an option, particularly in 'sensitive' areas and that the "*most suitable and cost effective method should be chosen that allows for a rapid response to the occurrence*" and recommended targeted campaigns to promote greater awareness and codes of good practice within high risk industries; including: recreational boating and shellfish industries (Laing *et al*. 2010; I. Laing, pers. comm.).

6.3.2 International

NEW ZEALAND

In New Zealand, the potential environmental and economic damage caused by Dv has led to significant research into the management of this species following introduction (Coutts & Sinner 2004; Coutts & Forrest 2007) and potential control methods (Denny, 2008). Eradication of Dv was attempted by the aquaculture industry between 2006 and 2008, but due to technical issues, re-infection problems and escalating costs the decision was made to try to manage the problem,in conjunction with other fouling species (Coutts & Forrest, 2007; B. Forrest, pers. comm.; A. Coutts, pers. comm.).

It appears that since the introduction of Dv in 2001, it has been through a 'boom and bust' cycle. At present, Dv is not causing the industry any significant problems, but during the 'boom' period in 2007, then the industry did incur additional costs, as anti-predator netting on salmon farms had to be replaced in one instance and mussel lines, in severe cases of Dv fouling, had to be stripped and re-socked. No farms, however, went out of business as a result of Dv (B. Forrest, pers. comm.; G. Coates, pers. comm., as cited in Laing *et al.* 2010). This supports the reports by previous experts in the U.S. (S. Shumway and S. Bullard, as cited in Laing *et al.* 2010), that although Dv can be a serious 'nuisance', the aquaculture industry has managed to adopt measures to control its' growth.In general, the mussel industry has found that the mechanical stripping, grading and re-stocking process that occurs between 6 – 12 months in the growth cycle is sufficient to control for fouling organisms, including Dv. Occasionally, this has had to be repeated later on in the cycle if the Dv is particularly abundant, but farms are generally reluctant to do this due to cost and difficulties in getting the larger mussels to re-attach securely to the lines (B. Forrest, pers. comm.).Production losses of less than 5% have been reported by the mussel farming industry as a result of Dv (see Laing *et al.* 2010), however, the actual cost of Dv is extremely difficult to quantify as there is a lack of distinction between native and INNS in pest management (B. Forrest, pers. comm.).

In addition, to mechanical control of Dv, the New Zealand aquaculture industry have produced a voluntary code of practice for stock movements of stock to help prevent the spread of fouling organisms (G. Coates, pers. comm., as cited in Laing *et al.* 2010) and the central government has established regional biosecurity partnerships which are planning to focus on the main pathways by which Dv can be spread (B. Forrest, pers. comm.). In relation to recreational vessels as a high risk pathway, these partnerships are considering various incentives to reduce fouling, such as reduced berthing fees if the owner can demonstrate 'approved' anti-fouling practices (B. Forrest, pers. comm.).

UNITED STATES, CANADA & ALASKA

Didemnum vexillum was first reported in the U.S. in 2002, where large colonies were observed on the Georges Bank fishing grounds and by 2005, the affected area was reported as 230 km^2, with up to 75% coverage of the seafloor (Valentine *et al.* 2007a). This affected area has doubled in size (473 km^2) over the last 5 years, with three areas now colonized with Dv on the Georges Bank (P. Valentine, pers. comm., cited in Laing *et al.* 2010). *Didemnum vexillum* has also spread over a considerable distance in coastal environments, particularly on the Northeast Pacific coast, from California (Lambert, 2009) to Alaska (Cohen *et al.* 2011) over the last 8 years. However, there is no direct evidence of Dv affecting the shellfish fisheries on the Georges Bank (S. Shumway and S. Bullard, pers. comm., as cited in Laing *et al.*, 2010) or the aquaculture industry in the affected regions (Laing *et al.* 2010).

IRELAND

In Ireland, where Dv has been present since 2005, the aquaculture industry has successfully minimised colonisation by Dv on Pacific oyster bags by using the standard management practice of regularly turning the oyster bags (Kelly & Maguire, 2008). Whereas, the rope-grown mussel industry have successfully conducted a removal programme during the grading and harvesting process, when small quantities have been found on the ropes (Laing *et al.* 2010).

7 ASSESSMENT OF CURRENT ECOSYSTEM SERVICES

7.1 Food

7.1.1 Shellfish farming

At a **national** Scottish level the total value of shellfish farming in 2010, at first sale for all species, was estimated at £8.3 million including the pastorially cultivated mussels from wild stocks (£0.42 million) (Mayes and Fraser,2011). Total production tonnage and value for table market is presented in Table 6 per region and species. Regional distribution of active shellfish sites are presented for both Scotland and the Clyde area in Figure 3.

TABLE 6: SCOTTISH SHELLFISH PRODUCTION FOR TABLE MARKET BY REGION AND SPECIES, 2010 (SOURCE: MAYES AND FRASER,2011)

Region	Businesses	Mussels	Pacific oyster	Native oyster	Queen	Scallop	Total Value
Highland	49	£677,539	£148,271		£2,174	£30,000	£857,984
Orkney	8						£0
Shetland	32	£3,573,830	£9,973				£3,583,803
Strathclyde	58	£1,272,246	£840,758	£100,000	£47,826		£2,260,830
Western Isles	17	£1,176,386	£997				£1,177,383
Total	**164**	**£6,700,000**	**£1,000,000**	**£100,000**	**£50,000**	**£30,000**	**£7,880,000**

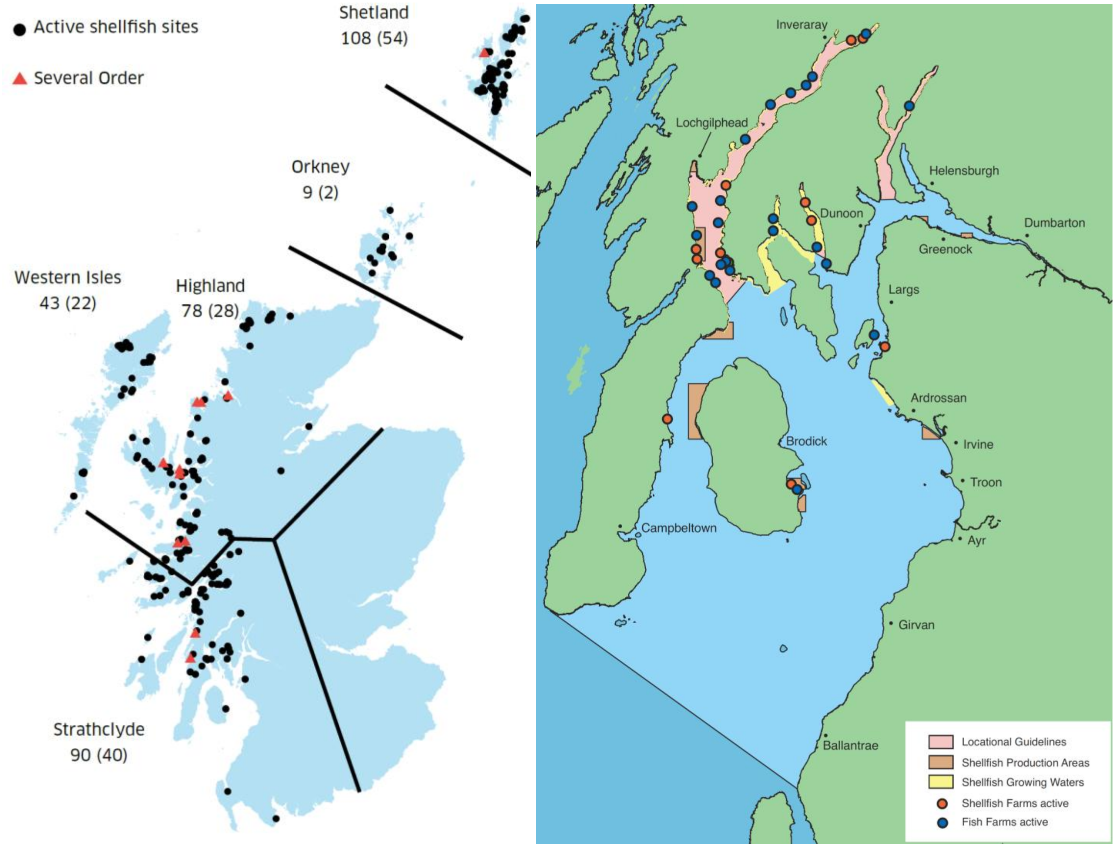

FIGURE 3: LEFT: REGIONAL DISTRIBUTION OF ACTIVE SHELLFISH SITES IN 2010 (NUMBER PRODUCING IN BRACKETS) (SOURCE: MAYES AND FRASER,2011). RIGHT: CLYDE MARICULTURE DESIGNATIONS AND SITES (SOURCE: SSMEI, 2010)

In the wider **Clyde and Strathclyde** region there are 58 shellfish farming businesses with a combined value of ~£2.3 million (Table 6). This is predominately rope grown mussels (~£1.3 million) and Pacific oysters and native oysters (~£950,000).

Rope-grown mussels are usually grown on ropes suspended from surface longlines that consist of a single or double headrope supported by grey plastic floats at regular intervals. The line is anchored to the seabed or shore at either end. The length of the line can be varied to suit the location, but it is generally between 200 – 400 m. The spacing of the plastic floats (buoys) depends upon their buoyancy and the expected load upon the line, but are generally up to 3 m apart. The rope 'droppers', on which the mussels are grown, are usually 12 mm in diameter between 6 – 10 m in length, depending on the depth of the water. 'Droppers' may be tied to the headlines or raft cross pieces at between 0.45 – 1 m apart, depending upon local tidal conditions (Seafish, 2005).

As part of normal management practises Seafish (2005) report that soft fouling, such as sea squirts and macro-algae or predators like starfish, can be controlled by raising the droppers from the water and allowing them to dry in shady conditions before they are resubmerged (although it is not known if this is undertaken on a regular basis by Scottish mussel farmers). Hard fouling, such as barnacles and tubeworm, are more difficult to control and the best method seems to be one of settlement avoidance. This may take the form of raising the droppers from the water when settlement of these organisms is expected, although this is hard to predict accurately since it varies from year to year and between locations (Seafish, 2005).

Management of fouling organisms can, however, often be impractical due to the level of labour required and associated costs. Currently native fouling can impact up to 30-50% of mussels harvested.

In the **local** Largs and Fairlie area there is one active Pacific oyster farm in Fairlie Bay owned by Cumbrae Oysters. Pacific oysters are grown in mesh bags secured to metal trestles. Current management practices include grading of oysters twice throughout the summer which involves removing the bags from trestles, transporting to harvesting area, sorting and returning to clean bags. The used bags are left to dry and cleaned of any fouling before being reused. Bags are checked regularly throughout the year and if heavy fouling is noted the bags are removed and cleaned.

Potential impact of management option

Option 1: Do nothing.

Dv can impact mussel farms by growing over mussel seed, adult mussels and rope. Should Dv spread to mussel farms throughout Scotland then significant losses to stock may occur and/or labour intensive management of fouling may be required.

While Pacific oyster farms have the potential to be impacted by Dv their intertidal location and the normal management practices instigated by Cumbrae Oysters is likely to minimize this impact. There may be concern if Dv were to foul the oysters themselves and suffocate them, although it is thought more likely that growth would concentrate on mesh bags, as is the case for native fouling species, with the exception of mussels. The potential impact of Dv on oyster farming is therefore considered low.

Option 2: Attempt eradication.

The eradication process would not affect any shellfish farms. If eradication was successful then no impact to mussel farms would occur.

Option 3: Containment and management.

If containment and management successfully limited Dv to current location then no impact to mussel farms would occur

7.1.2 Finfish farming

Finfish farming is a very important industry for rural Scotland, in particular for the west coast and the islands where many communities depend on the employment and revenue it provides. Total output of Scottish finfish farming is estimated at £426 million per year at farm gate (Scottish Government, 2011). In 2009 a total of 297 active marine finfish farming sites were recorded (Walker, 2010). The vast majority of these are salmon sites (85%)(Walker 2010). Scotland is the second-biggest producer of farmed Atlantic salmon in Europe after Norway, producing 144,000 tonnes in 2010 (Scottish Government, 2011).

Finfish farming has a significant presence in the Clyde, particularly in Loch Fyne, but also with active salmon farming sites in Arran (Figure 3). There are also a number of inactive sites in Loch Long, Loch Riddon, Loch Striven and around the islands of Cumbrae. There has been a consolidation of finfish activities into fewer more efficient units. The use of the units for production and fallow periods is synchronized across an area as part of management and control procedures for sea lice and disease. Companies therefore require a number of sites across the Firth of Clyde since not all famed synchronously (SSMEI, 2010).

