Project report: Assessment of the impacts of *Didemnum vexillum* and options for the management of the species in England

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Aim

The objective of this report is to provide an estimate, in as much detail as possible, of the potential impacts of the alien sea squirt *Didemnum vexillum* on biodiversity and on the shellfish industry in England and outline options for control of the species in order to enable decisions to be made on the most appropriate approach to management or control of the species in England.

Current status

World-wide, *D. vexillum* has been reported from Northern Europe (Ireland, Netherlands, France, Spain (El Nagar et al. 2010)), the East Coast of the United States (U.S.), offshore of New England on Georges Bank, the West Coasts of the U.S. and Canadian, Japan, and New Zealand.

The UK non-native species secretariat carried out a risk assessment for this species from which it is concluded that introduction and establishment are very likely and that spread will probably be rapid.

In the UK it was first recorded in Holyhead marina, Wales, and in Plymouth, England, in 2008. A survey of selected marinas in England, in late 2009, detected further populations in the Dart estuary and the Solent (Gosport, Lymington and Cowes). In Scotland a population was identified in the Clyde (Largs marina) during a routine survey in October 2009.

Potential spread

In order to predict the potential spread of *D. vexillum* a simple modelling approach employing a Geographic Information System (GIS) was used (Appendix I). Two models were developed. The first was designed to show all possible areas around the English coast that could support *D. vexillum* (i.e. worst case scenario). This revealed that an area of approximately 11,900 km^2 is at risk. The second model aimed to show the most likely areas that *D. vexillum* could spread over the short term. Lack of suitable substrate appears to be an important factor limiting spread. Due to the nature of the model and the limited time frame, no statistical tests on model reliability were undertaken. Ideally a more in-depth modelling approach should be used. More information on model reliability is given in the Appendix.

The model, however, accurately predicted the areas at which *D. vexillum* has already been detected. Further spread is predicted mainly in the Solent / Isle of Wight area. The second area of the most concern is Plymouth. The rest of England has a fairly low risk of *D. vexillum* spread, perhaps with the exception of the Thames area, due to populations in the Netherlands, and Whitehaven marina in Northwest England. The risk posed to these areas is much lower than that along the South Coast.

Impacts – Biodiversity

D. vexillum can overgrow most hard substrata in the sub-tidal zone and in tide-pools in the intertidal zone. This can include bedrock, pebbles, cobbles, gravel, boulders, biogenic reef and other hard bodied sessile animals and plants. Where *D. vexillum* has invaded, the effects on biodiversity are varied and not well understood, especially over long time scales. For example, increases and decrease in species diversity have been recorded yet most studies lack suitable temporal or spatial controls. In England, the immediate threat to biodiversity is primarily around the locations already infected, such as the Solent and Dart Estuary. These areas are either within or adjacent to, a number of Natura 2000 European Marine Sites and contain habitats and species in the Biodiversity Action Plan (BAP). Over 14, 000 ha of reef, lagoon and sea-cave feature are potentially threatened along with other areas outside of protected sites. In European Marine Sites compliance with Article 6(2) of the Habitats Directive imposes the obligation to

"*take appropriate steps to avoid, in the special areas of conservation, the deterioration of natural habitats and the habitats of species as well as disturbance of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this Directive".*

If *D. vexillum* was likely to cause "*deterioration of habitats*" or "*disturbance of species"* in a Natura 2000 site, then "*appropriate steps*" may need to be taken. Failure to do so would expose the UK to a risk of successful infraction proceedings. In addition, new Marine Conservation Zones (MCZs) are also likely to be at risk from *D. vexillum* and *D. vexillum* is likely to pose a risk to achieving Good Ecological Status under the Marine Strategy Framework Directive. Given that *D. vexillum* is likely to remain persistent, coupled with the lack of information on the ecological effects over long time scales, a precautionary interpretation should be adopted that the impacts of *D. vexillum* on biodiversity and habitats in England is likely to be, at least, locally significant. Additionally, the presences of invasive non-native species is likely to impact an areas ability to achieve Good Ecological Status under the Marine Strategy Framework Directive.

Impacts – Shellfish industry

There are a variety of wild and farmed shellfish fisheries around the English Coast. Potentially most at risk from *D. vexillum* introductions are bivalve molluscs, particularly those grown in suspended cultivation and where there is hard substrate. In an English context, the main species that might be affected are native oysters, mussels and, to a more limited extent, scallops. Clams, which occur in softer substrates, are less likely to be affected.

An examination of industry activity in the areas to which *D. vexillum* might spread suggests that shellfish aquaculture in England would not be significantly affected.

For example, mussels grown on the seabed are usually held inter-tidally, mainly to limit predation by starfish but also out of the reach of *D. vexillum*. There is, however, some recent development of offshore mussel farms, holding stock in suspended cultivation. This is expanding in the south west, an area in which *D. vexillum* is predicted to spread.

There is a valuable wild fishery for scallops in the South and Southwest of England. The beds are distributed in areas where colonisation by *D. vexillum* is not currently predicted, from the model.

There are nationally important crustacean (lobster and crab) fisheries in the Southwest of England. There are however no reports of any adverse affect on crustacean fisheries. Fixed gears (pots and creels) are widely used and are managed to prevent build up of fouling by leaving to air dry periodically. There may be some risk of spread of *D. vexillum* from the ports where the fishing vessels are based on to the fishing grounds.

Elsewhere in the world there is no obvious effect of introduced *D. vexillum* on performance of shellfish industries. This includes suspended mussel cultivation in New Zealand, which would potentially be most at risk. Here, fouling organisms of many species, although a nuisance, are a fact of life and industry essentially manages around the problem with little impact.

Should *D. vexillum* spread onto bottom substrate there is some concern for native oyster fisheries and possibly also scallops, although the latter tend to occur on finer sediments where *D. vexillum* is not expected to colonise.

Management options

There are various methods available that have been tried or proposed for eradication of *D. vexillum*, including wrapping populations in plastic and adding a chemical accelerant to kill it, removal of infected infrastructure from the water and allow drying, and addition of biocide to infected areas. Technically, using a combination of these methods could eradicate all known populations of *D. vexillum* in England. Realistically, this approach is not a viable option, as it is presented at a high cost and requiring significant manpower in order for eradication to proceed at a rate that would maximise chance of success. Risk of re-infection would remain high due to unmanaged populations in adjacent territories and the possibility of undetected populations in England. This would ensure that this strategy would remain a high, and continuing, cost.

Strategies to manage the spread of *D.vexillum* other than complete eradication include pathway management, involving key stakeholders such as the aquaculture and recreational yachting sectors and developing codes of conduct all coupled with an ongoing monitoring programme. Combining these methods could enable targeted eradication programmes to progress in areas that were at low risk to re-infection but represented a high risk to biodiversity or aquaculture. This approach would maximise the benefit, and chance of success, of any eradication techniques used.

Many of these techniques are not specific to *D.vexillum* and there is a generic problem that applies to all non-native invasive alien fouling species. The recommendations in this report could realistically be applied to other non-native species and there should therefore be a strategy for promoting greater awareness of the risks of spread of non-native fouling organisms and promoting codes of good practice to prevent the introduction and spread of these organisms to both the recreational boating and shellfish industries at relatively little cost.

Conclusions

1. Complete and continued eradication of *D. vexillum* at the English sites currently known to be infected is technically achievable but probably only a viable option at selected minimally infected sites. The level of effort needed to ensure eradication proceeds at a sufficient rate is probably not attainable and represents a costly option. Furthermore, baseline data for these regions is not complete and this would be a major undertaking. In addition the risks from re-infection from unmanaged sites in adjacent countries and from undetected colonies within the region are high.

2. Potential pathway management options do exist but require a level of stakeholder engagement and involvement in order to implement them effectively. If voluntary agreement cannot be reached then some regulatory mechanism may be required. There should be a targeted campaign to promote codes of good practice within the fisheries, aquaculture and boating sectors to prevent the introduction and spread of all alien marine fouling organisms in the first instance. Current plans to develop pathway management measures for *D. vexillum* should continue and any initiatives should be coordinated with those from the IMO such as Ballast Water Management Convention (IMO 2004) and the developing guidelines on bio-fouling.

3. The option to eradicate new populations should remain, particularly if they occur in areas that are sensitive for biodiversity and or shellfish aquaculture. The most suitable and cost effective method should be chosen that allows for a rapid response to the occurrence, for example drying out of marina pontoons.

4. Continued surveillance and monitoring is an important part of any strategy to determine its effectiveness, or to detect new populations. While this represents an ongoing cost, any monitoring program could be stratified to monitor only the most at risk, or sensitive sites. Partnership working with owners of marinas would assist this surveillance.

1. Background

Didemnum vexillum is an invasive non-native colonial marine tunicate (sea-squirt) that may impact on biodiversity and shellfish interests. It has been considered as a serious problem when it first appeared as an invasive alien species elsewhere in the world, especially in New Zealand and North America. In Europe, *D. vexillum* was first recorded in the Netherlands in 1991, and was subsequently observed in Northern France in 1998 and Ireland in 2005 (Ates, 1998, Breton, 2005, Gittenberger, 2007, Lambert, 2009, Minchin & Sides, 2006). During the last decade, the species has been recorded along much of the Atlantic and Channel coasts of France (Lambert, 2009). In the UK it was first discovered in Holyhead Marina in Wales in summer 2008 (Griffith et al., 2009). Its presence in England and Scotland has also been confirmed very recently (Figure 1).

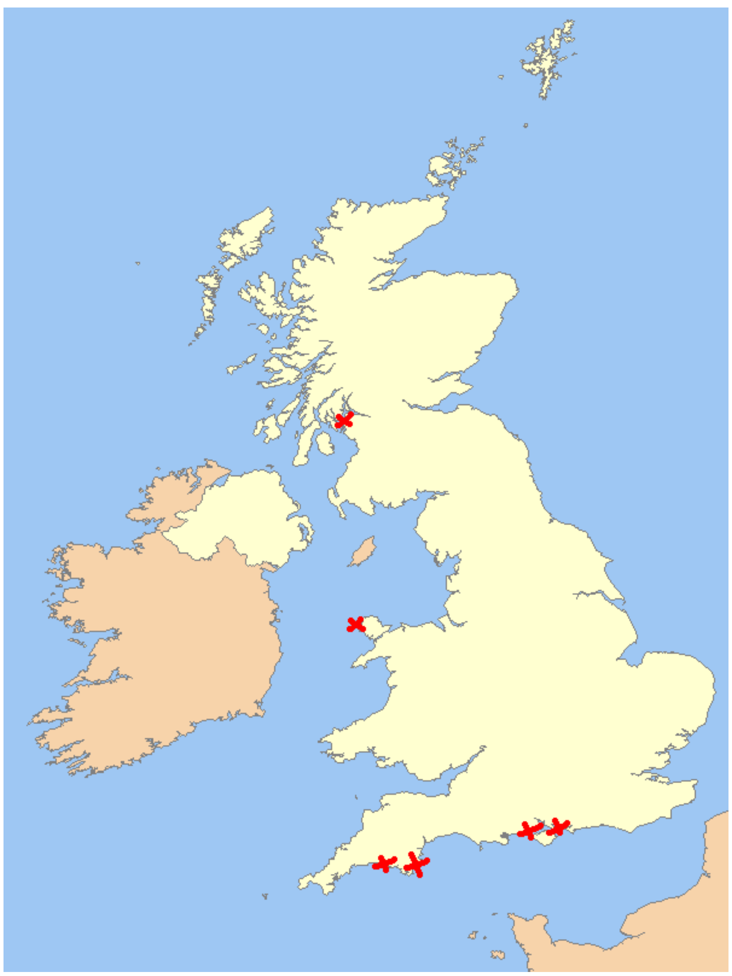

Figure 1: Map showing locations (crosses) of D. vexillum in the UK, including Plymouth, where a small colony seem to persist (John Bishop, personal communication)

A risk assessment of the threat posed by *D. vexillum* (this document can be found on the UK non native species secretariat web site, linked at:

https://secure.fera.defra.gov.uk/nonnativespecies/index.cfm?sectionid=51) indicated that introduction was very likely and spread by a number of pathways would be rapid with massive impacts. The biology, distribution and means of dispersal of *D. vexillum* are also well described in a recent report (Kleeman, 2009) and it is neither intended, nor necessary, to repeat this information.