Robust management practices are in place for minimizing fouling of nets and infrastructure. One salmon farm company consulted explained that nets are treated with antifouling chemicals at least once a year. In addition, fish will be moved into different nets of varying mesh sizes throughout their life cycle at a frequency dependent on their life stage, but estimated to be every 6 months to a year. When this occurs the unused nets are lifted and cleaned onshore through a process of air drying and jet washing.

The anti-fouling treatment uses a range of products and their release into the marine environment is managed by a license from SEPA under the Controlled Activities Regulations (CAR).

Potential impact of management option

Option 1: Do nothing.

If Dv were to spread throughout Scotland and establish growth on finfish farm infrastructure, without treatment it could reduce water flow and oxygen content through nets. Current anti-fouling measures are likely to be sufficient in managing this impact. However, additional anti-fouling measures may be required for nets, net support structures and other in situ infrastructure which could result in additional husbandry costs.

Option 2: Attempt eradication.

The eradication process would not affect any finfish farms. If eradication was successful then no impact to finfish farms would occur.

Option 3: Containment and management.

If containment and management successfully limited Dv to current location then no impact to finfish farms would occur.

7.1.3 Capture fisheries

As discussed in Section 5 the potential impacts to commercial fisheries are thought to be limited to shellfish species, namely smothering of shellfish habitat and growth on static gears such as pots or creels. Any impact to finfish will be indirect through impacts to food sources which are expected to be limited as discussed in Section 5: Impacts.

Shellfish fisheries form an important aspect of the Scottish fishing industry, with recent annual values of over £90 million. The most important and valuable shellfish species landed into Scotland is *Nephrops* (known as Norway lobster, langoustine or prawns) with 31,000 tonnes landed from Scottish waters in 2009 worth £78.3 million (Scottish Government, 2011). *Nephrops* are targeted by demersal otter trawlers and static potters/creelers; the latter also targets lobster, brown crab and velvet crab. Scallops are the second most valuable shellfish species and are targeted by a specialist dredge fishing fleet that landed 10,026 tonnes worth £25.1million in 2008 (Scottish Government, 2011).

The majority of commercial fisheries activity within the Firth of Clyde is focused on the *Nephrops* fishery which, as in the rest of Scotland, is targeted by demersal otter trawlers and static potters/creelers. Scallops are also targeted by dredging vessels in the Clyde area and razor clams are fished commercially in the Clyde to a limited extent (SSMEI, 2010).

Potential impact of management option

Option 1: Do nothing.

If Dv were to spread throughout Scotland it may cause impact by smothering seabed habitats associated with commercially important shellfish species (Dijkstra and Nolan, 2011), which has caused some concern for scallop grounds in New England, UAS (Valentine *et al*. 2007). Dv could also foul static pots or creels, as found in Largs Yacht Haven where keep pots were heavily fouled.

Option 2: Attempt eradication.

The eradication process would not affect any scallop fisheries. During the survey undertaken for SNH in 2010 any lose hanging objects were removed and disposed of including creel keep pots. Further eradication would involve air drying and cleaning of keep pots currently in the marina.

If eradication was successful then no impact to scallop grounds or creel fisheries would occur.

Option 3: Containment and management.

Future management measures in relation to anti-fouling practices are likely to extend to fishing vessels operating within the Clyde, specifically those that port at Largs Yacht Haven.

7.2 Recreation and tourism

7.2.1 Marinas and yachts

Sailing in Scotland is concentrated in the Clyde and along the west coast, although new marina facilities have recently created opportunities for cruising around the Northern Isles (Baxter *et al*., 2011). The Scottish Marine Atlas estimates the total value of Scottish sailing tourism at £101 million, with the Clyde area (including Clyde Estuary and Solway) providing the highest majority of berthing (43.6%) and a value of £44 million (Table 7).

The Clyde's sheltered waters allow recreational sailing and motor cruising throughout the year. There are over 5,000 leisure craft, such as keel boats and motor cruisers, based in the Firth of Clyde, with over 3,000 pontoon (marina) berths, and around 2,000 moorings. The number of marinas and associated facilities attract many customers from outwith the immediate area; around 20% of owners of vessels berthed in the Clyde live in England (SSMEI, 2010).

On the Firth of Clyde there are twelve locations offering pontoon berthing including the following marinas:

- Holy Loch Marina, Dunoon
- Largs Yacht Haven
- Portavodie, Lochgilphead
- Fairlie Quay Marina
- Kip Marina
- Troon Yacht Haven
- Rhu Marina

Beveridge *et al.* (2010) surveyed locations within the Clyde to establish extent of Dv distribution and confirmed presence within Largs Yacht Haven and Fairlie Quay Marina. These marinas are discussed in further detail below.

TABLE 7: SAILING AREA VALUE AND BERTH NUMBERS (SOURCE: SAILING TOURISM IN SCOTLAND AS CITED IN BAXTER *ET AL*, 2011)

Sailing Tourism study regions	Value	% of total available berthing	No. Of pontoons	No. Of moorings	Scottish sea areas included
North (Gairloch – Helmsdale – Peterhead, Orkney & Shetland)	£7.9 M	7.80%	1,792	224	North Scotland Coast, West Shetland, East Shetland, Moray Firth
East (Peterhead – Fife Ness – Berwick)	£10.1 M	10%	1,067	480	East Scotland Coast, Forth
Clyde (Clyde Estuary & Solway)	£44 M	43.60%	3,333	2,038	Clyde, Solway Firth, North Channel
West (Argyll, Ardnamurchan – Gairloch & Outer Hebrides)	£39 M	38.60%	1,030	2,637	Minches & Malin sea, Hebrides
Total	**£101 M**	**100%**	**7,222**	**5,380**	

Largs Yacht Haven

Largs Yacht Haven (LYH)is the biggest marina in Scotland with 730 berths that are utilized throughout the year. On average 700 vessels berth during spring, summer and autumn and 550 berth during the winter. A number of other vessels operate from the marina including three commercial sailing clubs, a commercial diving club, 2-4 fishing vessels, support vessels for Hunterston Terminal, Clyde pilot boats to support shipping.

The marina also supports a range of businesses including:

- Yacht services: marine engineers (North Western Automarine), surveyors (Paul Jeffes Associates), sailmakers (Saturn Sails), chandlers (Largs Chandlers), diving (C&C Marine), riggers (MRS Mast and Rigging Services) and tugs and workboats (Maritime Craft Services);
- Yacht sales: Euroyachts and DDZ Marine;
- Sailing schools and yacht charter: Catima Sailing Yacht Charter, Cumbrae Voyages, Flamingo Yacht Charter, Intuition H20, Nimbus Sailing School, Scotsail Yacht Charters, Scottish Sailing Institute, Sport Scotland Cumbrae; and
- Bistros, bars, restaurants and a health spa.

In terms of arrangement LYH has seven pontoon legs each with a double letter designation indicating berths with finger pontoons on either side of the central pontoon (Figure 4). An estimate using a satellite image suggested well over 2000 m of main pontoons, without considering the fingers (Beveridge *et al*., 2011). There are approximately 34-56 fingers per pontoon, depending on size of vessel berths, with an estimated total of 350 fingers, each approximately 10m in length. Pilings support the pontoon legs and, where large vessels are berthed, there are also pilings to support fingers. It is estimated that there are 15-20 pilings per leg, therefore a total of 140 pilings not including finger pilings. The water depth in the marina is on average 2.5m above chart datum.

LYH recommend a Check-Clean-Dry process to their clients, although this is not compulsory and it is not monitored which vessels are cleaned. On average it costs a yacht owner ~£600 for a vessel clean including lift (£200-300) and antifouling treatment (£200-300). LYH have a closed loop wash down system whereby jet washing run off and fouling are processed through a separator tank and filtration system before water returns to the marina and fouling is disposed of onshore.

LYH estimate that approximately 95% of the vessels berthed at LYH are cleaned and treated for anti-fouling on an annual basis (although this is not monitored and cannot be confirmed). The hoist does not have the capacity to lift approximately 3 to 4 of the larger vessels and it is unknown if these vessels are treated elsewhere.

LYH have an estimated annual turnover of £2 million and profit of £900,000 – £1million. The marina is currently undergoing maintenance to replace 30 pilings at a cost of £250,000.

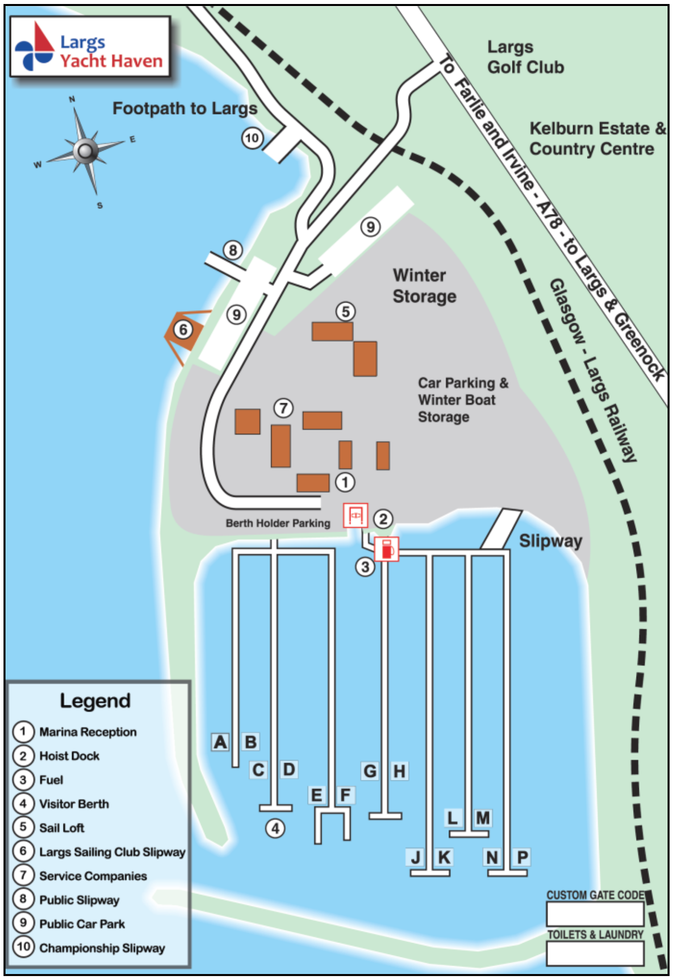

FIGURE 4: LEFT: MARINA LAYOUT AND RIGHT: MARINA GENERAL ARRANGEMENT OF PONTOONS AND FINGERS (LARGS YACHT HAVEN, 2011)

Fairlie Quay Marina

Fairlie Quay Marina (FQM) consists of 24 moorings, a 600m pier and 120m heavy duty service pontoons and is located less than 1km from LHY.

FIGURE 5: FAIRLIE QUAY MARINA (SOURCE: FAIRLIE QUAY MARINA, 2011)

FQM has significant capacity for hoisting, cleaning and storing vessels over the winter period with 60,000 sq ft of covered storage and 300 hard storage spaces.

On average FQM hoists 328 boats per year.

Vessels are hoist from the pontoon onto the pier where they are jet washed. Water and fouling material is drained through man-holes on the pier directly into the sea – no filtration or separation occurs. Large fouling organisms left on the pier area are brushed up and disposed of in a skip.

Potential impact of management option

Option 1: Do nothing. No impact to marinas.

Option 2: Attempt eradication.

Costs associated with eradication include the cost of implementing eradication techniques including wrapping by divers, removal of objects for air drying and closed loop washing of vessels; as well as the cost to the marina and allied local businesses due to inconvenience(including lost business) or disturbance of the eradication process.

Option 3: Containment and management.

Containment and management costs include pathway management such as a requirement for closed loop hull cleaning for all vessels prior to leaving a marina. The scale of pathway management will be crucial in containing spread and should be undertaken at national, UK and EU levels.

7.2.2 Other recreation

Other recreation within the Clyde area includes scuba diving, sea angling (from shore and from charter boats), sea kayaking, jet skiing, wind and kite surfing and wildlife watching tours.

Sportscotland's National Centre is based on Cumbrae, opposite Largs and is considered to be one of Scotland's premier water sports centers and instructor training facility.

A number of recreational events also take place in the Firth of Clyde including: River Festival, Tall Ships Race, world windsurfing championships (in 2002), national and international sailing events including Clyde Cruising Club's Scottish Series and the Fife Regatta.

Potential impact of management option

Option 1: Do nothing. If Dv were to spread then it could smother habitats and artificial structures such as wrecks therefore impacting quality of diving experience and number of dive sites available.