In Wales, *D. vexillum* appeared to be confined to Holyhead Marina where it was introduced on the hulls of yachts that remained in the marina for more than a year. Eradication at this site is being attempted. This is apparently making good progress although it will not be known if the outcome is successful until subsequent surveys within the marina are carried out.

In Scotland, a population has been identified in Largs Marina in the Clyde. Further survey work is being carried out on the West Coast of Scotland. The feasibility of eradication at the one known extant site is being considered.

In response to detection of *D. vexillum* at English South Coast sites a working group was convened to consider the appropriate approach. This group reports to the GB working group. The GB group was established to advise the GB Programme Board on any rapid response and associated actions. The GB non-native species programme board has indicated that this is a high priority issue.

2. Aim of the project

The aim of this project was to provide an estimate, in as much detail as possible, of the potential impacts of the alien sea squirt *D. vexillum* in England and outline options for control of the species in order to enable decisions to be made on the most appropriate approach to management or control of the species in England.

The impact was assessed in respect of the implications of a more widespread population to:

1. Biodiversity, in particular special areas of conservation

2. The shellfish industry

The options for long-term management and monitoring of the species, and for limiting the spread of the species, are explored, including the feasibility of a partnership approach between government, industry (aquaculture and yachting) and conservation organisations.

3. Current status

The current known distribution of *D.vexillum* in England is based on results from surface-based surveys that were conducted in late 2009 in 49 marinas or harbours on the southern and eastern coasts of England, from Watchet (Somerset) to Kingston upon Hull (East Yorkshire). The marinas visited represent approximately

40% of the total such locations along the coastline covered (Bishop et al., 2010a).

D. vexillum was found in two regions on the South Coast, the Dart Estuary (Devon) and in the Solent (Hampshire/Isle of Wight), where it was detected in Lymington, Gosport and Cowes. *D. vexillum* was not found on the East Coast. Further survey work has been commissioned on the Northwest Coast and has subsequently reported, with no *D. vexillum* found.

The surveys in the lower reaches of the Dart and Kingsbridge-Salcombe estuaries (Devon) in October 2009 (Bishop et al., 2010b) revealed a dense but relatively local population centred on the Kingswear side of the Dart Estuary, encompassing Dart Haven Marina, adjacent pontoons operated by the Dart Harbour Authority, and two relatively small structures towards the Dartmouth bank. Altogether it was found at 6 of the 17 sites examined (Figure 2). *D. vexillum* was not found in the Kingsbridge-Salcombe Estuary at 10 sites examined.

In the Solent region, visits to 17 marinas revealed relatively dense populations in three adjacent marinas in Gosport (Figure 3), plus apparently minor infestations in single marinas in Lymington (West Solent) and Cowes (Isle of Wight).

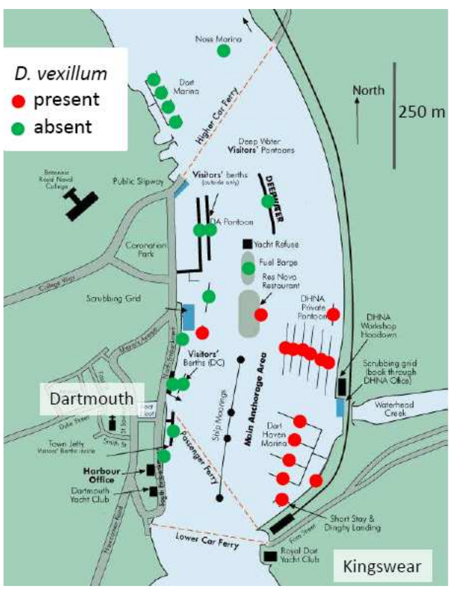

Figure 2: Survey results for presence of the invasive non-natvie sea-squirt, D. vexillum, in the River Dart (from Bishop et al., 2010b).

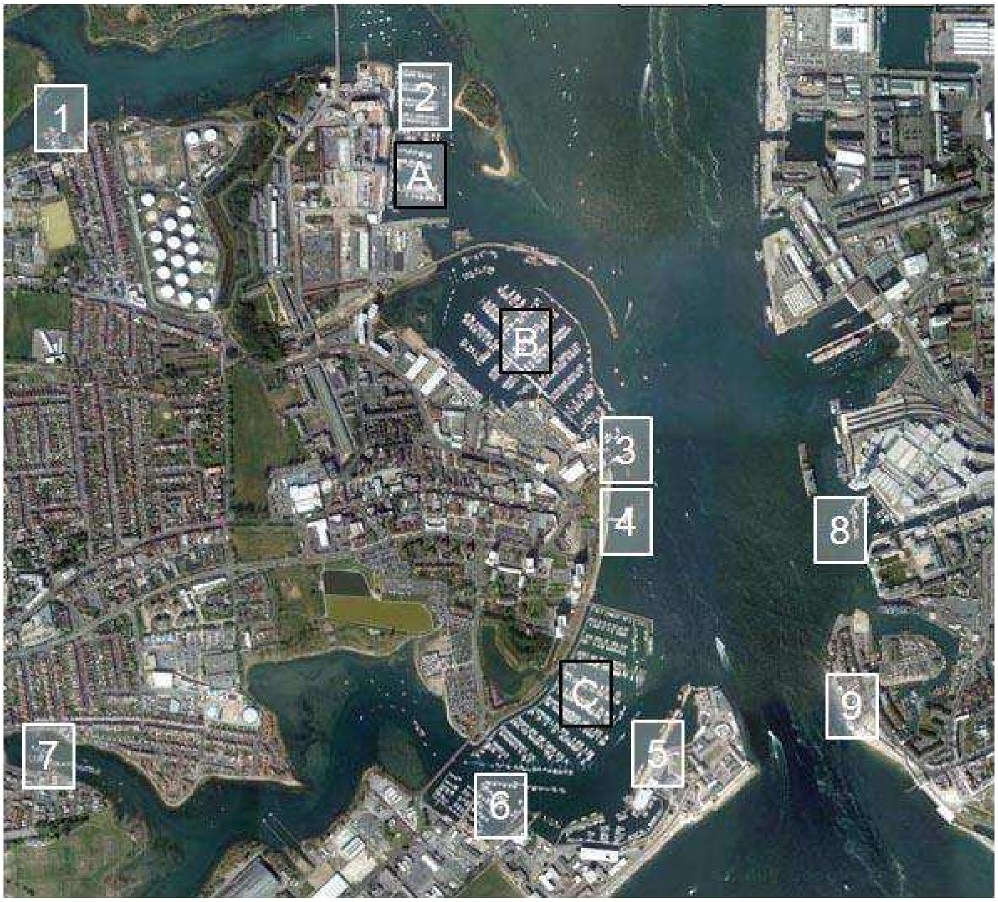

Figure 3: Marinas in Gosport (A, Royal Clarence; B, Gosport; C, Haslar) infected with D. vexillum and some of the nearby pontoon installations (1-9) not surveyed (from Bishop et al., 2010a).

These surveys focussed on floating structures such as pontoons and typically involved three person-hours of searching per site. The probability of detection of *D. vexillum* is thought to have been high at a site with a relatively dense population but inevitably lower in the case of a sparse infestation. Colonies or populations exclusively on substrates not accessible from the surface would not have been detected.

4. Potential spread

In order to predict the potential spread of *D. vexillum* a simple modelling approach employing a Geographic Information System (GIS) was used. Two models were developed. The first was designed to show all possible areas around the English coast that could support *D. vexillum* (i.e. worse case scenario). The second model aimed to show the most likely areas that *D. vexillum* could spread to over the short term.

The second model accurately predicted the areas at which *D. vexillum* has already been detected. Further spread is predicted mainly in the Solent / Isle of Wight area. The second area of the most concern is Plymouth. The rest of England has a relatively lower risk of *D. vexillum* spread, perhaps with the exception of the Thames area and Whitehaven Marina, although with populations in Ireland, Wales, Scotland, France and the Netherlands the whole coast could be considered under threat.

The model uses a combination of factors, gathered from an area of 5km around each Royal Yachting Association (RYA) marina in England, to assess *D. vexillum* spread. Vector density (i.e. number of yachting routes), distance to an infected site, number of infected yachting routes and the biological limits of *D. vexillum* are all used to create the model. Vector density is likely to be a good predictor of *D. vexillum* spread (Herborg et al., 2009) and is therefore given a high weighting in the model. It was decided that distance would heavily affect the spread of *D. vexillum*, as the majority of yachts are unlikely to travel large distances without stopping at marinas along the way (unless racing / international yachting) (see appendix 1 for further details), and any effect of larval movement in currents would be highly local (no data on direction of currents is included in the model). The number of infected routes was given a lower weighting in the model, as the probability of a yacht on a route becoming contaminated is unknown.

The distribution predicted is highly constrained by a lack of suitable substrate. The substrate layers from DEFRA SeaZone only showed hard substrates to be in a few limited places around the UK. In most seabed maps hard substrate is underestimated by grab sampling. In most cases in the current data set, a hard layer of bedrock is covered by mud or sand and it was considered that this would make the area unsuitable for colonisation by *D. vexillum*. Also, there was a lack of available data on artificial hard substrates, which can support *D. vexillum* growth. As such, it the potential area of 11,900 km^2 suitable for colonisation by *D. vexillum* predicted by the model will be an underestimation.

The limitations of the model should be considered when interpreting the results. Firstly, the model is hampered by a lack of quantitative data that results in arbitrary values being assigned to the factors at each stage of the model. Whilst they seem to enable accurate prediction of the hypothetical situation of colonisation along the South Coast of England from France, no quantitative estimates of model efficacy have been undertaken. Movement pathways, other than recreational yachting, identified by the risk analysis for *D. vexillum*, were not included in this model. *D. vexillum* may be moved by larger commercial shipping activity, commercial and recreational fishing activity, aquaculture and dispersal by fragmentation of colonies and rafting on flotsam (Carman & Grunden, 2010). Significant movement of *D. vexillum* is not expected from commercial shipping due to anti fouling and ballast water procedures although there is a possibility of transfer in sea-chests (Coutts & Dodgshun, 2007). Fishing activity is not expected to be a major pathway as very little occurs within marinas, boats are adequately anti fouled and do not spend large amounts of time at berth. However, experience from Georges Bank suggests this is a possible source of infection in offshore area which the model will not have predicted. There is also a low amount of aquaculture transfers in England. Despite these limitations we believe the model gives a good indication of those areas most at risk to infection by *D. vexillum*. We believe the areas most at risk are ranked in the correct order when compared to other areas at lower risk. If anything, the model underestimates the risk of spread by *D. vexillum* and this should be considered when assessing the potential impact on biodiversity and aquaculture.

5. Impacts

5.1. Biodiversity

5.1.1. Introduction

In its global distribution *D. vexillum* has been observed growing on most hard substrates including; bedrock (Valentine et al., 2007a) pebble, gravel and cobble (Lengyel et al., 2009, Valentine et al., 2007b), native fauna (Gittenberger, 2007), including sea grass (Carman & Grunden, 2010), and artificial substrate such as marina pilings, pontoons and boat hulls (Bullard et al., 2007). Only sandy and muddy surfaces and substrates are not colonised by *D. vexilllum* and it is intolerant to smothering by sand (but see Valentine et al., 2007b). The location of these habitats is also varied including offshore gravel banks (Lengyel et al., 2009, Valentine et al., 2007b), tide-pools (Valentine et al., 2007a), estuaries and lagoons (Morris et al., 2009, Carman & Grunden, 2010).

Due to its ability to colonise a wide range of habitats, reputation as a globally invasive species, ability to over grow native fauna, low number of natural predators (but see Carman et al., 2009 describing predation by periwinkle *Littorina littorea* on unhealthy colonies), and the threat that non-native ascidians are considered to pose to biodiversity (Blum et al., 2007, Castilla et al., 2004, Dijkstra et al., 2007, UKNNSS risk assessment for *D. vexillum* at https://secure.fera.defra.gov.uk/nonnativespecies/index.cfm?sectionid=51) it is highly intuitive that overgrowth by *D. vexillum* will reduce biodiversity. There are, however, relatively few studies documenting the environmental effects of introduced *D. vexillum*.

Most information is available from the USA where *D. vexillum* has become established on both coasts (Bullard et al., 2007). In Long Island Sound *D. vexillum* occurs in patches of up to 1.5m^2 covering an area of 1.5km^2. Although no data is available prior to the arrival of *D. vexillum*, species richness was sometimes higher inside patches of the sea squirt compared to outside. Abundance was also increased, primarily by the snail *Anachis* sp. Despite these small differences, no abundant species was unique to either habitat. Multivariate analysis, however, suggested that temporal variability in community composition might be reduced inside the patch (Mercer et al., 2009).

In experimental manipulations at different time scales in New Hampshire, *D. vexillum* has been associated with shifts in the dominant species from mussels to ascidians (Dijkstra & Harris, 2009). In these situations, settlement of native fauna was much reduced on to the primary habitat compared to the secondary habitat provided by the mussels. Diversity was maintained due to the creation of space caused by winter die back of the ascidian colonies (Dijkstra & Harris, 2009) which was facilitated by scavenging snail such as *Littorina littorea* (Valentine et al., 2007a) and *Trivia arctica* (Gittenberger, 2007).

Offshore, northeast of the USA, *D. vexillum* has colonised a 230km^2 area of cobble, pebble and gravel on Georges Bank, with up to 75% coverage of the seafloor in the four years since its discovery (Lengyel et al., 2009, Morris et al., 2009, Valentine et al., 2007b). Most recent data shows that three areas have been colonised totalling 473km^2 indicating an increasing trend (pers. comm. Page Valentine). Comparison of data before, and after, the arrival of *D. vexillum* showed a different community of invertebrates post arrival, although there was no spatial control (Lengyel et al., 2009). From video observations it was clear that there was negative correlation between cover of *D. vexillum* and amount of hyrdroid turf and visible macrofauna with only anemones able to persist (Lengyel et al., 2009). However, the cover of *D. vexillum* does not appear to exclude infauna or significantly alter community composition despite its apparent ability to form a barrier between fish and benthic prey such as worms and bivalves (Valentine et al., 2007b). At present, there is no evidence that the spread of the tunicate on Georges Bank will be held in check by natural processes other than smothering by moving sediment.

In other areas, such as New Zealand, *D. vexillum* does not appear to be able to accumulate sufficient biomass to spread on and across gravel sea beds (Kleeman 2009) and while *D. vexillum* has become the most common colonial ascidian in parts of the Netherlands (Gittenberger, 2007) no negative environmental effects have been reported, although this is probably because all coastal hard substrates in the Netherlands are artificial.

While there is a lack of clear and consistent evidence for the impact of *D. vexillum* to biodiversity, its potential effects on an ecosystem were summarised by (Bullard et al., 2007) and Kleeman (2009) as being caused by its ability to:

- Smother other organisms
- Inhibit settlement of other organisms
- Reduce of the spatial complexity of benthic habitats
- Reduce the food supply for bottom feeders
- Provide a predator refuge

• Increase prey and subsequently predator abundance,

5.1.2 Immediate threats to biodiversity

In England the current distribution *of D. vexillum* poses most threat to areas of conservation in and around the Solent and Dart Estuary. These areas are subject to high amounts of recreational boat and marina use and as such there is potential for *D. vexillum* to be spread along the South Coast fairly rapidly. Modelling work has successfully predicted the introduction of *D. vexillum* from France into the Solent and Dart Estuary, as well as Plymouth Sound (Appendix I). When this model was applied to predict the spread of *D. vexillum* around the coast from known locations in England then the likely hotspots for colonisation and transfer are around Plymouth, Torbay and Dartmouth and an expansion and increase around the Solent. Marinas in the Brighton area and the Thames and Whitehaven Marina are also at high risk. Given that *D. vexillum* has also invaded Wales and Scotland the over time, *D. vexillum* could spread to a variety of habitats in England that occur all around the coast. Of most concern is the immediate threat posed to features of designated nature conservation sites (Table 1).

Table 1. South coast Special Areas of Conservation (SACs) candidate SACs (cSACS) and possible SACs (pSACs) with suitable habitat for Didemnum vexillum *(Dv) and the associated risk to the relevant feature. A further site with reef feature, Studland to Portland draft SAC, is currently being considered by government prior to consultation but is not included here.*

Location and site name	Feature	Risk
Torbay and Dart Estuary		
Lyme Bay and Torbay cSAC (31,248 ha)	Reef (14,289 ha)	**Medium**. A significant amount of boat traffic means that the chance of Dv being introduced to the reef feature is medium. If this occurs then there is medium risk of a significant amount of feature being impacted around Torbay. However, given the reefs' extent and the wide distribution within the site the whole feature is not at high risk.
Lyme Bay and Torbay cSAC (31,248 ha)	Sea Caves (na)	**Low/Medium**. Caves are inaccessible to most boats and pleasure craft and Dv would have to be introduced by other means, such as larval dispersal. If Dv were introduced to the caves however, then a significant habitat could be quickly impacted.
Plymouth		
Plymouth Sound and Estuaries SAC (6402 ha)	Reef (320ha)	**High**. The likely reintroduction of Dv into Plymouth Sound and the enclosed nature of the estuary mean that the reef feature is likely to be impacted by Dv introduced by boats and spread around the estuary by natural and artificial vectors

Location and site name	Feature	Risk
Prawle Point to Plymouth Sound and Eddystone cSAC (31,525 ha)*	Reef (8,974 ha)	**Medium**. The site adjoins Plymouth Sound and, while there are no marinas within the site, the boat traffic going to and from Plymouth poses a risk to the large reef feature of the site. Introduction will be primarily by fragmentation of colonies from passing vessels and by larval dispersal.
The Solent		
Solent Maritime SAC (11325 ha)	Biogenic Reef (unmapped)	**High**. Given high levels of recreational boat movement between marinas in the area Dv is likely to spread to reef feature through larval transport, through fragmentation of colonies and incremental growth from existing colonies.
South Wight Maritime SAC (19862 ha)	Reef (13,900 ha)	**Medium**. No marinas within the site but a significant amount of boat traffic associated with the Solent marinas. Introduction likely to be by a combination of fragmentation of colonies from passing boat traffic and larval dispersal from the Solent.
Solent and Isle of Wight Lagoons SAC (36 ha)	Lagoons (36 ha)	**High**. A large amount of hard substrate from associated infrastructure and high boat traffic means the lagoons are a high risk for introduction of Dv by larval transport, fragmentation of colonies and incremental growth from existing colonies.
Thames Area		
Thanet Coast SAC (2,803 ha)	Reefs (897 ha)	**Medium.** One marina within the site increases the risk for introduction of Dv to the reef feature. Introduction likely to be from fragmentation of colonies
Thanet Coast SAC (2,803 ha)	Sea Caves (na)	**Low/Medium**. Caves are inaccessible to most boats and pleasure craft and Dv would have to be introduced by other means, such as larval dispersal. If Dv were introduced to the caves however, then a significant habitat could be quickly impacted.

* The current consultation for Prawle Point to Start Point pSAC could increase the size of this site by 2574 ha

5.1.3. Torbay and Dart Estuary.

The population already within the Dart is likely to spread within the estuary although this may be limited by low salinity, particularly during flood events and long periods of rainfall. Within the Dart itself are numerous marinas and their associated infrastructure as well as mussel beds. Immediately outside the Lyme Bay and Torbay candidate Special Area of Conservation (cSAC) is of European importance and the reefs cover an area of over 14,000ha and are nationally renowned for their dense floral and faunal assemblages and support significant populations of nationally important species including the nationally scarce pink sea fan *Eunicella verrucosa*. The wider Torbay area is also a European site important for sea caves covering a variety of rock and community types with some nationally important species. The draft conservation objectives for this site indicate that species and biotope composition and distribution should be maintained. Many of the species and habitats, such as pink sea fan, are highly susceptible to overgrowth by *D. vexillum*.

5.1.4. Plymouth

Recreational boat traffic between Plymouth and the Dart, as well as between France and Plymouth, means that re-introduction of *D. vexillum* into Plymouth is likely. Plymouth Sound and Estuaries SAC has important reef features covering over 320ha including limestone with a variety of animals that bore into the rock that would be particularly vulnerable to smothering which would result in the unfavourable condition of the site.

The reef areas are also important for animal dominated habitats including fragile and rare species of soft corals, sea fans, anemones, sponges, hydroids (sea firs) and bryozoans (sea mats) all susceptible to overgrowth. A rarely recorded habitat with uncommon species including the rare sea slug *Okenia elegans*, the kelp *Laminaria ochroleuca* and the trumpet anemone *Aiptasia mutabilis* occurs on the shallow sub-tidal limestone of Batten Bay (Hiscock & Moore, 1986). Where the reefs are of creviced slate, the rare but locally abundant brittle star *Ophiopsila arenea* occurs (Devon Wildlife Trust, 1993).

Filamentous algae, including some rarities, are abundant on cobbles, shells and muddy sediments off the Ballast Pound (Hiscock & Moore, 1986). The rare hydroid *Hartlaubella gelatinosa* for example, forms clumps on upper estuarine mixed substrata. The fully marine lower reaches of the Yealm are predominantly rocky and support a wide variety of species including the nationally uncommon community dominated by the orange peel sponge *Hymeniacidon perleve* and the peacock worm *Sabella pavonina* on the extreme lower shore.

Most circalittoral rocky reefs occur in areas of the Outer Sound, such as off Wembury, the Mewstone, Penlee Point and south of the breakwater. In the approaches to Plymouth Sound, abundant populations of the slow-growing, long-lived, nationally important pink sea-fan *E. verrucosa* occur. Shellfish are also common including mussel beds and the native oyster, *Ostrea edulis*. There are 3 SSSI within the estuary, of which the tide pools within Wembury Point would be most at risk from *D. vexillum*.

Outside the estuary is the Prawle Point to Plymouth Sound and Eddystone cSAC which is designated for its extensive reef features (nearly 9,000 ha) with outcropping bedrock pinnacles, boulder fields and complex broken geological features being frequently recorded and supporting an important suite of species.

Prawle Point to Plymouth reefs is an area with high species and biotope diversity with 388 species having been recorded in the area (Hiscock & Breckels, 2007). The area's representativity, in terms of European Habitats Directive description of reef, is considered excellent. The offshore areas are also known to support some species rarely encountered in south-western waters especially Hatt Rock, are good examples of deeper water reefs that support species (such as the starfish *Porania pulvillus* and the parchment tube worm *Phyllochaetopterus anglicus*) that are unlikely to be so frequent on the more common inshore reefs. A consultation for Prawle Point to Start Point pSAC could increase the size of this site by 2574 ha.

5.1.5. The Solent

A number of SAC's are designated in and around the Solent. Solent Maritime is designated for its estuaries and saltmarsh habitat which by themselves are not particularly vulnerable to *D. vexillum*. There is small amount of *Sabellaria spinulosa* reef near Chichester harbour, which would probably be destroyed if overgrown by *D. vexillum*. *S. spinulosa* is common around England but its ability to form reefs, which are now poorly distributed, makes it an important habitat.

A number of saline lagoons are also present as part of Solent and Isle of Wight Lagoons SAC which are managed as SSSI and are some of the most important lagoons in Europe. These areas provide specialised habitat for a number of rare species and while a high freshwater input may restrict growth of *D. vexillum* although some of the sub-tidal shingle habitats would be suitable for growth as well as much of the hard infrastructure such as sluice gates. In particular the lagoon specialist bryozoan *Conopeum seurati* would be locally vulnerable.

The South Wight Maritime SAC is important for its 13,900ha of subtidal reefs including chalk, limestone and sandstone reefs including some of the most important subtidal British chalk, representing over 5% of Europe's coastal chalk exposures. Intertidal pools support a diverse marine life, including a number of rare or unusual seaweeds, such as the shepherd's purse seaweed, *Gracilaria bursa-pastoris* and the uncommon strawberry anemone *Actinia fragacea*. All these habitats and species are susceptible to overgrowth by *D. vexillum*.