Option 2: Attempt eradication.No impact expected, with exception of potential economic benefit should local commercial dive companies be hired in eradication process.

Option 3: Containment and management.Monitoring of Sportscotland's National Centre Cumbrae and code of conduct for their vessels.

7.3 Navigation and shipping

7.3.1 Ferries

A number of international and domestic ferry routes operate throughout Scotland (Figure 6) including vehicle and passenger ferry services that operate within the Clyde.

2008 data suggests that 4 of the top 5 ferry routes in Scotland(by passenger numbers) are located in theFirth of Clyde (Burt, 2011) including the service from Largs to Cumbrae.

Burt (2011) investigated the potential for Dv spread via ferries and concluded that ferries between the Scottishmainland and Ireland are unlikely to act as vectors due to the speeds at which the ferries travel andthe short period of time vessels spend in each port. Similarly the ferries operating within the Clydedo not remain in port for prolonged periods of time, but theproportion of time spent in contaminated zone is relatively high compared with time in crossing (especially Largs/Cumbrae) and they operate at lower average speeds than ferries to Ireland which could increase thelikelihood of them acting as a vector.

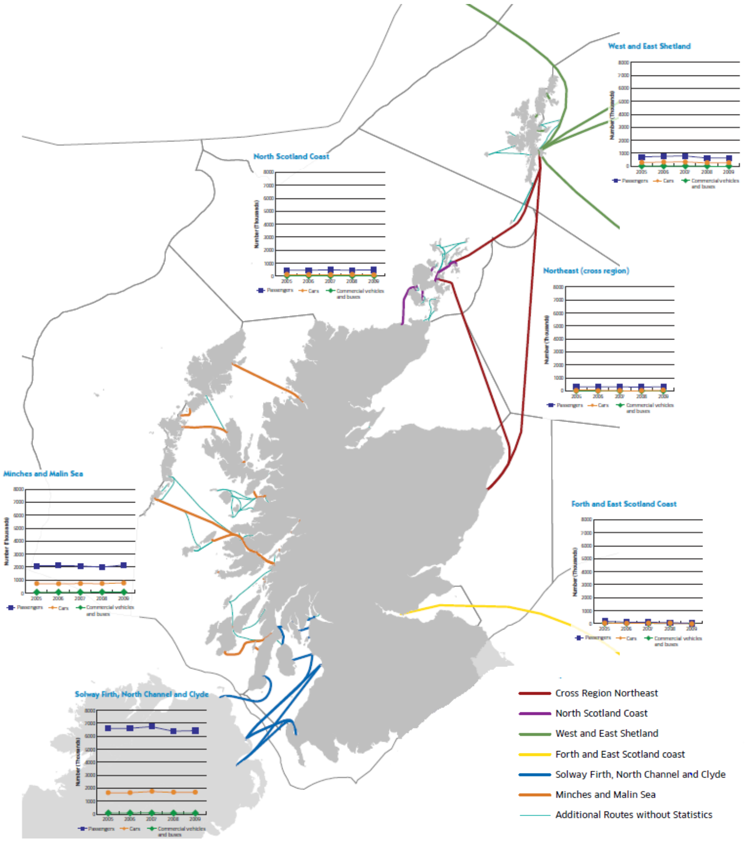

FIGURE 6: INTERNATIONAL AND DOMESTIC FERRY ROUTES (SOUREC: BAXTER *ET AL*, 2011)

Potential impact of management option

Option 1: Do nothing. Potential for ferries to act as a vector for spread of Dv within the Clyde area.

Option 2: Attempt eradication. No impact to ferries anticipated.

Option 3: Containment and management.Potential impacts in relation to codes of practice and monitoring, particularly for Largs-Cumbrae ferries.

7.3.2 Shipping

The company 'Clydeport' manages the Firth of Clyde, its area of jurisdiction stretching from AlbertBridge in Glasgow to seaward limits at Arran.

Current levels of local, national and international marine traffic on the Clyde is increasing. Theselevels are likely to increase further in response to policy drivers encouraging freight and people to betransported by alternative methods excluding road and air.Vessels operating in the Largs/Fairlie area can be resident, passing or ships destined for the localarea. Of note in the immediate area is the Hunterston Coal Terminal.

FIGURE 7: HUNTERSTON TERMINAL AERIAL VIEW (BURT, 2011)

Burt (2011) describes the Hunterston terminal and potential for importing ships to act as vectors for spread of Dv. Hunterston terminal is located a few miles from Largs in thevillage of Fairlie and imports coal fora variety of energy companies across the UK. The coal terminal is along L shaped structure that extends into the deepwater of 'Fairlie Roads' (Figure 7). In total the pierstretches approximately 1.5km from the MHWS.None of the submerged structures are treated with antifouling agent. A number of structures arecovered in a protective wrapping which is due to be upgraded in the next few years. This process wouldbe completed by adding the new wrapping on top of the existing protection.

Ships from around the world import/discharge to Hunterston Terminal including international boats and two coaster vessels that undertake round trips transporting coal to Northern Ireland and theManchester Ship Canal (Burt, 2011). The international boats that discharge at Hunterston do not necessarilyhave a "home port" but are constantly travelling around the world, berthing in numerous countrieseach year for varying amounts of time. From 2005 until the end of 2010 there were 285 ship imports/discharges to Hunterston Terminal, equating to an average of 48 ships per year, with international ships recorded from nine countries: SouthAfrica, Russia, Colombia, Australia, China, USA, Latvia, Estonia and Indonesia.

Cruise ships are becoming more common with increased numbers visiting the Clyde each year. 2011 is anticipated to be Greenock Ocean Terminal's busiest season in terms of visiting cruise ships. 36cruise ships are already booked to visit the terminal during the cruise season.

It is unlikely that Dv would survivelong distances attached to hulls of fast moving ships, however it is more feasible it would survive in lowenergyareas such as the sea chests and the propeller shaft housing (Coutts and

Dodgshun, 2007;Lambert, 2009). On slower moving ships and barges Dv is thought to be able to survive on fouled hulls.

Potential impact of management option

Option 1: Do nothing. International shipping vessels may become contaminated with Dv and spread it to other global locations. The presence of Dv on the Hunterston Terminal Clydeport jetty has implications for the onward transfer of Dv via international boats that have discharged coal at the terminal or by the two coaster vessels that transport coal to Northern Ireland and the Manchester Ship Canal.

Option 2: Attempt eradication. No impact to shipping, unless eradication at Clydeport were to restrict vessels from docking.Also noted that surrounding commercial shipping could compromise the success of an eradication attempt.

Option 3: Containment and management.Significant impact in relation to codes of practice and monitoring.

7.4 Wild species diversity

7.4.1 Marine protected areas

There are approximately 25 marine Special Areas of Conservation (SACs) and 45 Special Protected Areas (SPAs) with marine components in Scottish waters. Somerwill (2010) mapped the predicted spread of Dv and locations of marine SACs and SPAs (Figure 8).

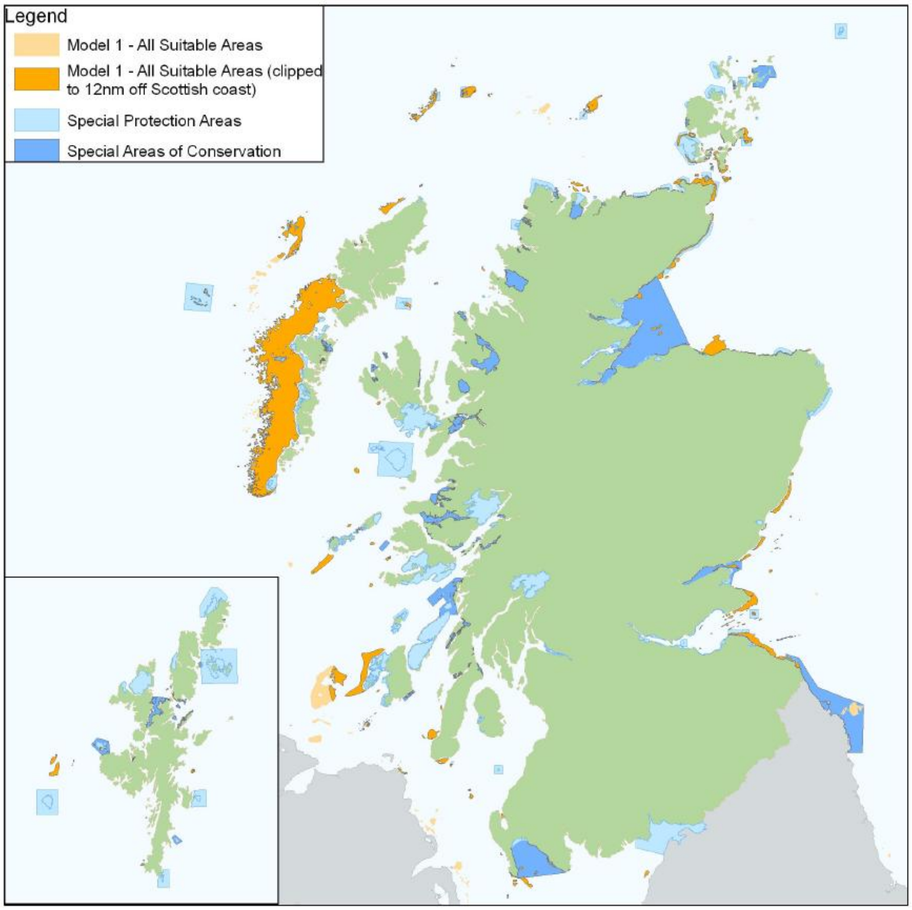

FIGURE 8: POSSIBLE AREAS AROUND THE SCOTTISH COAST THAT ARE SUITABLE FOR COLONISATION BY DV AND SELECTED BIODIVERSITY INTERESTS THAT MAY BE AFFECTED (SOURCE: SOMERWILL, 2010)

While the Somerwill (2010) modeling gives an indication of the potential spread it does not consider the primary and qualifying designated features that are most at risk from Dv colonization.

As discussed in Section 5.1 Kleeman (2009) and Laing *et al.* (2010) consider reefs and lagoons, designated as priority habitats under the EC Habitats Directive, as particularly vulnerable to colonization by Dv. Other Annex I features that could potentially be impacted by Dv include: sandbanks which are slightly covered by seawater all the time; estuaries; large shallow inlets and bays; submerged or partially submerged seacaves; and mudflats and sandflats not covered by seawater at low tide (SNH, *pers. comm.*).

Table 8 provides a list of those SACs containing the above features that could *potentially* be affected by Dv. The extent to which Dv would affect conservation objectives for these sites is likely to vary considerably as a result of a number of factors. The likelihood or risk of introduction will also vary considerably between sites. Some will have relatively low levels of human activity (e.g. St Kilda) while others have high traffic of activities that could form potential vectors (e.g. Moray Firth).

TABLE 8: SPECIAL AREAS OF CONSERVATION (SAC) CONTAINING FEATURES THAT COULD *POTENTIALLY* BE AFFECTED BY DV (SNH, PERS. COMM.)

Feature	Special Areas of Conservation
Sandbanks which are slightly covered by seawater all the time	Solway Firth; Luce Bay and Sands; Sound of Arisaig (Loch Ailort to Loch Ceann Traigh); Loch nam Madadh; Sanday; Moray Firth; Dornoch Firth and Morrich More; Firth of Tay and Eden Estuary
Estuaries	Solway Firth; Dornoch Firth and Morrich More; Firth of Tay and Eden Estuary
Large shallow inlets and bays	Luce Bay and Sands; Loch nam Madadh; Loch Laxford; Sullom Voe; Berwickshire and North Northumberland Coast
Reefs	Solway Firth; Luce Bay and Sands; Firth of Lorn; Treshnish Isles; Loch Creran; Sunart; Lochs Duich, Long and Alsh Reefs; St Kilda; Loch nam Madadh; Loch Laxford; North Rona; Sanday; Mousa; Papa Stour; Sullom Voe; Dornoch Firth and Morrich More; Isle of May; Berwickshire and North Northumberland Coast
Coastal lagoons	Loch nam Madadh; Loch Roag Lagoons; Loch of Stenness; The Vadills; Sullom Voe
Submerged or partially submerged sea caves	St Kilda; North Rona; Mousa; Papa Stour; Berwickshire and North Northumberland Coast
Mudflats and sandflats not covered by seawater at low tide	Solway Firth; Luce Bay and Sands; Moine Mhor; Loch Moidart and Loch Shiel Woods; Loch nam Madadh; Sanday; Dornoch Firth and Morrich More; Firth of Tay and Eden Estuary; Berwickshire and North Northumberland Coast

Under the EC Birds Directive SPAs around Scotland have been extended into marine environment for protection of existing seabird coastal breeding colonies, as well as inshore and offshore aggregations of non-breeding birds. Any impact of Dv on the features of SPAs is likely to be minimal and indirect in nature(i.e. the potential impact on food sources) and is therefore not considered further.