Clay exposures or mudstone reefs, which are not a very common subtidal habitat in Britain (Fowler, 1995), provide a good habitat for piddocks such as *Pholas dactylus* and *Barnea candida*. Turf communities have a particularly diverse sponge (26 species recorded so far and bryozoan fauna, with a number of unusual species, some only rarely recorded, such as the rare sponge *Stelletta grubii*, or (at the edge of their range in the Channel) the erect sponge *Stelliger* bryozoans *Parasmittina trispinosa*, *Smittoidea reticulata* and *Schizomavella auriculata*, and tunicates *Lissoclinum perforatum* and *Pycnoclavella aurilucens* (Fowler, 1995). On the boulder and cobble area off Bembridge ledges, the rare bryozoan *Epistomia bursaria* has been recorded. Growth of *D. vexillum* would risk impacting these uncommon species and putting the site in unfavourable condition, particularly in relation to its characteristic biotopes and species associated with sea caves, kelp forest, faunal turf and algae communities as well as tide pools.

The whole Solent area has many natural shellfish beds of which the native oyster *Ostrea edulis* is particularly important. The west Solent has an extensive gravel habitat that extends offshore.

To the west of the Isle of Wight, at Poole Harbour, recreational boat traffic is expected to transport *D. vexillum*. There are areas of sub-tidal reef but at most risk are the shellfish beds such as native oyster and mussels. *D. vexillum* is also likely to spread to the marinas around Brighton yet there is little suitable habitat for its spread into the wider marine environment.

5.1.6. Thames area

While much lower risk, the results of modelling work indicated that marina around the Thames are vulnerable to introduction of *D. vexillum*. Of the European Marine Sites around the Thames, only Thanet Coast SAC has features suitable for *D. vexillum*. The sub-littoral chalk reefs contain rare species of boring algae and are also important as there is a paucity of other hard substrate in the area. In the wider area there are areas of gravel bed and *S. spinulosa*, although the occurrence of reef is not well mapped. The most extensive areas predicted to be at risk from colonisation by *D. vexillum* are shellfish beds with mussel and native oyster of most concern.

5.1.7. Whitehaven Marina

Whitehaven Marina is at similar risk of infection by *D. vexillum* as the Thames area. However, there a few habitats nearby that support *D. vexillum* growth and as such, there is a low risk to any nearby areas of conservation importance.

5.1.8. Wider threats to biodiversity if allowed to spread

Modelling work predicted that the threat of spread to other areas of the coast was low, yet suitable habitat does exist. As the risk assessment for *D. vexillum* (https://secure.fera.defra.gov.uk/nonnativespecies/index.cfm?sectionid=51) indicate a very likely introduction and rapid spread following introduction by a number of pathways not all included in the model, threat to other areas must not be ignored. On the East Coast, suitable areas in The Wash are associated with shellfish beds while in The Outer Wash there is extensive gravel habitat. Further north, the Berwickshire and North Northumberland SAC reefs support diverse assemblages at the northern and southern limit of many species. In the southwest, the Fal and Helford SAC supports native oyster, while Lizard Point pSAC and Lands End and Cape Banks pSAC have extensive reef feature, along with other areas of bedrock outside of designated sites. In the Severn Estuary, there are large amounts of gravel and bedrock habitat.

Priority habitats under the Biodiversity Action Plan (BAP) that are vulnerable to decline if *D. vexillum* is introduced include subtidal chalk, tide swept channels, blue mussel beds, horse mussel beds, maerl beds, file shell beds, serpulid reefs and *S. spinulosa* reefs. In addition to this, certain BAP priority species would be vulnerable to decline including, pink sea fan *E. verrucosa*, pink sea fan anemone *Amphianthus dohrnii*, native oyster *O. edulis* and sunset cup coral *Leptopsammia pruvoti*.

The Marine and Coastal Access Act 2010 requires marine conservation zones (MCZs) for features of conservation importance that will form a network of marine protected areas (MPAs). The network needs to be connected, representative, coherent, viable and adequate. This means MCZs, once designated, will almost certainly occur near hot spots for *D. vexillum* introduction as many of the habitats and species will be suitable for *D. vexillum* colonisation (see Ashworth et al., 2010).

The Marine Strategy Framework Directive 2008/56/EC aims to achieve good environmental status (GES) of the EU's marine waters by 2020. One of the 11 descriptors that will be used to measure GES is the presence, and impact, of invasive non-native species. *D.vexillum* in English waters is, therefore, likely to have a negative effect on GES which represents a significant driver for its control and management.

5.1.9. Summary

The overall effects of *D. vexillum* spread are difficult to predict given the current evidence base. There is some evidence that *D. vexillum* can either reduce, or increase, diversity and some evidence that ecosystem structure and function may be affected. If diversity is increased this may also lead to an adverse effect through alteration of species composition or loss of protected species. It is also likely that growth in shallow water or in tide pools will be subject to winter die back that allows free space to occur and potentially reduce the effects on the ecosystem. This respite is, in reality, often short lived as re-growth in the spring can quickly smother settled organisms (pers. com. Page Valentine). In deeper water however, *D. vexillum* cover may be more stable and persistent, increasing the threat to habitats such as cobble reef. On Georges bank there were no reductions in colony size over a 5 year study period (Valentine et al. 2010) yet York et al. (2008) suggest seasonal fluctuations can occur on the same habitat. *D. vexillum* is a relatively newly identified species named in 2002 (Kott 2002) with genetics confirmed in 2009 (Stefaniak et al. 2009). Uncertainties over its taxonomy have led it to be described as *D. vestum*, *Didemnum* sp. and *Didemnum* sp. A. As such, most studies are unable to report strong trends or effects and interpretations of data are constrained by the difficulty in designing robust experiments with before and after impact controls. Of particular concern is the lack of information on the long-term effects of introduced *D. vexillum* as most global introductions are relatively recent.

In protected European Marine Sites compliance with Article 6(2) of the Habitats Directive would be relevant to the *D. vexillum* threat.

Article 6(2) imposes the obligation to:

"*take appropriate steps to avoid, in the special areas of conservation, the deterioration of natural habitats and the habitats of species as well as disturbance of the species for which the areas have been designated, in so far as such disturbance could be significant in relation to the objectives of this Directive".*

This obligation would be relevant to any damage caused by *D. vexillum*, as it applies to both man-made caused deterioration/disturbance as well as that which is naturally occurring (see *Commission of the European Communities v United Kingdom of Great Britain and Northern Ireland* C-6/04).

If *D. vexillum* was likely to cause "*deterioration of habitats*" or "*disturbance of species"* in a Natura 2000 site, then "*appropriate steps*" would need to be taken to avoid this. Failure to do so would expose the UK to a risk of successful infraction proceedings. Given that *D. vexillum* is likely to remain persistent, the lack of information at longer time scales and the constraints of the model used in this report, a precautionary interpretation should be adopted that the impacts of *D. vexillum* on biodiversity and habitats in England is likely to be, at least, locally significant.

5.2. Shellfish industry

5.2.1. Introduction

The shellfisheries and aquaculture in the regions where *D. vexillum* has been detected and are therefore at the most immediate risk should the species spread beyond the harbours and marinas where it is currently established are dealt with separately below, This is followed by an account for the Thames and Essex area as a region identified by the model as at risk of invasion from *D. vexillum* and then an examination of the wider picture, if *D. vexillum* was to spread more widely. This area by area examination therefore follows a similar pattern as that used in the previous (biodiversity) section.

It is the sedentary species (molluscs) that are most at risk from either smothering of the animals themselves or fouling of aquaculture installations holding or supporting them. Those cultivated or harvested from the continuously submerged zone are the ones predominately at risk and these are considered in more detail. Species, particularly Pacific oysters, *Crassostrea gigas*, which are generally cultivated inter-tidally, are at much lower risk as *D. vexillum* does not survive well in this environment. There are known infestations on oyster trestles in Ireland, although these are in an area where the bags are turned less frequently. When bags were turned and exposed to air and sunlight the *D. vexillum* died off (O'Brien, BIM, personal communication). For these submerged molluscs, experience elsewhere in the world where *D. vexillum* has invaded has shown that bivalve molluscs held in suspended cultivation are most at risk from the fouling and smothering effects as well as shellfish beds in rocky areas. Offshore mussel farms, especially in areas with a sandy or muddy seafloor, may be much less prone to tunicate fouling than near shore farms, provided biosecurity measures to prevent transfer with boats and equipment are followed.

Mobile species (crustaceans) would much less likely be affected, unless there was significant loss or alteration of habitat, should *D. vexillum* become extensively established on the seabed. Crabs are known to be able to consume non-indigenous ascidians, although they are not preferred food and the predation rate is unlikely to be sufficient to control the spread of the species (Epelbaum et al., 2009). There may, however, be some risk that *D. vexillum* is spread by the fishing activity for these species and so they are also considered, more briefly. There is no aquaculture in the marine environment of any crustacean species in the currently known infected regions or elsewhere in England.

There is no marine finfish farming in the infected regions or elsewhere in England that would be at risk from fouling of submerged cages and/or structures with *D. vexillum*, therefore, this report deals exclusively with shellfish.

Alteration of seabed habitats by extensive colonisation of *D. vexillum* may affect fin fisheries, for example in nursery areas, but this is not considered to be an immediate risk and is beyond the scope of this project.

5.2.2. The Solent

The Solent and its adjacent harbours (Portsmouth, Langstone, Chichester) supports the largest native oyster fishery in Europe, although catches have been declining in recent years, probably due to lack of recruitment, and currently stand at about 300 tonnes per annum, worth around £360,000. Slipper limpets, *Crepidula fornicata*, are increasing in number and are a serious pest. The oyster fishery is managed through byelaws and the larger part of the Solent itself is designated as a Regulated Fishery. In addition, two Several Orders have been granted for oyster beds in Stanswood Bay and Calshot, which are administered by fishermen's co-operatives and may be seeded from the wild stock. Most of the catch before Christmas is sold to the Continent, but there is also demand from the east coast oyster farms for oysters for re-laying in the spring. Should *D. vexillum* spread to the oyster beds in the Solent there is some risk of transfer of the species to the east coast through this trade.

There is a small stock of non-native American hard-shelled clams, *Mercenaria mercenaria,* in Southampton Water, the northern part of the Solent and in Portsmouth and Langstone Harbours that supports a small, occasionally exploited, dredge fishery of around 15 tonnes per annum, worth maybe £23,000. The non-native Manila clam, *Tapes philippinarum,* is reportedly spreading rapidly in this region and supports an increasing fishing effort, although accurate landing figures and values are not easily available. It is estimated that it might be about 200 tonnes per annum, worth £350,000. These clam species tend to establish in areas where there are soft sediments, into which they burrow, and so it is considered that they are less likely to be affected by any spread of *D. vexillum* onto the seabed, although the model shows that *D. vexillum* could become established in some of these areas.

There is also in the Solent a dredge fishery for scallops, although this is not large and is opportunistic, as the beds tend to be rather transient. More important scallop beds occur further offshore to the east of the region, along the channel coast from Selsey Bill to Rye.

There is just one small shellfish farm in the Solent region, in Langstone Harbour. Here mussels are cultivated on the bottom from re-laid seed stock obtained from beds over six nautical miles out in the English Channel. About 30 tonnes are produced annually.

There are twelve fishing boats registered at Gosport, nineteen at Lymington and eight at Cowes (Walmsley & Pawson, 2007) using both mobile and fixed gear. The model suggests that *D. vexillum* could become established, by transfer, in many of the near coastal areas where there are crustacean fisheries. The effect on these fisheries is not known although there are no reports of adverse effects from *D. vexillum* on crustacean fisheries from elsewhere, where it is established.

5.2.3. Dart estuary and Torbay

About 3 miles upstream of the marinas at Dartmouth where *D. vexillum* is present is the Waddeton Fishery Order for oysters, mussels, cockles clams and crabs, although only Pacific oysters and mussels are currently under cultivation and reported annual production is of just under 20 tonnes of Pacific oysters only. Pacific oysters are kept in bags on trestles or on the substrate. Some of the mussels are also cultivated in bags or other containers. Inspections of the beds are made at extremely low tides and the organism has to date not been detected. It is probable that low salinity episodes will help prevent *D. vexillum* becoming established at this site and the model confirms this. The majority of the cultivated area is, in any case, in the inter-tidal zone.

The port of Dartmouth lands shellfish worth £1.4 million annually from wild fisheries, comprising a mixture of species. Kingswear is mainly a brown crab port with around 30 boats setting pots. Together with the potting fleet in Salcombe, this area is one of the main brown crab fisheries in the UK. In total, the crustacean landings are valued at £1.2 million annually, with the molluscs landed at Dartmouth, mainly clams, scallops and whelks, worth less than £200,000.

Brixham in Torbay, which is only about 10 miles by sea from Kingswear is one of the largest ports in the south-west. Here, 4,700 tonnes of shellfish are landed annually, the highest tonnage of shellfish landed in the South West and in terms of value also the highest being worth just over £6.8 million. Otherwise it has a traditional trawling background supplying a large daily fish market.

There is a near shore shellfish farm at Brixham growing mussels on long lines. This produces up to 40 tonnes annually. The proximity of this to areas to which *D. vexillum* might spread suggests that it may be at risk of colonisation of the floating and suspended equipment.

5.2.4. Plymouth

More widely in South Devon, scallops are found in the near shore areas on loose shingle and dead shell and spawn in the spring and are then of poor quality. The commercially important scallop beds are further offshore. The South Devon coastline supports one of the largest brown crab potting fleets in the UK.

5.2.7. Thames area

The Thames cockle fishery supports both local and visiting vessels and is the most productive in the UK. Over 10,000 tonnes of cockles are landed annually from the Fishery Order run by the Kent and Essex Sea Fisheries Committee, with a value around £6 million.

There are wild and cultivated oyster fisheries along the Essex and North Kent coast, although the native oyster fishery in most of Essex has been much affected by the disease *Bonamia*. Hatchery-reared juvenile Pacific oysters and half-grown native oysters from the south English coast are re-laid onto on-growing beds during spring. Oyster fishermen also prepare natural beds and encourage the settlement of native oyster spat by cleaning the ‘cultch’ (a mixture of dead shells) prior to spat settlement. The oyster-harvesting season usually begins in late summer and can last until spring. Pacific oysters grow faster than the native species, and can be harvested during the closed season for native oysters in the summer. Large populations of this species have become established in some areas. They are resistant to frost, which allows them to be harvested earlier in the year and cultivated inter-tidally. It would be the native oysters on their sub-tidal lays that would be most at risk if *D. vexillum* became established here. Production of this species from this area is small compared with that from the managed fisheries in the Solent and has been declining steadily in recent years in favour of the Pacific oysters, with increasing exploitation of naturally recruited inter-tidal beds that would be of lower risk. Several Orders cover many native and Pacific oyster beds along the Essex coast.

Table 2: Shellfish Aquaculture and Fisheries in areas potentially most at risk from D. vexillum. Values are per annum.

Location	Shellfish (value)	Relative risk

Location	Shellfish (value)	Relative risk
Solent	Mussels (£20K)	**Medium**: cultivation site is in an enclosed area with high recreational boating use, but site is inter-tidal.
	Native oysters (£360K)	**High – Medium**: area is heavily used by shipping and recreational boating. Sub-tidal beds.
	Clams (£490K)	**Low**: substrate is probably not suitable.
	Crustaceans (£470K)	**Very low**: no documented effects and fixed gear is managed to remove fouling.
Dart	Mussels, Pacific oysters (£2K)	**Medium – Low**: inter-tidal cultivation and salinity is probably limiting but there is close proximity to marinas and moorings.
	Scallops (£7K)	**Low**: commercial beds are offshore on unsuitable substrate.
	Crustaceans (£1.2 million)	**Very low:** no documented effects and fixed gear is managed to remove fouling.
	Other molluscs (clams and whelks, £200K)	**Low**: fished offshore from substrate that is not suitable. Fixed gear for whelks is managed to prevent fouling.
Brixham	Mussels (£28K)	**High**: suspended (long-line) cultivation is at risk from fouling and is close to areas of predicted spread.
	Scallops (£4 million)	**Low**: commercial beds are offshore on unsuitable substrate.
	Other species (£2.8 million)	**Low**: mainly crustaceans.
Plymouth	All species (£3.3 million)	**Low**: Scallops from offshore beds and crustaceans
Thames and Essex	Cockles (£6 million)	**Low**: from inter-tidal beds where substrate is not suitable.
	Oysters (£300K)	**High - Medium**: sub-tidal beds in an area with heavy recreational boating.

5.2.6. Wider potential threats if allowed to spread

The only other area identified by the model (Appendix I) as at low risk of invasion is Whitehaven Marina. There is no aquaculture or any species at risk at this location.

The nearest aquaculture and shellfishery area to the Solent is in Poole Harbour, which is about 40 miles to the west of Gosport. Here there is a Fishery Order that covers the whole Harbour and gives both Several Order and Regulating rights for oysters, mussels, clams and cockles. All species, including Pacific oysters, are cultivated both sub-tidally and inter-tidally, on the seabed. It is mainly mussels and Pacific oysters that are produced, with up to 750 tonnes and 200 tonnes, respectively, being sold annually, with a value of about £670,000. Clams, mainly Manilas, are harvested from a self-sustaining natural population in the harbour and small quantities (about 20 tonnes per annum) of scallops are landed. The model predicts that only small areas of Poole Harbour could be impacted by *D. vexillum* although this includes some of the aquaculture leased areas to the northwest of Brownsea Island.

The River Teign is 20 miles from the Dart and here there is a Fishery Order that covers mussels and Pacific oysters, both of which are cultivated in the enclosed estuary. Similar to the Dart, most of the activity is in the inter-tidal zone and *D. vexillum* is not expected to invade these areas. Annual production is about 60 tonnes of mussels and less than 10 tonnes of Pacific oysters. Wild shellfish landings are less than 85 tonnes.

Both mussels and Pacific oysters are similarly cultivated in the enclosed estuary of the River Exe, 25 miles from the Dart. The model shows that this area is also unlikely to be invaded by *D. vexillum*. Here annual production is 250 tonnes of mussels and 50 tonnes of oysters. Wild shellfish landings are about 1,000 tonnes, mostly from crabs, whelks and scallops.

Crustacean shellfish, predominantly crabs and lobsters, are also landed at Poole. Total landings for 2009 were 137,000 tonnes, worth £350,000.

Weymouth is a further 20 miles to the west. Here, in Portland Harbour, there is a Several Fishery Order for scallops and although there is little production recorded there is stock on the ground. It is not possible to establish a value for this, but there could be a few thousand shells. There is also some mussel farming, in suspended cultivation, still under development, in Portland Harbour. *D. vexillum* is not predicted to spread to Portland Harbour by the model, although the floating mussel cultivation equipment may be at risk from settlement if spread by recreational vessels. Suspended cultivation of Pacific oysters in trays is also being attempted. Production is currently only about 20 tonnes per annum. Pacific oysters are also farmed, in Australian style suspended basket systems, in the Fleet lagoon. These inter-tidal systems will not be at significant risk of fouling from *D. vexillum*.

At the port of Weymouth 2,400 tonnes of shellfish from wild fisheries, valued at just under £2 million, are landed annually. There are seed mussel beds offshore from Portland Bill that supplies the cultivation activities in Portland and Poole harbours. It is not known to what extent these might be affected should *D. vexillum* spread to them. The results from the model show that *D. vexillum* is not expected to colonise the seabed in the area of the mussel beds. These are in any case usually ephemeral and seed not collected would be washed away in winter storms so the risk of *D. vexillum* becoming permanently established in this area will be low. It might affect settlement and become attached to the seed mussels prior to harvest. There would then presumably be some loss of this fouling organism during transfer of the mussel seed to the relaying areas but there is perhaps some small risk to this industry.

The rivers Fal and Helford in Cornwall are the other main shellfish producing area in England. There are both traditional fisheries for native oysters and cultivation of Pacific oysters here. A Fishery Order covers most of the native oyster areas and about 30 tonnes per annum are produced.

Table 3: Shellfish Aquaculture and Fisheries in areas to which D. vexillum might spread in the longer term. Values are per annum.

Location	Shellfish (value)	Relative risk
Poole Harbour – cultivated species	Mussels and oysters (£470K)	**Medium**: some sub-tidal cultivation and there is close proximity to marinas and moorings.
Poole Harbour – fished species	Native oysters (£11K)	**High – Medium**: area is heavily used by shipping and recreational boating. Sub-tidal beds.
	Clams (£580K) Scallops (£31K) Crustaceans (£350K)	**Low**: substrate not suitable, fished offshore or managed fixed gear.
Weymouth – cultivated species	Scallops, mussels (£20K)	**Medium**: suspended cultivation of mussels in area with heavy recreational boating.
Weymouth – fished species	All shellfish (£2 million)	**Medium - Low**: Some seed mussels and scallops fished offshore, otherwise crustaceans.

Location	Shellfish (value)	Relative risk
Teign – cultivated species	Mussels, Pacific oysters (£53K)	**Low**: intertidal cultivation and salinity limiting for *D. vexillum.*
Teign – fished species	All species (£1.4 million) ~ Scallops (£78K)	**Low**: fished offshore in areas to which *D. vexillum* is not expected to spread.
Exe – cultivated species	Mussels, Pacific oysters (£275K)	**Low**: intertidal cultivation and salinity limiting.
Exe – fished species	All species (£1.4 million) ~ Scallops (£260K)	**Low**: fished offshore in areas to which *D. vexillum* is not expected to spread.
Fal and Helford - fished species	Native oysters (£90K)	**High – Medium**: area is heavily used by shipping and recreational boating. Sub-tidal beds.
Fal and Helford - cultivated species	Pacific oysters (£110K)	**High - Medium**: some cultivation is in cages held sub-tidally and area used for recreational boating.

Summary

The English shellfish aquaculture industry is relatively small, although it is has socio-economic importance for coastal communities. The harvest is around 4,700 tonnes of shellfish annually, worth an estimated £4.4 million. The bulk of this production is of mussels (about 4,000 tonnes) and Pacific oysters (600 tonnes). The greater proportion of this production is carried out in inter-tidal areas that may not be immediately at risk from colonisation with *D. vexillum*. It is also conducted mainly in sheltered estuaries where invasion is not expected by the model.

There is nevertheless increasing interest in expansion of offshore farming of mussels in suspended cultivation, particularly in the Southwest. Areas of interest are Lyme Bay and St. Austell Bay. This move is driven mainly by better quality water, but is close to the areas where *D. vexillum* has become or is potentially likely to become established and so is at risk of colonisation with this species.

The value of shellfish taken from the wild in the UK is much greater than that from aquaculture. Much of this wild catch is from fisheries managed for sustainability. Of the 145,000 tonnes of shellfish worth £260.3 million landed in the UK, about 61% is landed in England. The sedentary species (molluscs) make up 40% of this total and this includes inter-tidal species such as cockles. Of the species of major economic importance, it is probably only scallops that are at any risk from establishment of *D. vexillum* onto beds with subsequent smothering of the animals. According to the model, as the best information currently available, the areas from which scallops are fished are at relatively lower risk from colonisation than more near shore habitats yet the possibility of colonisation of this habitat cannot be ruled out. The fishery for this species is worth about £42 million in the UK.

It has nevertheless been shown that overgrowth with *D. vexillum* can affect fecundity and recruitment of mollusc species, including scallops (Morris et al, 2009) and mussels (Auker and Harris, 2010).

The species perhaps at most risk is *Ostrea edulis*, the native oyster. This is produced from managed beds in areas, mainly the Solent and adjacent harbours, where there is a lot of recreational boating and associated marinas and moorings. The native oyster is a Biodiversity Action plan species.

An effect on the more valuable mobile species (crustaceans) by loss or alteration of habitat by *D. vexillum* becoming established on the seabed cannot be entirely ruled out however.

5.2.8. Experience from elsewhere

D. vexillum is established in other countries with important aquaculture and shellfisheries industries. While it is widely claimed that it is potentially a significant threat to these industries (Coutts, 2006) there is very little documented evidence for this in real terms in the scientific literature. It is therefore instructive to examine the industries in these countries to determine how they are performing in the presence of *D. vexillum*. This in itself however can only be a qualitative assessment as there are many other factors, including market demand, price and level of exploitation, that have an effect on industry performance.