The Clyde itself has no SAC designations, but there are a number of distinctive natural habitats within the Firth of Clyde, such as sea lochs, maerl beds and intertidal mud flats. Firework anemone, fan mussel and the Loch Goil sea squirt are just some of the nationally rare or scarce species that can also be found in the Clyde (SSMEI, 2010). There is a Marine Consultation Area surrounding the Isles of Cumbrae and a Marine Nature Reserve including no-take zone in Lamlash Bay, Arran.

Potential impact of management option

Option 1: Do nothing. Potential smothering of habitats and species including moderate risk to SAC sites that are located across areas of predicted Dv spread and are designated for reefs and lagoon habitat systems. Possible infraction penalties imposed by the EU if quality targets are missed, for example with respect to Good Ecological Condition.

Option 2: Attempt eradication. No impact to wild species diversity.

Option 3: Containment and management. No impact to wild species diversity

7.5 Cooling water

7.5.1 Power plant

Hunterston (nuclear) power station is located on the Clyde and uses sea water in the cooling process to reduce the need for cooling towers.Hunterston power station accounts for over 11% of Scotland's electricity generating capacity. It is scheduled for decommissioning in 2016.

Another power station at Inverkip (oil) was never fully operational as it was uneconomic to run and was used only as a backup supply. It ceased fully in 1999 and is planned to be demolished in 2009.

Larvae and juvenile stages of a number of species can pass through intake filter screens and settle and grow in cooling systems. Within the system the animals can cause blockages and erosion-corrosion in condenser tubes, thereby threatening plant integrity. Coastal power stations control fouling by chlorination or other biocides.

Potential impact of management option

Option 1: Do nothing. Low risk that additional anti-fouling measures may be necessary assuming Dv spreads to this location and dependent on the level of Dv growth and current management practices.

Option 2: Attempt eradication.No impact

Option 3: Containment and management. No impact

7.6 Water quality regulation

7.6.1 CAR

Under the Water Environment (Controlled Activities) (Scotland) Regulation (CAR) 2005, SEPA are responsible for controlling the abstraction and discharge of water and antifouling products are included within these regulations. Any eradication that utilized an accelerant would require consultation with SEPA and a CAR license for discharging the biocide into the environment.

Furthermore there may be potential costs if quality targets set out by the Marine Strategy Framework and Water Framework Directives are not met due to presence of Dv impacting such targets.

Potential impact of management option

Option 1: Do nothing. Potential cost of not meeting targets of Marine Strategy Framework and Water Framework Directives.

Option 2: Attempt eradication. CAR license if accelerant used.

Option 3: Containment and management. No impact.

8 ASSESSMENT OF COSTS TO ECOSYSTEM SERVICES

The potential for the management options to impact each sector as presented in the previous section is summarized in Table 9. It is these impacts that are discussed further in this section. Under Option 2 and 3 where potential impact is stated as ‘none’ it is on the assumption that the management applied for these options has been effective.

TABLE 9: TABLE PRESENTING SECTORS THAT WOULD BE POTENTIALLY AFFECTED BY MANAGEMENT OPTIONS 1-3 (SHADED IN BLUE)

Ecosystem Service	Sector	Option 1	Option 2	Option 3
Food	Shellfish farming	🟦	None	None
	Finfish farming	🟦	None	None
	Capture fisheries	🟦	🟦	🟦
Recreation and tourism	Marinas	None	🟦	🟦
	Yachts	None	🟦	🟦
	Other recreation	🟦	None	None
Navigation	Ferries	None	None	🟦
	Shipping	None	🟦	🟦
Wild species diversity	Marine protected areas	🟦	None	None
Cooling water	Power plant	🟦	None	None
Water quality regulation	CAR and MSFD & WFD	None	🟦	None
PROCESS COSTS		None	🟦	🟦

8.1 Food

8.1.1 Shellfish farming

Option 1: Do nothing

It is difficult to accurately determine the potential impact to mussel production volumes. A number of estimates have been used in other national cost and benefit analysis of Dv management to monetize the cost to the mussel industry.

In Wales, Keenman (2009) considered subtidal mussel beds to have a 90% chance of infestation, with a potential coverage of 40% and as high as 25% in loss of production (if it is assumed that the pest would smother mussels and result in poor growth or mortality). In addition to lost production, costs would be incurred through increased processing costs, potential loss of export markets as well as restriction to certain seed beds.

In New Zealand Coutts and Sinner (2004) estimate that 10% of mussel lines would be impacted to point where production would be lost or ongoing treatment was necessary.

For the purpose of this study an estimate of 10% and 25% reduction of rope grown mussel production has been usedand is presented in Table 10. In the absence of reliable estimates of the rate of Dv spread, it is not possible to specify the geographical extent of Dv at any given point and thus the extent and duration of potential damage. This, combined with the uncertain nature of impacts where Dv is present, means that the application of discounting to possible future damage costs would not be grounded empirically and as such has not been conducted here. Rather recurrent annual losses under some simple assumptions are suggested, sufficient for comparison with up-front management costs.

The previous analyses for New Zealand (Coutts and Sinner, 2004) and for Wales (Kleeman, 2009) used industry output as a measure of worth rather than the Gross Value Added (GVA). Here, both output and GVA figures are presented - although GVA has had to be estimated. Assuming that GVA is approx 40-50% of turnover, a GVA of £3.5 million is estimated for national mussel production and £1.1 million for regional (Clyde, Minches & Malin Sea, Hebrides)[5] production.

Hence, for Scottish mussel production an impact of 10% would result in an annual total production loss of around £700k (£350k GVA) for the entire of Scotland, assuming Dv spreads throughout Scotland and that all mussel farms are impacted. An impact of 25% would result in a total production loss of around £1.7m million (£875k GVA) on the same basis. Uncertainty over both the speed at which DV might spread and its actual impacts mean that the cumulative effects of Dv over time are unknown and thus there is little

For regional mussel production (Clyde, Minches & Malin Sea, Hebrides) an impact of 10% would result in a total NPV production loss of ~£220k (£110k GVA) peryear, assuming Dv spreads throughout the Western regions and that all mussel farms are impacted. An impact of 25% would result in a total production loss of around £550k (£275k GVA) on the same basis.

The mussel farm within Lamlash Bay is included within the regional study area; therefore with no mussel farms in the immediate vicinity of the Largs and Fairlie area, no impact will occur.

Impacts to oyster farms on a national, regional and local basis are anticipated to be minor and can be dealt with through current management practises.

TABLE 10: PREDICTED IMPACT TO MUSSEL INDUSTRY ASSUMING 10% AND 25% LOSS ON A NATIONAL (SCOTLAND) AND REGIONAL (SCALES

Geographic scale	Production	10% loss	25% loss	GVA	10% loss	25% loss
Scotland	c.£7.1m	c.£710k	c.£1.8m	c.£3.5m	c.£350k	c.£875
Regional	c.£2.3m	c.£220k	c.£575k	c.£1.1m	c.£110k	c.£275k

Given the necessary assumptions (i.e. 10% or 25% loss), the overall cost to the shellfish farming industry of Option 1: do nothing is therefore expected to be **considerable**, but probability of occurrence is **uncertain**. This gives an overall impact rating of ***moderate***.

8.1.2 Finfish farming

Option 1: Do nothing

The finfish farming industry have well-established robust management practices regarding control of fouling organisms; nets are also routinely taken out of the water and cleaned as fish are moved into progressively large mesh size nets.

Consultation with one salmon farm company indicates that nets are changed (due to mesh size) or treated for fouling on average three to four times a year. Based on the scale of this management for fouling organisms, additional management for Dv fouling is unlikely to be necessary. However, if fouling was extensive then associated costs would include additional fouling treatment including acquisition of a CAR license from SEPA.

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[5] A wider regional area than predicted by the colonisation modelling and thus a relatively pessimistic view on immediate impacts.

Additional fouling management costs could be considerable if not part of normal routine and given the scale of Scottish finfish farming, the predicted spread (Figure 8) and the fact that Dv can grow on most artificial structures, the scale of impact could be widespread. While this is not likely to affect the actual aquaculture species, since management will be taken before water flow or oxygen content are affected, it will add additional labor and process costs if further treatment is necessary.

For example, fish farming turnover for Scotland as a whole is around £420m, equating to perhaps[1] £60m GVA. For the Western reporting regions most likely to be affected, the totals are around £250m and £38m respectively. Hence a 2% reduction in GVA from higher handling costs would imply £1.2m nationally or £0.8m regionally – larger figures than for mussel farming due to the relative sizes of the two sectors. Again, these would be upper-bound annual losses and 2% may be overly pessimistic.

The overall cost to the finfish farming industry of Option 1: do nothing is expected to be **considerable**, but probability of occurrence is **highly uncertain**. This gives an overall impact rating of ***low***.

8.1.3 Capture fisheries

Option 1: Do nothing

Key fisheries in the Clyde include *Nephrops* targeted by demersal otter trawlers and creelers/potters and scallops targeted by scallop dredgers.

Nephrops are found sublittorally in soft sediment and are commonly targeted by creelers at depths of between 30-100 m. There are many records of *Nephrops* populations <30 m in Scottish Sea Lochs. They live in shallow burrows and are common on grounds with fine cohesive mud which is stable enough to support their unlined burrows (Sabatini and Hill, 2008). Due to the seabed type they inhabit Dv smothering is not expected. *Impact of Option 1: Do nothing is anticipated to be limited to fouling of creels and pots which can be removed and air dried on a rotating basis if fouling becomes an issue.*

Scallops prefer areas of clean firm sand, fine or sandy gravel and may occasionally be found on muddy sand. Distribution in this species is invariably patchy and often found in shallow depressions in the seabed (Marshall and Wilson, 2009). Given that scallopscan inhabit more course sandy gravel sediment, there may be a risk of Dv smothering potential habits. However, given the diverse range of habitats within the Clyde and extent of fine mud and sand sediments the risk is reduced and highly unlikely to impact a significant portion of scallop habitat within the Clyde.

In balance taking into consideration the level of uncertainty regarding impact to scallop grounds, *the overall cost to the fishing industry of Option 1: do nothing is expected to be* ***minor,*** but probability of occurrence is **uncertain**. This gives an overall impact rating of ***low***.

Option 2: Eradication

The process of eradication would be limited to the keep pots within Largs Yacht Haven. The process of removing keep pots for air drying is not expected to impact the fishing industry. The two fishing vessels that port at Largs Yacht Haven may require anti-fouling management. The cost to the fishing industry of Option 2: eradication is expected to be **slight** and probability of occurrence is **certain**. This gives an overall impact rating of ***low***.

Option 3: Management

Management including codes of conduct designed to minimize spread of Dv will include vessels that utilize Largs Yacht Haven. It is understood that two vessels land their catch and port at Largs Yacht Haven.

Management is likely to include monitoring, anti-fouling practices and a code of conduct for creels including recording presence of Dv and action to be taken if Dv is found on creels.

The cost to the fishing industry of Option 3: management is expected to be **slight** and probability of occurrence is **probable**. This gives an overall impact rating of ***low***.

8.2 Recreation and tourism

8.2.1 Marinas and yachts

Option 2: Eradication

Largs Yacht Haven is open all year with approximately 550 vessels during winter months and thus contributing to the annual turnover of £2m and profit of around £1m. Due to the sheltered nature of the Clyde yacht owners can sail throughout the year and will require continued access to the marina and yachts.

An eradication process is likely to cause significant disruption to the daily operations of the marina. Consultation with Largs Yacht Haven has shown resistance to any form of eradication that would disrupt or restrict access or use of any part of the marina. If eradication were to proceed careful planning would be required to ensure entry to the marina and to minimize disruption. Despite this the scale of the impact largely depends on whether and for how long the marina would have to shut and the extent to which displaced customers would come back afterwards.

Jet washing of yachts would also be required as part of the eradication procedure. Associated costs are included within Process Costs, it is unknown whether these costs could be expected to be borne by the yacht owners (and if so how this could be enforced) or funded as part of the eradication program.

Eradication at Fairlie Quay Marina would not be as disruptive. Wrapping of the pilings would not force closure of the hoist system; furthermore the moorings are out of use over the winter period allowing for wrapping and/or removal for air drying where practical.

Taking all impacts into consideration, including the relatively unknown scale of the impact should disruption occur to normal marina practices, the overall cost to the marinas and yachts of Option 2: eradication is expected to be **high** and it is **certain** that this high cost will occur. This gives an overall impact rating of ***very high***.