Netherlands

The first official sighting of *Didemnum* sp. in the Netherlands was in 1991. In 1998-1999, *Didemnum* sp. suddenly became very common in the Grevelingen and Oosterschelde, covering much of the available hard substratum. Both of these areas are important for shellfish. Most of the colonies die in winter (December and January), and therefore other organisms (ascidians, sponges, sea anemones, among others) are able to settle in early spring, before the didemnids begin to expand their colonies. The colonies are more successful (larger) in the Grevelingen than in the Oosterschelde. They are most common at depths between 3 and 12 meters in the Grevelingen and from just below low water to 14 m in the Oosterschelde. The colonies grow over all hard substrata (rocks, mussels, oysters) and also over other organisms (hydroids, tunicates) that are normally not overgrown by other species (Gittenberger, 2007).

The Netherlands has an economically important bottom mussel culture industry. This has been under some pressure from nature conservation bodies to scale down in favour of leaving stock as food for wading birds and to become more sustainable. Notwithstanding this, there was no obvious immediate effect on yields through the period of invasion with *D. vexillum*. Yields in 1998 and 1999 were greater than 100,000 tonnes, compared with the decadal average of 82,000 tonnes (FAO data).

It is recognised that the use of yield as an indicator of no significant adverse effect is not perfect, but it is the most available and reliable data and is widely used as a yardstick for the performance of the industry as the figure is for marketed product, which implies an acceptable standard of quality.

France

Here the first documented observation is more recent, in 1998. Aquaculture production in France is predominately of Pacific oysters and as an inter-tidal species an effect on yield would not be expected and indeed there is none. Annual production (FAO data) is stable throughout the 2000s, at just over 100,000 tonnes. Yields are expected to fall significantly from 2010 onwards, but this is attributed to an emerging disease problem experienced over the last three years. Interestingly, production of blue mussels in France is also stable, at 50-60,000 tonnes per annum. There has not, as far as we are aware, been any attempt in France to control the spread of *D. vexillum*.

Ireland

The species has appeared here more recently (2005) so it is not possible to assess any effect on shellfish production. It has been shown to colonise Pacific oyster aquaculture installations but the impact this species has and the level of colonisation is minimal if bags are turned regularly (Kelly & Maguire, 2008). This would be normal management practice for general control of fouling organisms. Oyster culture areas most affected were those situated on the lower inter-tidal where access for turning the bags is more limited. *D. vexillum* has also been found in small quantities on rope grown mussel installations. Upon discovery the operators have conducted an active programme of removal. This is done by hand during grading and harvesting. In 2010 the presence of *D. vexillum* on the mussel farms was less than in previous years, thought to be a combined consequence of the cold winter and active removal.

United States of America

In the USA *D. vexillum* was first documented in 2003 (Carman & Roscoe, 2003) and it is reported that parts of the Georges Bank, where there is an important American sea scallop, *Placopecten magellanicus*, fishery, have been colonised by *D. vexillum* (Valentine et al., 2007b). There is, to date, no obvious impact on production. Since

2003, and following a period of growth since 1998, when production was less than 50,000 tonnes, yields from the USA Atlantic coast scallop fishery have been stable at around 220,000 tonnes per year (FAO data, to 2007). Drs Sandy Shumway and Stephan Bullard of the National Shellfisheries Association have confirmed that there is no evidence of it directly affecting shellfish fisheries in these areas (personal communication). The reasons suggested for this are that the area affected is relatively small, the impact is seasonal, with die back of *D. vexillum* over winter, and the scallops are able to move away from temporarily affected areas.

D. vexillum is also widespread along the Northwest Atlantic seaboard where the major aquaculture species is the Quahog or Hard Clam (*Mercenaria mercenaria*). This is the same species for which there is a small fishery in the Solent in the UK. Average annual production of this species has increased from 25,000 tonnes to 38,000 tonnes since the advent of *D. vexillum*, suggesting little impact, as expected as these clams occupy soft sediments on the seabed. The other shellfish species of note is the blue mussel and for this also there is no change in industry performance, with annual production continuing at around 2,000 tonnes.

On the Northeast Pacific coast, where *D. vexillum* is also widespread, the main shellfish aquaculture species are Pacific oysters and Manila clams. Average annual production of the former is stable, at 40,000 tonnes per annum and for Manila clams has increased by 30% to just less than 4,000 tonnes, from 2003 to 2007.

New Zealand

The first documented occurrence of *D. vexillum* in New Zealand was in 2001, when attempts were made to eradicate the species. These were unsuccessful and it ultimately spread to locations on both North and South Islands, including the Marlborough Sounds, the major aquaculture producing area. The main aquaculture species in this area is the Greenshell™ mussel (*Perna canaliculus*). It is grown by suspended cultivation methods and so is a species at potential risk from *D. vexillum* (Coutts, 2002). Notwithstanding this, there has been steady growth in mussel production through the period of *D. vexillum* establishment in 2001 (Figure 4). Much of this production is exported, suggesting that there is little if any effect on product quality.

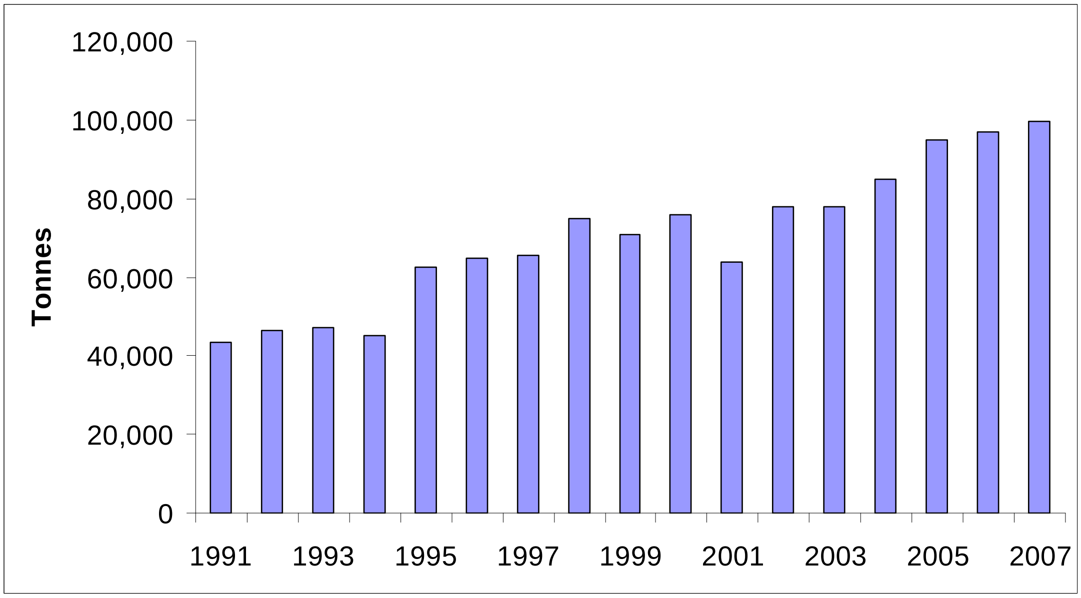

Figure 4: Greenshell™ mussel production in New Zealand (Tonnes, 1991-2007)

Nothing on the impacts of *D. vexillum* is documented from New Zealand since 2006. As suspended mussel cultivation is the industry that is expected to be the most affected and the one that may develop offshore in the south west of England further enquiries were made and Graeme Coates of the New Zealand Mussel Farmers Association was contacted. Industry now manages around the problem, with little impact. It seems that although *Didemnum* is a serious nuisance in that it covers the mussels, it does not kill them. Other enquiries of John Holmyard, who has visited New Zealand mussel farms and experienced the organism first hand, confirm this conclusion of a nuisance species, albeit a serious one, rather than one that is a critical problem for the industry. The view from experts in the USA (Drs Sandy Shumway and Stephan Bullard, personal communication) is also that *D. vexillum* is a serious concern, but no more so than the other fouling organisms for which the industry has adopted control measures.

Graeme Coates confirms that no farms went out of business as a result of *D. vexillum* although there were cash flow problems due to the costs of attempted eradication. In hindsight he suggests that careful management to kill or remove this and other fouling organisms during routine maintenance, particularly the re-socking phase, and careful timing of these operations and the production cycle are effective as a management option, as opposed to eradication. By these means production losses are kept to much less than 5%. There is in addition in New Zealand a voluntary code of practice for movements of stock to help prevent the spread of fouling organisms. He also volunteered the information that *D. vexillum* is not a problem on the seabed, but can if necessary be controlled by smothering with a covering of stone. Other sources (Pannell and Coutts, 2007) suggest that *D. vexillum* does not easily persist on the seabed and where colonies are present this is usually due to them being replenished from colonies dropping off from structures above. Experience in New Zealand has also show that eradication is unlikely to be effective as the organism can establish colonies on hard surfaces not easily detected in an area, from which they can easily and rapidly re-colonise the cleared areas (Coutts and Sinner, 2004).

Wales and Scotland

This species has been detected only recently and distribution is currently very restricted so it is too early to judge any effect on the shellfish industry.

5.2.9. Summary of Impacts

While it is difficult to predict the biological and economic impacts on the shellfish industry through the presence of *D. vexillum*, it seems that there is little documented evidence of major harm and an absence of concern from other countries where there are much larger and more important shellfish industries than in England. There is apparently no effect on production of any major shellfish species in countries where *D. vexillum* is established. Certainly it does not wipe out the value of the industry, as suggested by the UKNNSS risk assessment. This is the case even for the activity (suspended mussel cultivation) potentially most at risk, where the situation is managed effectively and industry continues to flourish. This sector of the industry experiences problems from fouling organisms, especially sea squirts, both native and non-native species, and has developed strategies to deal with them.

In any case, the shellfish cultivation industry in England generally uses species and employs methods that are of low risk from impact from *D. vexillum*.

Shellfisheries in England are of much greater value than cultivated production. Little is known of its effect on seabed habitats and there is limited evidence other than from studies in the USA following colonisation of some areas of Georges Bank (Valentine et al., 2007b). Here observations show that the tunicates overgrow scallops, mussels, other sessile species, and gravel. Dense mats of tunicate colonies possibly form a barrier between fish and prey such as worms and bivalves. The apparent repellent nature of the mat surfaces possibly reduces the area of seabed suitable for settlement of larvae of other benthic species, including sea scallops. An increasing area has been colonised by *D.vexillum* yet there is so far no clear impact on performance of the fishery. These data, however, cover relatively short time scales and there is no evidence of effects in the longer term.

Little attention has been paid to effects on crustacean fisheries and there are no reports of any adverse affects. Fixed gear (pots and creels) is widely used and is managed to prevent build up of fouling. The methods currently used, of routinely recycling to allow air drying, would be equally effective to control *D. vexillum* as it is for other fouling organisms. There may be some risk of spread of *D. vexillum* from the ports where the fishing vessels are based on to the grounds. It is considered highly likely that *D. vexillum* may have been introduced offshore on Georges Bank via contaminated scallop dredging gear and boats from their home ports (Lambert, 2009).

6. Management Options

While this report refers only to the situation in England, the issue should be addressed from a Great Britain perspective, as *D. vexillum* is also present in Wales and Scotland. There are several options that are available for the management of *D. vexillum* on artificial structures in marinas and shellfish aquaculture. Most of the approaches below would be unsuitable to control populations of *D. vexillum* that had spread outside marinas or shellfish farm or other moderately accessible and manageable areas. Many of the options can be considered in isolation, but, any management programme is likely to be more successful and efficient if options are considered in combination. Different approaches are therefore considered individually initially in the first part of this section. An approach will be outlined and where possible the likely costs and benefits will be inferred. A full cost benefit analysis has not been attempted as it is difficult to assess the cost of all options and nearly impossible to estimate the cost of the benefit to biodiversity. However, all costs should be interpreted with the understanding of the potential impacts, based on model predictions, to the shellfish industry as presented in section 5. It should also be noted that there is, at present, no clear benefit of eradication for the shellfish industry as there is currently no good evidence for significantly adverse effects. If the organism was a major pest it would be expected to be cited in various industry and government documents as a constraint on development, but this does not seem to be the case. There are however areas important for biodiversity that might be at risk should *D. vexillum* spread further and eradication might be an option for sites in these areas, although this would require regular monitoring to detect an incursion at an early stage of development. For biodiversity, the cost of the risk of infraction proceedings on European marine sites as outlined in section 4 should also be considered as should its potential impact on Marine Conservation Zones (MCZs) and the risk it poses to achieving Good Ecological Status under the Marine Strategy Framework Directive. The second part of this section considers some potential scenarios involving combinations of management options along with an assessment of the likely risks involved.

6.1. Approaches that might be used to eradicate D. vexillum

6.1.1. The ‘Wrap it up’ method

Most attempts to eradicate *D. vexillum* to date have employed this method both in Wales (Kleeman 2009) and New Zealand (Coutts 2006). Briefly, this method involves wrapping the marina pontoons and pilings in a specially manufactured bag. The bag is put in place by dive teams and left in situ for a period of time. Sodium hypochlorite is sometimes added to the bag as an accelerant in order to speed up the process. Other substances that can be used to kill *D. vexillum* can include freshwater, acetic acid, salt brine (Carman et al. 2010a) and bleach (Denny 2008) The freshwater method was particularly effective. Where *D. vexillum* occurs on mooring chains this method can be modified to a simple 'wrap it and leave it' approach. In this situation a chain is wrapped in plastic and secured with cable ties and left in situ for a period of time until epifauna are dead. Applying this method to pilings and pontoons is relatively straightforward involving minimal use of divers. However, mooring chains require a greater amount of work involving extensive use of dive teams.

The advantages of both these methods are that they are thought to be 100% effective at eradicating *D. vexillum* if all occurrences within a marina are found. The method is likely to be expensive however, involving dive teams. Also, if some populations are missed then the possibility remains that *D. vexillum* would 're-seed' from these missed occurrences and the process would need to be repeated. Materials, such as the piling bags can, however, be re-used. As with all these methods, this method is unsuitable for treating natural structures should *D. vexillum* be found in 'wild' populations.

In Wales, a decision was made to attempt eradication using this method, and this is currently being carried out. The decision to proceed with this approach was based on this being the only known GB location for *D. vexillum* at the time, with the level of infestation deemed still sufficiently low for successful treatment using methods developed and tested elsewhere, mainly in New Zealand. A view was taken that mussel cultivation sites in the Menai Strait were at significant risk of being impacted. An immediate decision was needed to allow time to complete the process during low water temperatures and before the organism became reproductive.

This has met with some success in Wales with most populations apparently being eradicated in the first year of a three year programme. However, ongoing survey and eradication work is needed to continue in year two due to growth of *D. vexillum* from small colonies that were missed in the first year. (R. Holt pers. comm.) As the method is quite time consuming the risk of larvae surviving and being produced before all populations can be detected is quite high.

A thorough evaluation of both these methods can be found in section 4.2.1.1 and 4.2.1.2 of Kleeman (2009) and a detailed description in Coutts (2006).

The estimated total cost of this approach in Holyhead marina was estimated to be between £300,000 and £350,000 over three years, including follow up monitoring. Holyhead marina has 230 berths (Kleeman, 2009). The majority of *D. vexillum* in England has been found in Gosport and the Dart Estuary. These areas contain marinas with an estimated 1,650 to 2,300 berths. Assuming whole marinas should be treated to ensure eradication and that extra materials would need to be produced and extra divers employed to ensure eradication can proceed at the same rate as in

Holyhead (i.e. over the winter spring non-reproductive cycle) the estimated cost for eradication in England is between £2.20 m to £2.68 m. This excludes the costs of monitoring beyond these areas as well as talking smaller populations in Cowes and Lymington. Also known locations are based on a surface-based survey that although targeted at the most likely locations did not comprehensively cover all potential sites of establishment. Therefore additional populations may yet be identified and a more thorough and extensive survey would be needed before a true cost of eradication using these methods could be estimated.

It is unlikely that these methods will have to be employed wholesale across English marinas however, as they are a different construction to Holyhead. The four main impacted marinas in England are largely constructed by securing pontoons using upright erect pilings, as opposed to mooring chains to the sea bed in Holyhead. As such an alternative method could be employed.

6.1.2. Remove and dry method

Other potentially less expensive methods might be applicable at English marinas (Rohan Holt, personal communication), where structures are modular and can be more easily removed for maintenance. Pontoons could, under appropriate tidal conditions, be held clear of the water for sufficient time to dry out to kill *D. vexillum*. Alternatively, sections of marina could be towed and beached and allowed to dry out. This approach would entail greater inconvenience to marina operators than the previous method and would require a carefully planned and coordinated operation. The permanently submerged supporting structures would still need to be treated in a conventional manner. However, in these types of marinas the numbers of underwater chains are much reduced and the underwater pilings are relatively easy to treat. This approach, therefore, may significantly reduce costs by reducing the use of dive teams compared to the previous method although there is a potential that some costs may be incurred by the marina operators. If carried out correctly this method should be 100% effective at eradicating *D. vexillum* from within the marina but there is still the risk of residual hidden populations rapidly re-colonising cleared surfaces.

Should *D. vexillum* be discovered in aquaculture facilities then this method could also be appropriate here, certainly in shellfish aquaculture where product is grown on trestles or ropes that can easily be removed from the water. The drying is not however optimal in aquaculture despite being the most widely used method in the USA (Carman et al., 2010b). Results of experiments showed that *D. vexillum* survives up to 6 hours of exposure to air but major mussel die offs began at 5 hours (Carman et al., 2010a). This method could, however, also be employed alongside current techniques used to manage around fouling organisms in the industry (see section 5.2.8).

6.1.3. Biocides

In some situations it may be possible to isolate the marina from the wider environment. If this was the case then an appropriate biocide such as the 'BioBullet' could be added to the marina. The BioBullet is a developmental toxic chemical encapsulated in an inert substance that *D. vexillum* will filter out of the water and ingest. When it does it dies. This was tested recently against *D. vexillum* in New Zealand where it, along with another invasive ascidian, *Ciona intestinalis*, was killed in large numbers. This product will however require rigorous testing to ensure that it is safe for open water dosing in the UK.

If done in sufficient quantity using appropriate biocide then this technique should prove to be 100% successful. There is, however, significant risk that this method could have an impact on the wider environment if the biocide was released. To reduce this risk, the marina would have to remain closed for a significant amount of time resulting in a loss of earnings. Also, all flora and fauna are likely to be destroyed within the marina. This method would not be applicable in all situations (some marinas may be too large) and public perception of biocide use would have to be carefully managed. This would also involve some potentially tricky licensing issues which may delay the process. The BioBullet is hoped to be species specific so may ameliorate some of these risks. However, as it is largely untested this could not be guaranteed and effectiveness could be expected to fall below 100%.

The part of the shellfish industry most at risk from the harmful effects of fouling organisms such as *D. vexillum* is the suspended mussel cultivation sector, which is not large in England at present but is developing rapidly in the Southwest, where *D. vexillum* is or is likely to become established. It is therefore reassuring that, as in New Zealand, it can be dealt with to minimise the impact. Treatment methods have successfully been developed; it was determined that dipping *Didemnum* spp. in a 0.5% solution of bleach for 2 min was a 100% effective method of treatment that also left seed-mussels relatively unaffected (Denny, 2008).

6.1.4. Clean boat hulls

The current distribution of *D. vexillum* in England is based on surface observation in marinas and as such, the presence of *D. vexillum* on boat hulls is currently unknown. In some cases, boats can remain moored in a marina without moving for considerable time. In Holyhead, this allowed a considerable population and growth of *D. vexillum* to occur on two boats that had remained in place for at least a year.

Depending on the size of the boat a similar method to that used in 6.1.1 could be used similar to Pannel & Coutts (2007). Plastic covers would need to be specially manufactured and put in place using dive teams and surface assistants. Sodium hypochlorite could be used as an accelerant and covers left in place for 7 days. Estimated costs would be around £600 per vessel (Kleeman, 2009).

An alternative would be to remove the vessels form the water and clean the hulls and apply anti-fouling paint. Waste material would need to be disposed of carefully. This treatment would, however, increase the risk of fragmentation of *D. vexillum* and increases the inconvenience to boat owners. Both of these methods should prove to be 100% effective.

6.2. Methods to control and prevent spread of D. vexillum

6.2.1. Pathway management

Pathway management would, in reality, involve a variety of techniques all aimed at the same goal; preventing the movement of *D. vexillum* form current known and unknown locations into new locations. Currently the known extent of *D. vexillum* in GB is still restricted. One of the key objectives of any management should be to limit the spread to new areas and from neighbouring European countries.

Vector management is the primary method for reducing and preventing non-indigenous species invasions and their ecological and economic consequences. The primary vector for *D. vexillum* is fouling on recreational boats and minimising this risk can be summarised as:

- ensuring vessel hulls and marine equipment are free of fouling, and regularly treated with anti-fouling paint
- regularly cleaning hulls in a facility with collection and land-based disposal of fouling material
- minimising the movement of excessively fouled structures from one location to another.

Work on communicating/promoting the issue is already underway as part of GB strategy. In Holyhead the possibility of using a quarantine bay is being explored. Here, vessels arriving from areas of known *D. vexillum* populations can be inspected and treated appropriately, if necessary.

There is also a risk of spread with transfers of aquaculture animals. The relatively high shellfish health status of GB prevents the import of many species from many other countries and thereby helps to prevent the introduction of non-native species. The nature of the industry is such that in most cases seed from hatcheries or locally sourced wild seed stock are transferred to an on-growing area and reared to market size, then marketed for human consumption. There is little in the way of movement of stock during the process and so a low risk of transfer of fouling organisms. There are exemptions to this. As previously noted, part grown native oysters from the Solent are re-laid in Essex estuaries for fattening.

It is difficult to estimate the costs of these approaches as effective management would involve a variety of sectors and stakeholders. Cost could be expected to be lower than for eradication techniques, at least in the first instance, but it is likely that costs would be ongoing. Also, these techniques in isolation are not going to remove any *D. vexillum* and their effectiveness can only be judged by the appearance of colonies in new locations. Even so, these techniques are unlikely to be 100% effective (Floerl et al., 2005). The GB *Didemnum vexillum* working group are currently working on plans to assess pathway management which may include a mixture of voluntary and regulatory mechanisms depending on the pathway and the sector involved.

6.2.2 Codes of conduct and stakeholder communication.

There is a wealth of guidance that has been published on control and prevention of spread of alien marine fouling organisms that would apply to *D. vexillum*.

Examples are the Irish *Didemnum* species management plan (Kelly & Maguire, 2008) and experience with control in New Zealand is described in Pannell & Coutts (2007). This is available on-line at http://woodshole.er.usgs.gov/project-pages/stellwagen/*Didemnum*/htm/dms.htm. In addition, the FAO Aquaculture Service has recently put out a call for contributions to the development of a worldwide overview and databank of Codes of Practice, Codes of Conduct, Best (Better) Management Practices, Technical Guidelines, etc. in aquaculture and once collated these will provide an invaluable source of information. The International Council for the Exploration of the Sea (ICES) already has a published code on introductions and transfers of marine organisms (ICES, 2005). The ICES Working Group on Ballast and Other Ship vectors is developing a Code of Practice on hull fouling.

There is scope for promoting greater awareness of the risks of spread of non-native fouling organisms and measures that can be taken to reduce these risks within the shellfish industry. The mussel growers in North Wales have developed a Code of Practice (Wilson & Smith, 2008) for this that could be adopted more widely. For oysters, these could be treated, or subjected to an emersion time sufficient to kill *D. vexillum*, during transfer without affecting viability of the shellfish themselves. The new aquatic animal health regulations require all growers, as authorised aquaculture production businesses, to have a biosecurity management plan and this might be a mechanism for incorporating preventative measures into the routine operation of farms. These methods, while potentially low cost could involve significant staff time and are unlikely to be very effective in isolation. Also, any costs are likely to be ongoing.