Option 3: Management

Management measures to minimize spread of Dv through haul fouling are likely to include monitoring of hauls, jet washing and anti-fouling treatment on a regular basis. Detailed consideration is required for the scale and frequency of such practice including: national UK wide code of practice e.g. monitoring/treatment before leaving marina and also consideration of yachts coming in from elsewhere in the EU including Ireland and France.

The onus of management measures will be on yacht owners. Current Check-Clean-Dry practices are advised by LYH; and it is estimated that approximately 95% of the boats undertake this annually, although this is not monitored. If Check-Clean-Dry were to become mandatory and undertaken at a higher frequency this would add considerable cost to yacht owners. For example, a check-clean-dry cycle for all 730 berths would incurs over £0.4m in costs – more if berths are time-shared. Enforcement would be challenging and responsibility unclear; this is not something one marina should necessarily have to enforce while others do not, which could significantly affect business. It should be noted that marinas cannot slip, clean and paint all yachts at the same time and this process tends to be spread through winter and may take place shortly after a yacht arrives, or shortly before it leaves. Future management plans may consider advising cleaning and fouling treatment on departure.

A potential area of improvement would be ensuring closed loop systems for jet washing of vessels, as currently practiced at LYH.

The overall cost to marinas of Option 3: management is expected to be **minor** and **probable** with an overall risk rating of***moderate*.**

The overall cost to yachts of Option 3: management is expected to be **minor**, with **certainty** and an overall risk rating of***moderate*.**

8.2.2 Other recreation

Option 1: Do nothing

If Dv were to spread throughout the Clyde area it could impact popular dive sites, including wrecks. However the cost to other recreational activities of Option 1: do nothing is expected to be **slight**, but with an **uncertain** probability of occurrence and therefore an overall risk rating of ***low***.

8.3 Navigation and shipping

8.3.1 Ferries

Option 3: Management

Containment and management practices are likely to include continued monitoring of ferries and related infrastructure. The cost to ferries of Option 1: do nothing is expected to be **slight** with a **possible** level of occurrence and therefore an overall risk rating of ***low***.

8.3.2 Shipping

Option 2: Eradication

Hunterston Coal Terminal (HCT), owned by Clydeport but operated by Fergusson Copal, has an annual throughput capacity of 8m tonnes with extensive storage and transport facilities. Imported coal is sent to Long Gannet and to Drax in Northern England, but exports also occurs.

The submerged structures at HCT are relatively homogenous and regular cylinder shaped pilings. However the number of pilings, circumference of pilings and the depth of the pilings is substantial. There is no reference in the literature to a structure the size of HCT being involved in a Dv eradication programme before (Burt, 2011).

HCTmay be required to cease/reduce imports and exports during an eradication programme to allow divers access to fit plastic wrapping and potentially during treatment to avoid damaging the plastic wrapping. It is unclear the scale of the latter as the ships may not have contact with the pilings when they dock at the pier. Despite this the process of eradication could be highly expensive unless scheduled to coincide with any other closure for maintenance

Current coal prices of around £75/t imply a turnover figure of around £600m. This implies that suspension of vessel movement for a month during eradication could impose a turnover loss of £50m. Converting this into GVA is difficult, but HCT represents more than 5% of Scottish port capacity which has a total GVA of

£160m[6]to £430m[7], so HCT might account for £8m to £22m (c.£650k to £1.8m a month). HCT has not been approached for comment or verification of these estimates.

Delaying even one coal shipment could potentially out-weigh any other commercial cost considerations. Furthermore it should also be noted that the success of an eradication attempt at the Largs/Fairlie sites currently infected with Dv could be compromised by surrounding commercial shipping and transport activity.

The cost to shipping, specifically at HCT, of Option 2: eradication is expected to be **high** and a **possible** occurrence, therefore overall risk rating is ***high***.

Option 3: Management

The global nature of vessels docking at HCT represents a significant challenge to pathway management. While there is considerable uncertainty regarding the spread and potential impact of Dv, it is thought that Dv can survive trans-oceanic crossings on ships in low energy areas such as the sea chest and propeller shaft housing or as post-metamorphosed individuals on the sides of ballast compartments or rafting on free debris in the ballast compartment (Burt, 2011).

The cost to shipping, specifically at HCT, of Option 3: management is expected to be **considerable** and **probable** to occur, therefore an overall risk rating of ***moderate***.

8.4 Wild species diversity

Option 1: Do nothing

The risk and impact of Dv spread to marine SACs is presented in Table 8 and assessed as low, low-moderate and moderate depending on the location of SAC and qualifying features. There is also potential for Dv to impact other priority habitats outside SACs, including reefs and maerl beds. The overall cost to wild species diversity of Option 1: do nothing is expected to be **considerable** and **possible** to occur, therefore an overall risk rating of ***moderate***.

8.5 Cooling water

Option 1: Do nothing

This risk is limited to Hunterston Nuclear Power plant and given normal management practices to manage fouling of cooling water intake the cost of Option 1: do nothing is expected to be**minor** and **possible** to occur, therefore an overall risk rating of ***low***.

8.6 Water quality regulation

Option 1: Do nothing

Potential costs may arise if quality targets set out by the Marine Strategy Framework and Water Framework Directives are not met due to presence of Dv impacting such targets.

The cost to water quality regulation of Option 1: do nothing is expected to be **considerable** but **highly uncertain**, therefore overall risk rating is ***low***.

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[6] See p27 at *Measuring the value of the freight transport sector to the Scottish Economy* http://www.transportscotland.gov.uk/files/documents/roads/Measuring_Value_of_Freight_Report.pdf

[7] See Marine Atlas, sea & coastal water transport GVA

Option 2: Eradication

This risk is limited to the requirement for a CAR license should accelerant be used as part of the eradication process which is advised if the bags/wrapping are at risk from over-topping or wave-driven mixing.

The cost to water quality regulation of Option 2: Eradication is expected to be **slight** with a **possible** occurrence; therefore overall risk rating is ***low.***

8.7 Direct process costs

Option 1: Do nothing

No process costs are associated with Option 1.

Option 2: Eradication

The process of eradication by wrapping pontoon, fingers and pilings at Largs Yacht Haven and pilings at Fairlie Quay and Clydeport has been costed as presented in Table 11. Total cost, based on four dive teams, is estimated at just under £980,000; not including jet washing of vessels which is estimated at £330,000 for 550 vessels. Costs have been estimated based on four dive teams to allow a trade off with time taken and the need for simultaneous treatment to maximize likelihood of success.

These costs are for one year of eradication. Based on previous experience it is likely that two or even three years of eradication will be necessary. These costs do not include follow up monitoring which is likely to be in the region of £20-30,000 per year.

The total area to be treated is estimated at 39,771 m^2 based on an estimated 400 piles at Clydeport, 288 piles at Fairlie Quay, 140 piles at LYH and 2,200m of pontoon and 350 fingers at LYH.

The surface area treated at Holyhead marina equated to 6,138 m^2 (Holt and Cordingley, 2011). Costs of treating Holyhead in year 1 were estimated at £375,000, with a second annual treatment estimated at £400,000 including follow up monitoring. The area at LYH, Clydeport and Fairlie Quay is 6.5 times the area treated at Holyhead. Due to depth, the frequency of scuba diving will be more restrictive at Clydeport (26m) and to a lesser extent Farilie Quay (10m) in terms of the number of dives per day.

Obtaining a license under the Marine (Scotland) Act 2010may also be necessary as experienced by Holt and Cordingley (2011) in relation to depositing any articles or substances in the sea or under the seabed.

Where over-topping or wave-driven mixing is a risk then an accelerant should be considered in which case a CAR license (Water Environment (Controlled Activities) (Scotland) Regulation 2005) will be required from SEPA. The pilings at Fairlie Quay Marina and Hunterston Terminal Clydeport jetty are more exposed and likely to experience wave action, so either wrapping should extend well beyond the water line, or accelerant should be considered.

Process costs of Option 2: eradication are expected to be **major** and **certain** to occur with an overall risk rating of ***very high.***

Likelihood of success

In general, eradication in the marine environment is extremely difficult. The few successful efforts that have been recorded in the marine environment have several common elements (Kleeman, 2009):

- Early detection and correct identification of the invader;
- The pre-existing authority to take action;

- The pest could be sequestered to prevent dispersal, or else had very limited dispersal capabilities;
- There was political and public support for eradication, and acceptance of some collateral environmental damage;
- There was a high degree of certainty that a lack of action would have major consequences; and
- Follow-up monitoring verified the completeness of the eradication.

In the case of Dv the encapsulation technique (including use of accelerant and no accelerant) has been shown to be 100% effective on similar substrates i.e. after encapsulation no Dv exists; however, Dv has always returned. Globally, where attempted to-date, a Dv eradication programme has never been fully successful.

In relation to probability of success Kleeman (2009) assessed a 50% chance of eradication at Hoyhead marina in the first year of trials and 98% chance of ensuring thepopulation remains at a low level of infestation. Furthermore a 95% chance of complete eradication was assessed foreach subsequent year of treatment, if it is revealed that no other substrates were infected. Funding is currently being sought for a second year of eradication at Holyhead marina.

Kleeman (2009) identified that success very much depends on the confidence of surveys conducted and a clear understanding of the distribution and occurrence of Dv.

Coutts and Sinner (2004) assessed the probability of successful eradication at three bays in New Zealand to be 25% in year 1 and 28% in year 2; with a combined probability over two years of 46%. Eradication of pontoons was considered to have a 75% probability of success, piles 90% and ropes and anchors 50%.

Both the eradication programs in Wales and New Zealand were not fully successful.

Based on the range of Dv coverage, both geographically and structurally, the Coutts and Sinner (2004) estimation of success if probably more applicable to the Largs and Fairlie case than the Welsh example.

TABLE 11: ESTIMATED COSTS OF ERADICATION INCLUDING WRAPPING MATERIAL, DIVING TEAMS AND VESSEL WAHSING

		LYH	Clydeport	Fairlie Quay
Wrapping material				
Piles	Number of piles	140	400	288
	Max depth	2.5m	26m	10m
	Estimated pile diameter	0.3m	0.8m	0.5m
	Estimated area per pile	2.36m^2	65.35 m^2	15.71 m^2
	Estimated area of piles	329.87 m^2	26138.05 m^2	4523.89 m^2
Pontoon	Length of pontoons	2200m		
	Width of pontoon	2.4m		
	Depth of pontoon	1m		
	Estimated area of pontoons	5280 m^2		
Fingers	Number of fingers	350		
	Length of finger	10 m		
	Width of finger	1 m		
	Depth of finger	1 m		
	Estimated area of fingers	3500 m^2		
Sub-total		9109.87 m^2	26138.05 m^2	4523.89 m^2
Total				39771.81 m^2
Cost @ £1 per m2				**£39,772**
Diving teams				
Diving	Assumption	Less restrictive due to depth	3 piles per day	5 piles per day; 5 moorings per day
	Dive teams	4	4	4
	Number of days wrap	25	33	20
	Number of days unwrap	25	33	20
	Mob&de-mob	2	2	2
	Total dive team days	208	272	168
	Cost for dive team per day	£1,445	£1,445	£1,445
Sub-total		£300,560	£393,040	£242,760
Total				**£936,360**
Jet-washing vessels				
Vessels	Number of vessels	550		
	Vessels @ £600 each	£330,000		
Total		**£330,000**		

Total cost of wrapping & dive teams	**£976,132**
Total costs incl vessel jet washing	**£1,306,132**

Option 3: Containment and Management

Containment and management of Dv to limit detrimental impacts could be implemented from winter 2011/12 and would, subject to ongoing review, continue indefinitely. The costs associated with response option 3 (containment and management) depend critically on the stringency and extent of the measures taken. Two approaches are considered: rigorous and pragmatic.

Rigorous

A rigorous approach would closely follow the recommendations laid out in the GB Non-native Species Secretariat's (GBNNSS) Pathway Management Plan. Rigorous containment and management would focus specifically on Dv and work to contain it to current locations in Scotland and manage potential spread through detailed Codes of Conduct for yachts and other vectors entering Scottish marinas from infected locations, including English, Welsh, French and Irish marinas, as well as Largs Yacht Haven and Fairlie Quay Marina.

The greatest risk of spread is associated with yachts that have been moored and laid stagnant for a number of months. Rigorous pathway management would require that these boats be slipped, power washed and anti-fouled prior to departure, irrespective of treatment earlier in the year. Direct costs of this (to be borne either by the yachtsmen or through some form of government funded scheme) are estimated at approximately £600 per vessel. Rigorous pathway management would require this process for all vessels leaving a marina known to have Dv colonisation, including English, Welsh, French and Irish marinas, as well as Largs Yacht Haven and Fairlie Quay Marina. These actions would have to be backed up by strict protocols/regulations for yachts using the LYH and FQM marinas, as well as marina practises including introduction of closed loop system for FQM and appropriate enforcement of the use of closed loop systems at both marinas.

Management would also be necessary for other vessels using LYH including fishing vessels and Cydeport support vessels. Ships visiting Hunterston Coal Terminal would also require sufficient pathway management to minimise risk of spread from Clydeport jetty to other global locations. The on-going disruption and cost of such measures could lead to reduced demand for marina/port facilities and displacement of trade to more lax jurisdictions.

Indicative costs have been estimated for rigorous pathway management of Dv within the report by *Didemnum vexillum* GB working group (2011) titled: Recommendations for Reducing the Rate of Spread and Potential Re-Invasion of *Didemnum vexillum*. The total cost for reducing rate of spread and potential re-invasion within Great Britain is estimated at £545,000 plus £10-15,000 per marina closed loop wash down system. The recommendations and associated costs are summarized in Table 12 with an additional priority coloumn added as part of this assessment.

Pragmatic

A pragmatic approach would involve building on existing initiatives for all invasive species and would not necessarily have a species specific focus. Such local initiatives include the Clyde Forum Biosecurity Plan and the Green Blue Codes of Good Practise; national initiatives include general marina best practice, Codes of Good Practise for shellfish and fish farms including internal procedures and UK level invasives strategies. Key aspects of this approach will include: education and awareness, expanding codes of best practice to ensure adequate coverage of invasives and controls on vector movement. The costs of developing and enforcing such measures are difficult to estimate, but are likely to be less than an eradication programme – particularly if they build on existing information dissemination and training mechanisms. However, unless made mandatory, effectiveness will depend on high rates of information uptake and voluntary compliance with guidance amongst stakeholders – which in turn may rest on how well information reaches its target audience and/or how onerous/inconvenient adherence to guidance is. The latter represents a cost that should be accounted for.

Many of the costs are associated with developing guidance, awareness raising and encouraging behavior change. It is considered that such costs could be somewhat reduced by employing a Project Officer to undertake these tasks across sectors. This could be at a Scottish or GB level.

There is considerable opportunity to join forces with the current efforts to produce and implement a Clyde Biosecurity Plan (Box 3) and dovetail with standard industry codes of practice and biosecurity measures in the aquaculture industry and leisure yachting industries.

Box 3: Clyde Biosecurity Plan

A Clyde Biosecurity Workshop was recently held for stakeholders in the Clyde area and provided a synopsis of the current status of the Clyde Biosecurity Plan and held workshops to develop areas of the management strategy.

The Plan will set out purpose, background and context including policy, legislation and planning framework before discussing biosecurity issues in the Clyde including Dv and other non-native species. The Management Strategy itself will be based on 3 objectives:

Objective 1: Reduce risk of introduction and spread

- *Output 1 - Raise stakeholder awareness*

Objective 2: Surveillance, detection, monitoring, rapid response

- *Output 2.1 - Early warning and monitoring systems in place*
- *Output 2.2 – Rapid response mechanism*

Objective 3: Control programmes

- *Output 3 – Control and eradication programmes in line with national policy*

Process costs of Option 3: containment and management are expected to be **minor** and **probable** to occur with an overall risk rating of ***moderate.***

Likelihood of success

The probability of successful containment and management very much depends on the level of compliance with the Biosecurity Plan across all sectors. Implementation and enforcement of anti-fouling measures to be adopted by yacht owners and within marinas requires careful consideration, specifically in relation to what can reasonably be expected of recreational sailors.

TABLE 12: SUMMARY OF RECOMMENDATIONS FOR REDUCING THE RATE OF SPREAD AND RE-INVASION OF DVIN GREAT BRITAIN (*DIDEMNUM VEXILLUM* GB WORKING GROUP, 2011)

Primary Objectives	Secondary Objectives	Recommendations	Indicative Cost Estimate	Priority
Recreational Boating and Diving				
Awareness raising and behaviour change	Improve understanding of and need for better biosecurity. Encourage early identification of new populations. Improve up take of appropriate cleaning.	Consolidate and maximise the use of existing guidance and information (e.g. Green Blue and RYA material), develop additional materials in partnership if necessary. Disseminate information to relevant stakeholders . Develop and roll out simple, clear guidance for appropriate cleaning for boat owners and marina operators. Encourage the inclusion of INNS in RYA and BMF training courses. Provide key points of contact at NE / CCW /SNH / SAMS to provide guidance to stakeholders. Establish ID service to confirm species records e.g. through MBA. Facilitate provision of closed loop wash down systems in priority marinas / yacht clubs	Total: £50-100k pa (+ £10-15k per marina for closed loop wash down system)	High
Planning	Reduce the rate of marina infection and provide easier control within infected marinas.	Develop guidance for planners and others on better marina design with regards biosecurity. Build biosecurity aspects into environmental accreditation schemes	Total: £25-30k	Low
International Cooperation	Share responsibility where relevant with European partners. Improve biosecurity in high risk areas	Identify key marinas at risk of acting as an invasion source for GB. Make key contacts relevant to each high risk marina. Share awareness raising materials and attempt to agree appropriate controls.	Total: £25k	Low
Fisheries				
Awareness raising and behaviour change	Increase the up-take of good practice and discourage high risk activities.	Develop sector specific guidance on good practice / biosecurity for fisheries activities in partnership with relevant organisations. Disseminate key messages through appropriate media (e.g. posters, leaflets, newsletters, websites etc). Provide guidance and materials for regulators to encourage good practice.	Total: £50-100k	Low
Policy and enforcement	Required if voluntary arrangements are insufficient	If necessary, review whether existing licensing and permit conditions can be used to encourage good practice and provide guidance for this to regulators.	Total: £5-10k	Low
International cooperation	Encourage uptake of good practice beyond GB and reduce the risk of INNS	Identify and share information with relevant counterparts outside of GB	Total: £20k	Medium

	entering or leaving GB.			
Ship Recycling				
Awareness raising, behaviour change and enforcement	Support responsible approaches to ship recycling through better understanding of INNS issues.	Input into existing initiatives (e.g. MILC). Develop clear guidance, with relevant partners, on risks associated with INNS and ship recycling, including key messages about good practice. Review policy / regulation for ship recycling and develop clear guidance on how it should be used. Disseminate guidance for regulators (e.g. through training) on how to respond to INNS issues associated with ship recycling. Conduct research on sustainable methods for decontaminating large vessels and best methods for preventing spread of INNS	Total: £150k	Low
International cooperation	Improve adoption of good practice beyond GB.	Work with the IMO to raise awareness of the issue of INNS and ship recycling and incorporate into any future guidance	Total: £20k	Low
Marine Industries				
Awareness raising and Behaviour Change	Raise awareness across all relevant industries.	Work with partners to develop general guidance for all industries use existing information (e.g. oil and gas guidance document). Encourage uptake among industries Where relevant, provide additional awareness raising materials (including information for websites and for workshop / presentations). Conduct research to establish that the introduction of fixed and hard substrates do provide suitable substrates for INNS and if so, how to best control for the spread of INNS via these structures.	Total: £100k	Low
Policy, enforcement and international cooperation	Use of existing regulation to raise awareness of INNS and the risk and input into new developments.	Identify and input into existing policy initiatives (e.g. UK Marine Policy Statements). Develop and disseminate (including through training) guidance for regulators on INNS issues associated with marine industry	Total: £15-20k	Low
Shipping				
Ballast	Utilise existing measures, i.e. Ballast Water Management Convention	No action necessary – monitor and engage with existing provision. Ratification expected shortly	NA	Medium
Biofouling	Utilise existing measures, i.e. draft guidelines being developed by IMO.	No action necessary – monitor and engage with existing provision. Guidance expected to be agreed 2011.	NA	High

9 ASSESSMENT OF BENEFITS TO ECOSYSTEM SERVICES

There are no current impacts to stakeholders due to presence of Dv at Largs and Fairlie. No known aquaculture, capture fisheries, shipping or wild species diversity are currently being affected as a result of the current presence of Dv. The benefits are therefore limited to the 'expected' benefits and will have an inverse relationship with costs under the different options for each sector. For example there are potential costs to shellfish farming if the do nothing option is chosen, however if option 2 or 3 were implemented then the 'expected' benefits would be no loss or additional management i.e. continue as normal. Also, note that since option 1 is the baseline it is not appropriate to assess benefits of costs avoided by not following other options.

Occurrence of expected benefits and descriptions of these are presented in Table 13 and Table 14.

TABLE 13: TABLE PRESENTING SECTORS THAT WOULD POTENTIALLY BENEFIT FROM MANAGEMENT OPTIONS 2 AND 3 (SHADED IN BLUE)

Ecosystem Service	Sector	Option 2	Option 3
Food	Shellfish farming	🟦	🟦
	Finfish farming	🟦	🟦
	Capture fisheries	🟦	🟦
Recreation and tourism	Marinas	None	None
	Yachts	None	None
	Other recreation	🟦	🟦
Navigation	Ferries	None	None
	Shipping	None	None
Wild species diversity	Marine protected areas	🟦	🟦
Cooling water	Power plant	🟦	🟦
Water quality regulation	CAR and MSFD & WFD	None	None

TABLE 14: EXPECTED BENEFITS OF MANAGEMENT OPTIONS

Ecosystem Service	Sector	Benefits
Food	Shellfish farming	Options 2 and 3: moderate expected benefit due to reduced risk of Dv fouling. Benefit is not considered high (which would mirror the scale of the cost) due to the probability of success anticipated for both management options.
	Finfish farming	Options 2 and 3: low expected benefit due to reduced risk of Dv fouling
	Capture fisheries	Options 2 and 3: low expected benefit due to reduced risk of Dv fouling
Recreation and tourism	Other recreation	Options 2 and 3: low expected benefit due to reduced risk of Dv fouling recreational dive sites
Wild species diversity	Marine protected areas	Options 2 and 3: low expected benefit due to reduced risk of Dv fouling SAC and vulnerable habitats (see Section 9.1)
Cooling water	Power plant	Options 2 and 3: low expected benefit due to reduced risk of Dv fouling cooling water intake

9.1 Wild species diversity

There are a number of expected environmental benefits that may result from the eradication or containment and management of Dv. These benefits have an economic value, some of which may be captured in recreational values. However, most will take the form of non-use values that are difficult to quantify (HMT, 2003; Nunes & Markandya, 2008). Estimating such values is very complex and uncertain and has not been attempted in this report. These benefits are qualitatively described in greater detail below.

The protection of habitats and species of European and UK importance, through site protection mechanisms, provides benefit through existence value, the non use value enjoyed by individuals due to the knowledge that the species or habitat exists and are not threatened. This value is likely to provide international as well as local benefits.

The protection of species and habitats in general reduces the risk of biodiversity loss and provides an option value through as yet unknown uses that may become apparent in the future. An example of such a benefit is often medicinal uses of natural substances. Like existence value, option value will accrue very widely resulting in international and national benefits as well as local ones.

Healthy, productive and biologically diverse sites provide numerous ecosystem services such as sustainable harvestable products (e.g. fish) as well more intangible benefits such as climate regulation and nutrient cycling. Should these ecosystems significantly change or collapse a flow of benefits currently enjoyed will no longer be provided. Maintaining strong and diverse flora and fauna in these sites reduces the risk of ecosystem change/collapse.

It should be noted that the environmental and social benefits listed above are explicit principles underlying the creation and subsequent protection of Natura 2000 sites. While it may be very difficult or impossible to quantify these benefits the EU directives and implementing laws of member states intrinsically recognise that these “intangible” benefits have significant value.

10 COST BENEFIT ANALYSIS

10.1 The economics of INNS

The introduction of invasive non-native species (INNS) to the Scottish environment clearly has biological dimensions, with ecological impacts depending on both the characteristics of the INNS and of the receiving ecosystem. For example, how tolerant of different conditions the INNS is and how rapidly it reproduces plus how favourable/hostile the ecosystem is in terms of habitats/competitors/predators.

However, the introduction of INNS also has socio-economic dimensions in that ecological impacts on provisioning ecosystem services may directly affect output and employment opportunities whilst impacts on less visible ecosystem services may also undermine such opportunities. This is the general point made in studies such as the National Ecosystem Assessment and The Economics of Ecosystems and Biodiversity (TEEB, 2011; UKNEA, 2011; Pecher & Mooney, 2009). For example, the viability of commercial shellfish production may be reduced through lower yields and/or higher production costs clearly attributable to the effect of Dv on provisioning services whilst other effects may occur more insidiously as changes to regulating and supporting services occur over time.

Such damage[8] costs may be reduced or even avoided if introduction of the INNS is prevented (e.g. via quarantine controls), if the INNS is removed once present (e.g. an eradication programme) or controlled via on-going management (e.g. routine biosecurity). However, efforts to reduce or avoid damage costs are not themselves costless since they typically require labour and other resources plus may disrupt existing patterns of commercial and other activities. For example, eradication of Dv is likely to entail the use of diving teams encasing marina structures in plastic whilst also temporarily displacing some boat moorings.

This means that efforts to reduce damage costs are only worthwhile if the damage costs avoided outweigh the management costs incurred, and as such (expensive) eradication may not be an optimal policy response (Perrings *et al*., 2000; Eisworth & Johnson, 2002). However, such judgements typically need to be made on a case-by-case basis since the stochastic and dynamic nature of INNS, the spatial and temporal variation in impacts and the use of different decision criteria can all make the optimal response somewhat ambiguous ex-ante (Eisworth & van Kooten, 2002; Olson & Roy, 2002; DeAngelo *et al*., 2006).

Calculation of the balance between damage costs avoided (i.e. the benefits of management effort) and management costs is made more complicated by a number of factors. First, not all costs and benefits occur at the same point in time, and the time-profile may vary with different management options. For example, eradication costs would be incurred up-front but the benefit of avoided damages would hopefully extend into the future, as would on-going biosecurity costs. Where sufficient data exist, this leads to the use of financial discounting to allow comparisons on a Net Present Value basis (HMT, 2003).

Second, many of the costs and benefits are uncertain in nature due to a lack of data and scientific understanding but also the stochastic influence of local circumstances and histories. This can mean that costs and benefits cannot be quantified with any great degree of confidence and/or that outcomes have to be weighted by their likelihood of occurrence. This can pose analytical difficulties if some outcomes are irreversible or catastrophic in nature but also more generally if outcomes can only be described in relatively vague terms and uncertain probabilities (Eisworth & van Kooten, 2002; Horan *et al*., 2002). In addition, different approaches to measurements can yield different results, hindering cross-study comparisons (Lovell & Stone, 2005; Oreska & Aldridge, 2011).

Third, INNS impacts typically take the form of an externality and many of the ecosystem service benefits potentially at risk are public good in nature (Perrings *et al*., 2002). That is, INNS effects are typically felt by

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[8] Of course, some INNS may convey benefits – but this is not the case with Dv and is thus not considered further here.

people other than those responsible for their introduction and changes in benefit levels are not reflected in market values but through less-easily measured non-market values (Campbell, 2008; Garcia-Llorente *et al*., 2008; Nunes & Markandya, 2008; Sharp *et al*., 2011).

INNS problems also have socio-economic dimensions since they often arise through individual human actions (i.e. deliberate or unintentional introductions) and any subsequent attempts at mitigation and/or adaptation will also typically require human actions, individually and/or collectively. For example, Dv probably arrived on the hulls of recreational boats and active management now requires enhanced biosecurity measures. As such, policy responses need to consider the incentive structures and informational and institutional constraints within which INNS risk management occurs (Perrings *et al*., 2002; Henessey, 2008; also Horan & Lupi, 2005; Feng & Hennesy, 2008).

Cost-benefit analysis (CBA) offers a framework within which information may beassembled on the economic gains and losses associated with a course of action (Hanley & Barbier, 2009),including attempts to combat invasive species. Official guidance – such as the Green Book (HMT, 2003) - on the types of information to be assembled and, particularly, on the setting of baselines against which costs and benefits are to be gauged helps to ensure consistency of approach. However, the robustness of any analysis depends crucially on the quantity and quality of data available for consideration.

Reflecting this, recent reviews of socio-economic analysis[9] of INNS policy responses suggest that such analysis is often relatively unsophisticated (Born *et al*., 2005; Olson, 2006; Gren, 2008; Heikkila, 2011). In particular, non-market (indirect use, option and non-use) values are generally neglected in favour of market (use) values whilst the human behavioural aspects involved in introductions and responses are under-represented. Such omissions may reflect short-comings in the conceptualisation of INNS policy problems and responses but are also likely to reflect empirical practicalities. For example, the complex and contested nature of non-market valuations, difficulties of accurately portraying behavioural responses and fundamental gaps in the scientific data and knowledge necessary to quantify INNS impacts and the effectiveness of control measures.

Unfortunately, as with many invasive species, the available evidence on Dv impacts is somewhat patchy and subject to considerable uncertainty. In particular, whilst detrimental effects on shellfish productivity and on biodiversity are frequently cited in the literature, empirical quantification of such effects is rare. This reflects difficulties of in-situ impact measurements, particularly in the presence of confounding factors that vary considerably from site-to-site. Moreover, the likelihood and rate of colonisation of other sites from Largs and/or elsewhere is uncertain, as is the likelihood of control measures being effective.

Such uncertainty hinders formal cost-benefit analysis of alternative policy responses in that quantification of relative effects is either highly dependent on certain assumptions rather than empirical evidence and/or not all elements can be quantified with equal robustness. Attempts at cost-benefit analysis for Dv controls in both New Zealand (Coutts & Sinner, 2004) and Wales (Kleeman, 2009) highlight these difficulties. Consequently, and in-line with Green Book guidance, speculative or overly complex analysis yielding spurious precision has been avoided here. Rather a cost-benefit framework has been used to identify impacts in a more qualitative manner, with no attempt at discounting over time but some discussion of likely relative magnitudes and outcomes. Moreover, whilst cost:benefit ratios could be calculated for a range of scenarios, sensitivity analysis is instead presented here in terms of the number of years of damage avoidance required to recoup management costs, which can then be viewed subjectively against the likelihood of avoiding Dv colonization from other sources for such a period of time.

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[9] The literature on INNS (also referred to as alien species or sometimes biological pollution) is typically focused on terrestrial examples – notably agricultural pests and diseases – but the general points apply equally to marine cases.

10.2 Summary of identified costs and benefits

A summary of the severity, occurrence and overall risk rating of costs to each ecosystem sector for each management option is presented in Table 15 based on the boundaries shown in Table 16.

Table 17 presents an overall summary of the costs and benefits to each sector.

TABLE 15: SUMMARY OF SEVERITY, LIKLIEHOOD OF OCCURENCE AND OVERALL RISK RATING OF COSTS ACROSS ECOSYSTEM SERVICES FOR EACH MANAGEMENT OPTION

Ecosystem Service	**Sector**	**Cost**								
		Option 1			**Option 2**			**Option 3**		
		Impact	**Uncertainty**	**Risk**	**Impact**	**Uncertainty**	**Risk**	**Impact**	**Uncertainty**	**Risk**
Food	Shellfish farming	3	2	**Moderate**						
	Finfish farming	3	1	**Low**						
	Capture fisheries	2	2	**Low**	1	5	**Low**	1	4	**Low**
Recreation and tourism	Marinas				4	5	**Very High**	2	4	**Moderate**
	Yachts				2	5	**Moderate**	2	5	**Moderate**
	Other recreation	1	2	**Low**						
Navigation	Ferries							1	3	**Low**
	Shipping				4	3	**High**	3	4	**Moderate**
Wild species diversity	Marine protected areas	3	3	**Moderate**						
Cooling water	Power plant	2	3	**Low**						
Water quality regulation	CAR and MSFD & WFD	3	1	**Low**	1	3	**Low**			
Public sector	Eradication process				5	5	**Very High**	2	4	**Moderate**

TABLE 16: BOUNDARIES FOR SEVERITY OF COST IMPACT AND UNCERTAINTY LEVELS AND (BOTTOM) DETERMINATION OF OVERALL RISK RATINGS

			Cost to Industry	**Cost to Environment**
Severity / Impact Level	**5**	Major	Unlikely to reduce GVA by more than 40%	Long-term, extensive environmental damage
	4	High	Unlikely to reduce GVA by more than 25%	Severe national environmental damage
	3	Considerable	Unlikely to reduce GVA by more than 10%	Regional environmental effect
	2	Minor / Limited	Unlikely to reduce GVA by more than 5%	Local environmental effect
	1	Slight	Unlikely to reduce GVA by more than 2%	Limited environmental impact

		Keyword	**Uncertainty Guidance**
Uncertainty/ confidence of occurence	**5**	**Certain**	Expected to happen with certainty
	4	**Probable**	More likely to happen than not
	3	**Possible**	May happen
	2	**Uncertain**	Uncertain whether it will happen
	1	**Highly uncertain**	Extremely uncertain whether it will happen

Severity / impact level		**Uncertainty**				
		1	**2**	**3**	**4**	**5**
		Highly uncertain	**Uncertain**	**Possible**	**Probable**	**Certain**
5	**Major**	**High**	**High**	**High**	**Very High**	**Very High**
4	**High**	**Moderate**	**Moderate**	**High**	**High**	**Very High**
3	**Considerable**	**Low**	**Moderate**	**Moderate**	**Moderate**	**High**
2	**Minor / Limited**	**Low**	**Low**	**Low**	**Moderate**	**Moderate**
1	**Slight**	**Low**	**Low**	**Low**	**Low**	**Low**

TABLE 17: SUMMARY OF OVERALL COSTS AND BENEFITS FOR EACH OPTION

Ecosystem Service	Sector	Option 1*	Option 2		Option 3	
		Cost	Cost	Benefit	Cost	Benefit
Food	Shellfish farming	Moderate		Moderate		Moderate
	Finfish farming	Low		Low		Low
	Capture fisheries	Low	Low	Low	Low	Low
Recreation and tourism	Marinas		Very High		Moderate	
	Yachts		Moderate		Moderate	
	Other recreation	Low		Low		Low
Navigation	Ferries				Low	
	Shipping		High		Moderate	
Wild species diversity	Marine protected areas	Moderate		Moderate		Low
Cooling water	Power plant	Low		Low		Low
Water quality regulation	CAR and MSFD & WFD	Low	Low			
Public sector	Eradication process		Very High	Low	Moderate	Low

* Since option 1 is the baseline it is not appropriate to assess benefits of costs avoided by not following other options

11 SYNOPSIS

Uncertainties regarding the likely incidence of Dv, the likely impacts of any given incidence and the likely effect of control efforts all make quantitative comparisons of costs and benefits over time somewhat speculative. Nevertheless, some categories of cost are considered to be more likely than others and hence some illustrative figures may be helpful. These are based on plausible assumptions, presented transparently for ease of interpretation and alteration with some sensitivity analysis. Given that the timings of Dv colonisation and impacts are highly uncertain, no financial discounting nor estimation of cost:benefit ratios has been undertaken. Yet the relative magnitudes are relatively clear when comparing possible recurrent annual damage costs with up-front management costs and the implied length of time needed to avoid re-contamination if management costs are to be recouped.

Option 1: do nothing

Under the baseline 'do nothing' option, some commercial damage costs are anticipated. Although impacts on (e.g.) nephrops and scallops are likely to be minimal, mussel production may be affected through Dv overgrowth reducing yields, lowering quality (and thus price) and increasing husbandry costs. Although Kleeman (2009) uses a 25% impact figure for Holyhead, this partly reflects significant sea-bed cultivation in the vicinity of the invasion. In the case of Scotland there is no seabed cultivation undertaken on the West coast, and rope culture is spread very widely up the West Coast, in the Western Isles and in Shetland. In New Zealand experience suggests that losses may actually be less than 5% and Laing et al (2010) report a lack of any great industry concern.

For Scotland as a whole, mussel turnover is around £7.1m, which perhaps equates[10] to a Gross Value Added (GVA) of around £3.5m. For the Western reporting regions perhaps most likely to be affected (Clyde, Minches&Malin Sea, Hebrides)[11], the figures are £2.3m and £1.1m respectively. If Dv spread and caused mussel farming to cease, these totals would be the damage costs, but a 10% reduction would limit GVA losses to around £110k regionallyor £350k if Dv spread nationally. These would be annual losses - although given that the spread of Dv would not be instantaneous, losses in early years would be lower but increasing gradually in subsequent years until the upper-bound loss was reached. In the absence of clear predictions on the rate of unchecked spread it is not, however, meaningful to attempt to put a time profile on annual losses.

No figures for impacts on fish farming operations elsewhere are available, with yield losses likely to be very limited but some additional handling costs perhapsnoticeable. Although not impacting on turnover, profitability could therefore be reduced slightly depending on the extent to which existing routines have to be augmented. Fish farming turnover for Scotland as a whole is around £420m, equating to perhaps[1] £60m GVA. For the Western reporting regions most likely to be affected, the totals are around £250m and £38m respectively. Hence a 2% reduction in GVA from higher handling costs would imply £1.2m nationally or £0.8m regionally – larger figures than for mussel farming due to the relative sizes of the two sectors. Again, these would be upper-bound annual losses and 2% may be overly pessimistic.

The other potentially significant damage cost relates to environmental impacts on habitats and biodiversity. The ecological assessment above suggests that significant impacts on ecosystem services such as fisheriesand

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[10] GVA for mussel farming is assumed to be around 40%-50% of turnover; for salmon farming it is around 15% (analysis undertaken in support of SARF45)

[11] This is actually a larger geographical area than suggested by the colonisation modelling and is thus a relatively more pessimistic view of likely damages arising from uncontrolled spread. Moreover, for both the regional and national cases the figures reflect full colonisation from now rather than a more likely phased pattern of more gradual colonisation over time.

water quality are unlikely. The main ecological impact would therefore be local displacement of native fouling and encrusting species and this would be regarded as more significant if displacement took place within protected sites, and/or on priority habitats such as reefs. It is also probable that, were they to occur, these impacts would be irreversible.

It is difficult to attach monetary values to these species and habitats, and the problem is compounded by the high degree of uncertainty associated with the extent and severity of these effects. In the absence of bespoke valuation exercises for the affected sites, benefit-transfer models could be used to infer values from previous studies elsewhere. However, the inability to predict the precise ecological impacts likely to arise means that any figures would be of dubious worth. Nonetheless the uncertainty associated with these impacts, and the possibility of irreversible change may be regarded as sufficient rationale to justify a precautionary approach to eradication or containment & management, which European and International conservation obligations might require (or at least require to be attempted). For example, requirements under the Marine Spatial Framework Directive, Habitats Directive or the Water Framework Directive with respect to quality targets such as Good Ecological Condition. Although, even if environmental damage was a serious concern, the management costs incurred in attempting to mitigate them would probably be accepted as disproportionate with low likelihood of success - no infraction penalties have been imposed yet on Member States experiencing Dv.

Option 2: Eradication

If successful, eradication would avoid the damage costs identified under option 1, perhaps around £0.9m regionally or £1.5m nationally (plus any environmental costs) per year. However, the practical difficulties of eradication – including technical challenges but also the need for sustained stakeholder support, plus the possibility of recontamination from elsewhere - mean that the likelihood of success and thus expected value of damage costs avoided will be substantially less than 100%. For example, a 10% chance of success reduces expected commercial use-value benefits to under £0.1m regionally, £0.15m nationally; 50% success yields £0.45m and £0.75m. Again, it is important to note that these are upper-bound commercial losses assuming instantaneous colonisation regionally or nationally. Given the potential for further contamination from outwith Scotland, the durability of any benefits is likely to be limited but might extend for a few years (partly dependent on uptake of option 3 measures in Scotland and elsewhere).

By contrast, an eradication programme will almost certainly incur process costs of around £1.3m in year one, with possibly similar expenditures in years two and three depending on progress made. In addition, it would impose business disruption costs on local businesses. These could be particularly significant for Largs Yacht Haven (LYH) and Hunterston Coal Terminal (HCT) since movements of vessels would have to be suspended for a period of time – at a minimum of several days to allow dive teams to operate and possibly several weeks to prevent vessels damaging plastic wrapping around structures.

HCT, owned by Clydeport but operated by Fergusson Copal, has an annual throughput capacity of 8m tonnes with extensive storage and transport facilities. Imported coal is sent to Long Gannet and to Drax in Northern England, but exports also occurs. Current coal prices of around £75/t imply a turnover figure of around £600m. This implies that suspension of vessel movement for a month during eradication could impose a turnover loss of £50m. Converting this into GVA is difficult, but HCT represents more than 5% of Scottish port capacity which has a total GVA of £160m[12] to £430m[13], so HCT might account for £8m to £22m (c.£650k to £1.8m a month). HCT has not been approached for comment or verification of these estimates.

Notwithstanding the legislative powers now in place for addressing invasive species, LYH has indicated likely opposition to an eradication programme - not least due to anticipated disruption costs. For example, if 550 berths are usually occupied over the winter months (when eradication would be best attempted), cleaning each boat would incur costs of around £600, amounting to over £300k – borne either by LYH and/or boat owners. There is also a logistical issue here in that a requirement to treat (up to) 550 yachts over a relatively short time period would probably exceed the capacity of local facilities. Separately, rather than retain berths at LYH, boat owners may temporarily or permanently relinquish them in favour of other marinas. This would potentially displace contamination risks whilst also reduce LYH revenue. For example, a 10% loss of winter berths could equate to around £80k in lost profit to LYH, with knock-on effects to businesses allied to the marina.

The direct costs of eradication over a three year period are thus fairly certain to lie in the range of £2m to £4m with additional disruption costs of perhaps £0.5m to £2m depending on how affected HCT would be. Upfront eradication costs are thus unlikely to be recouped in terms of damage costs avoided unless some fairly optimistic assumptions are made about both the likelihood of success and its duration (i.e. avoiding recontamination), and/or pessimistic assumptions about the magnitude of damage costs under option 1 (see Table 18 and Table 19). To be effective, option 2 would probably need to be accompanied by option 3 measures to enhance the likelihood of sustaining benefits for a longer period of time than otherwise – thus further adding to the management costs incurred.

Option 3: Containment and management

Under option 3, if 100% successful at containing Dv to its current locations in Scotland, all of the damage costs identified under option 1 would be avoided or at least delayed. However, the likelihood of 100% containment is low. Hence, again, the expected benefits will be less than the maximum possible. This reflects some practical treatment issues, but also behavioural aspects of stakeholders' awareness of and compliance with pathway management measures. Moreover, given the presence of Dv in neighbouring countries, un-coordinated attempts at pathway management, that neglect transboundary movement, are unlikely to be successful.

Pathway management will impose costs on bodies (e.g. government, trade associations) seeking to design, promote and monitor codes of good of good practice but also upon businesses and private individuals seeking to comply with them. At the GB-level, the design etc. costs were estimated at over £0.5m, plus capital costs of £10k to £15k per site to install a closed-loop cleaning system at each marina (although as noted under option 2, the capacity of a single cleaning facility at a site to cope with peak-loading during eradication or, for example, a regatta, is questionable). Direct expenditure at a Scottish level should be less than this if a GB-wide approach was adopted, but could perhaps reasonably amount to £0.25m depending on precise cost-sharing arrangements.

However, in addition to depending on technical design and co-ordination, the success of pathway management in containing Dv will also be a function of how well they are complied with, and this in turn depends on the behaviour of private businesses and individuals facing costs and constraints imposed by

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[12] See p27 at *Measuring the value of the freight transport sector to the Scottish Economy* http://www.transportscotland.gov.uk/files/documents/roads/Measuring_Value_of_Freight_Report.pdf

[13] See Marine Atlas, sea & coastal water transport GVA

compliance. For example, limits on freedom of movement and actual expenditures on anti-fouling measures. Perceptions of and reactions to the latter will be important. For example, if not co-ordinated across different sites, individual sites such as LYH will simply lose custom as boat owners are displaced to sites with less onerous constraints. For example, effective pathway management may require that vessels berthed for any significant period of time at LYH are cleaned (if not anti-fouled) shortly prior to departure, especially at those times of year when spread is most likely. Apart from the financial cost, this will inevitably inconvenience owners since capacity constraints will lead to queuing. If this prospect led to a 10% loss of all 730 berths, this could represent a loss of £730k to LYH. This highlights the need to consider incentive effects in the design of control measures and the impact on individual businesses.

If imposed uniformly, biosecurity constraints will impose compliance costs on all boats owners (i.e. not just at LYH but also elsewhere in Scotland). This may reduce displacement from LYH to other Scottish marinas, but could simply displace trade to England; approximately 13% of Scottish berths are for visitors rather than visitors.[14] In aggregate, such costs could be significant and lead to a general reduction in the demand for recreational boating facilities in Scotland, with knock-on effects for other businesses allied to marinas. Marinas are estimated to attract around £100m of sailing tourism expenditure[15], around £44m in the Clyde region generating around £50m of GVA nationally, £22m in the Clyde. Hence, although the sensitivity (elasticity) of demand is unknown, a 10% reduction in demand due to higher costs or other constraints would equate to a reduction of £2m regionally and £5m nationally.

Hence, as with eradication costs, the costs of meaningful pathway management will easily exceed expected benefits depending on how costs are shared/co-ordinated and on assumptions about success rates and option 1 damage costs. Weaker constraints would impose lower costs, but would have even lower chances of successful containment.

However, pathway management for Dv is likely to share some common elements with attempts to control other invasive species. Hence not all of the costs described are necessarily additional to existing expenditure or to expenditures that might have wider utility. For example, dissemination activities can present Dv management alongside broader marine biosecurity issues, monitoring activities can cover multiple species and anti-fouling/cleaning treatments can combat multiple hazards. Hence support for existing initiatives, such as the Clyde Biosecurity Forum may be merited.

In addition, it may be possible to apply measures selectively, perhaps applying more rigorous controls to movements from known infected sites and/or movements to environmentally sensitive sites. The latter may be important if International and European conservation obligations require some demonstrable mitigation action on Dv but will accept that eradication or blanket movement controls are impractical. Similarly, if voluntary compliance with codes of practice is generally good, it may be possible to target resources at particular stakeholder segments (if they can be identified) where compliance is weaker.

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[14] http://www.scottish-enterprise.com/~/media/publications%20archive/About%20Us/economic%20research/Sailing_tourism_in_scotland.ashx

[15] See http://www.scottish-enterprise.com/~/media/publications%20archive/About%20Us/economic%20research/Sailing_tourism_in_scotland.ashx

TABLE 18: EXPECTED ANNUAL FARMED MUSSEL GVA DAMAGE AVOIDED UNDER ALTERNATIVE ASSUMPTIONS

% loss if not eradicated	Likelihood of eradication or pathway management success							
	Regional				National			
	10%	25%	40%	100%	10%	25%	40%	100%
2%	£2k	£6k	£9k	£22k	£7k	£18k	£28k	£70k
5%	£6k	£14k	£22k	£55k	£18k	£44k	£70k	£175k
10%	£11k	£28k	£44k	£110k	£35k	£88k	£140k	£350k
25%	£28k	£69k	£110k	£275k	£88k	£219k	£350k	£875k
40%	£44k	£110k	£176k	£440k	£140k	£350k	£560k	£1400k

TABLE 19: EXPECTED ANNUAL FARMED FINFISH GVA DAMAGE AVOIDED UNDER ALTERNATIVE ASSUMPTIONS

% loss if not eradicated	Likelihood of eradication or pathway management success							
	Regional				National			
	10%	25%	40%	100%	10%	25%	40%	100%
2%	£76k	£190k	£304k	£760k	£120k	£300k	£480k	£1200k
5%	£190k	£475k	£760k	£1900k	£300k	£750k	£1200k	£3000k
10%	£380k	£950k	£1520k	£3800k	£600k	£1500k	£2400k	£6000k
25%	£950k	£2375k	£3800k	£9500k	£1500k	£3750k	£6000k	£15000k
40%	£1520k	£3800k	£6080k	£15200k	£2400k	£6000k	£9600k	£24000k

TABLE 20: MINIMUM DURATION OF SUCCESS (YEARS) REQUIRED TO PAYBACK £5M OF PROGRAMME COSTS

% loss if not eradicated	Likelihood of eradication or pathway management success							
	Regional				National			
	10%	25%	40%	100%	10%	25%	40%	100%
2%	63.9	25.6	16.0	6.4	39.4	15.7	9.8	3.9
5%	25.6	10.2	6.4	2.6	15.7	6.3	3.9	1.6
10%	12.8	5.1	3.2	1.3	7.9	3.1	2.0	0.8
25%	5.1	2.0	1.3	0.5	3.1	1.3	0.8	0.3
40%	3.2	1.3	0.8	0.3	2.0	0.8	0.5	0.2

Expert opinion and findings from the literature suggest that commercial impacts are likely to be lower rather than higher and that the likelihood of eradication will also be lower rather than higher. In this case, outcomes in the top left of the regional or national blocks in Table 19 (which simplistically combines costs from Tables 17 & 18) are more likely and thus the duration of success required to justify management and disruption costs (e.g. £5m) is relatively long given the acknowledged potential for recontamination from outwith Scotland. Higher management costs would extend this period further, as would lower annual damage costs from a phased (rather than uniform and instantaneous) spread of Dv under option 1 or indeed financial discounting of future damage costs.

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