6.2.3. Monitoring methods

If successful attempts are to be made to either eradicate or control the spread of *D. vexillum* then an ongoing monitoring programme is essential. The identification of key sites should be identified. Currently this would depend on the options chosen. Should eradication be implemented then monitoring might reasonably be focussed on the location where eradication has been attempted. If a strategy is employed to limit the spread of *D. vexillum* then those locations, either adjacent to existing sites, or those predicted to be at risk along major recreational yachting routes, could be monitored as a priority. An alternative approach is to identify sites that would warrant protection. For example, marinas that are adjacent to areas protected for their nature conservation value. This approach is not a tool to manage or eradicate *D. vexillum* in itself but would represent an ongoing cost to any management strategies. Monitoring of the wider environment should also be undertaken to ensure spread to natural areas has not occurred. This could be combined with many ongoing monitoring programmes for example those used to report on the environmental status of European Marine Sites.

6.3. Strategy Framework.

Table 4 summarises the different methodologies presented above. The above methodologies could be applied in combination in a number of ways in England. There are then identified four basic strategies for addressing the issue of management of *D. vexillum*. These are listed below, and the techniques/options referred to are as described in Tables 4A and 4B, below.

Table 4A: Management options for treatment of D. vexillum in England –eradication.

Option	**1A**	**1B**	**1C**	**1D**
Method outline	Use similar approach to that adopted in Wales. Target all known locations in Marinas. Wrap marina structures in plastic bag and use Sodium hypochlorite to accelerate.	Adopt different approaches to different marinas. Remove pontoons and marina structures from the water and allow to dry where possible. Remove infected aquaculture infrastructure and allow to dry where possible	Isolate infected marinas and kill everything using biocide (or BioBullet). Allow to recover.	Remove and Clean (Boats and aquaculture) using existing techniques such as hull cleaning.
Positives	Some success already shown in Wales. Bags are reusable so only need to make as many as you can reasonably deploy at one time.	100% effective Should be cheaper than 1A as requires no specialist kit or divers.	Potentially 100% effective	No new methods needed. Good chance of success for the industry

Option	1A	1B	1C	1D
Negatives	High Cost. All colonies need to be found. 7 times more staff required than in Wales to ensure sufficient eradication speed. Would be very disruptive to the business of marinas.	Effectiveness not tested. Likely to be very disruptive to marinas. Not all sites suitable	Kills everything Not all sites suitable. Size of marina could be limiting. Public perception issues. Potential environmental harm. Could be very disruptive to the business of marinas.	May not protect biodiversity interests if escapes into natural substrates. Adds to the problems of aquaculture and yachting (possibly at additional cost).
Estimated Costs	Based on Wales figures scaled up to England estimate initial outlay of at least £2.5m	Possibly less that 1A assuming all marinas suitable.	Unknown but should be cheaper than 1a and 1B.	Only cheap if it doesn't cause users to have to carry out cleaning more frequently or make it more difficult.
Feasible (y/n)	Technically yes but practicalities make it low.	Possibly, but potential scale makes it difficult.	Only in certain marinas	Yes
Chance of success	Moderate to Low	Moderate to Low	Unknown	Moderate
General Comments	High cost needs to be considered against the benefits. It is likely that further populations would be found. This approach would also require substantial monitoring to ensure success. There is a substantial risk of re-infection from overseas populations as well as untreated and undiscovered UK populations. Costs could be reduced by using dive volunteers	It is likely that in any approach to eradication combinations of 1A and 1B would be required along with other methods that arise on a site by site basis. Success of any eradication would be dependent on eradicating introduction pathways and monitoring enough sites to be sure of success.	Consider only in extreme cases (small massively infected marina) where pathways are controlled and there is little chance of re-infection due to wider environmental concerns.	Would need good assessment of effectiveness of current strategies to mange fouling pests. Costs could be reduced by using volunteer divers.

Table 4B: Management options for treatment of D. vexillum in England – other management.

Option	**2A**	**2B**	**2C**
Method outline	Pathway management	Codes of conduct and communications	Monitoring for effectiveness of interventions or new arrivals
Positives	If eradication is unlikely or feasible then would help to significantly reduce spread and mitigate impacts. Raises awareness amongst stakeholders and encourages responsibility for their effect on the environment.	Can have huge impact if managed properly and accompanied by a plan for practical action.	Allows early detection of new sites. Can assess effectiveness of interventions.
Negatives	No legislative requirement for stakeholders to co-operate although this could be addressed subsequently if voluntary measures and existing legislation were inadequate.	Potentially a huge undertaking if to be really effective. Requires a shift in public understanding and interest in the issue. Limited impact unless it leads to constructive behaviour change.	Very difficult to get adequate coverage.
Estimated Costs	Could be relatively cheap but ongoing.	Variable depending on the level of engagement and ongoing	State wide monitoring in Wales considered to cost between £30-45k a year so in England could expect this to be at least £112-168K based on length of coastline.
Feasible (y/n)	Yes	Yes	Yes
Chance of success	Moderate to Good	Poor to good	Not applicable

Option	2A	2B	2C
General Comments	Assumes that boating and aquaculture are the major pathways. This approach would need to include •ensuring vessel hulls and marine equipment are free of fouling, and regularly treated with anti-fouling paint •regularly cleaning hulls in a facility with collection and land-based disposal of fouling material •minimising the movement of excessively fouled structures from one location to another. Higher costs could be incurred if new infrastructure were required such as quarantine facilities. The potential use of existing legislative powers should be further explored.	Should be considered as part of a wider marine non-native strategy at the highest level along the lines of the 'Be Plant Wise' campaign.	Sea bed monitoring also needs to be carried out to ensure no spread to natural structures. Costs could be reduced by using local biodiversity groups and volunteers.

6.3.1 Strategy 1: Complete eradication.

Complete eradication of a species has never been achieved and is particularly unlikely in the marine environment. However, experience in Wales suggests that if money, time and staff resources were sufficient then full eradication could proceed using the methods outlined. It is likely, however, that the cost, and the number of people need to be employed in order to carry out a full eradication at a sufficient rate, will be restrictive. In England, with the number of marinas impacted it is likely that a combination of all methods listed under eradication in Table 4A could be employed with the possible exception of the use of biocide's on whole marinas (Method 1C). Techniques 1A and 1B should be combined depending on marina type. Preference should be given to option 1B if lower cost and rapid action can be assured. Also, if possible both approaches should be combined in the same marina to ensure rapid eradication. Monitoring, as in option 2C, to ensure success and identification of new populations should be carried out as a priority. Monitoring would need to be in targeted at adjacent and higher risk marinas to ensure eradication success. Options

2A and 2B should be carried out at least to a minimum level in the targeted areas.

In Wales, one full time project manager was employed to co-ordinate the eradication programme. An assistant was also more or less permanently engaged with the project. During the active phase of the project, dive teams of up to 8 People, including surface, boat and safety cover, were contracted. If we assume that all sites in England infected with *D. vexillum* are known and then the problem in England is on a scale 7 times larger than in Wales then to carry out the eradication at the same rate would necessitate dive teams of up to 56 people as well as a significantly greater project management load involving liaison with at least 4 times as many marina owners. This is an unlikely scenario, however, as the four main impacted marinas in England are predominantly piling and pontoon construction rather than pontoons moored to the sea bed by chains.

Even if full eradication were attempted, continued success could only be guaranteed if appropriate monitoring and pathway management options were also employed, particularly in relation to un-managed populations of *D. vexillum* in neighbouring countries. The following section therefore outlines a number of strategies that could be employed to manage or eradicate *D. vexillum* to a greater or lesser extent in England with an estimate of the cost and risks involved in each strategy. The estimated cost of £2.5m does not fully consider the cost of pathway management and monitoring at this scale.

The major risks are that eradication speed will not be rapid enough over such a large area. Also, monitoring will need to be ongoing and there is a high likelihood that new populations will arise from neighbouring unmanaged populations resulting in repeat treatments even with pathway management.

6.3.2. Strategy 2: Manage spread of current populations and control small populations.

Strategy 1 considers the eradication of the sites in England where large populations exist, at considerable cost and risk of failure. Some of the known locations in England consist of a single or a few occurrences of *D. vexillum* (e.g. Cowes, Plymouth, Lymington). Strategy 2 would attempt eradication at only these sites using appropriate methods from Table 4A and only treating known occurrences of *D. vexillum* rather than whole marinas. This would reduce the risk of these sites becoming heavily infested with *D. vexillum* from their current populations. Vector management and a communications strategy (2A and 2B in Table 4B) should then be targeted on the larger populations in Gosport and the Dart Estuary as well as populations in neighbouring countries where possible. This would reduce the risk of spread around the coast from these populations, but not eliminate it. A monitoring programme would be needed to compliment this strategy, ideally located on marinas most at risk from introduction of *D. vexillum* from the Gosport and Dart sites as well as overseas populations. These sites could be determined from the modelling work presented in this report. Using this approach, eradication techniques could be applied to any new populations appearing in monitored sites as they would be suitably small and potentially cost effective.

6.3.3. Strategy 3: Eradicate new populations at low risk of re-infection in sensitive areas.

The model presented in this report (Appendix 1) successfully predicted the locations of introductions based on known overseas populations. As these populations are unmanaged, risk of infection and re-infection from these sources is high. Due to this Strategy 3 proposes no eradication in these high risk locations (namely the Solent, Dart Estuary and Plymouth, and possibly the Thames area depending on Dutch populations) as they would likely require repeat treatments and produce escalating costs. A more cost-effective solution could be to employ pathway management and communications techniques around these areas. Monitoring can then be targeted to marinas that are adjacent to areas that have high nature conservation value or host important shellfish fisheries but are at lower risk of infection as predicted by the model. In the first instance consideration should be given to marinas in and around the Fal and Helford Estuaries, Weymouth, Brighton and the Norflok coast up to The Wash. If *D. vexillum* is found at these sites then eradication techniques could be employed as per Strategy 2. As these marinas are predicted to be low risk to re-infection the likelihood of needing treatment in the first place, or repeat treatment, is reduced and therefore keeps costs down.

The advantage of this strategy is that it might provide a cost effective technique to protect sensitive sites keeping down the cost of monitoring and eradication, although monitoring would be an ongoing cost. The disadvantage is that it does not protect sensitive sites already adjacent to populations especially in the Solent and Plymouth Sound and the Dart. Also, staff and equipment required for eradication would need to be 'on-standby' and ready to deploy to ensure a rapid response if *D. vexillum* were detected in risk areas.

6.3.4. Strategy 4: No eradication techniques but manage spread.

Any eradication technique will be costly and none of the strategies outlined above can guarantee successful eradication. Strategy 4, therefore, presents an approach that will reduce costs and yet control the impacts of *D. vexillum* by slowing the spreads using pathway management and communications. While there is obvious significant risk of spread substantially more than in other strategies, any savings can be used to improve the efficacy of pathway management and stakeholder communications. Also, these techniques are not necessarily *D. vexillum* specific and there may be added benefits to control of other non-native invasive species.

6.3.5 Summary of approaches

The suggested strategies give a range of management options from complete eradication (Strategy 1), which though technically feasible will be very expensive and has high risks associated with re-infection from hidden residual populations and re-introduction from unmanaged populations, through to control of small populations (Strategy 2) and eradication of new populations at low risk of re-infection in sensitive areas (Strategy 3). These strategies are supported by pathway management and stakeholder involvement in codes of practice which if done effectively can be considered as an approach to controlling *D. vexillum* in its own right (Strategy 4). Strategies 1 to 3 inclusive have a much greater on-going monitoring commitment.

6.4. Conclusions.

1. Complete and continued eradication of *D. vexillum* at the English sites currently known to be infected is technically achievable but probably only a viable option at selected minimally infected sites. The level of effort needed to ensure eradication proceeds at a sufficient rate is probably not attainable and represents a costly option. Furthermore, baseline data for these regions is not complete and this would be a major undertaking. In addition the risks from re-infection from unmanaged sites in adjacent countries and from undetected colonies within the region are high.

2. Potential pathway management options do exist but require a level of stakeholder engagement and involvement in order to implement them effectively. If voluntary agreement cannot be reached then some regulatory mechanism may be required. There should be a targeted campaign to promote codes of good practice within the fisheries, aquaculture and boating sectors to prevent the introduction and spread of all alien marine fouling organisms in the first instance. Current plans to develop pathway management measures for *D. vexillum* should continue and any initiatives should be coordinated with those from the IMO such as Ballast Water Management Convention (IMO, 2004) and the developing guidelines on bio-fouling.

3. The option to eradicate new populations should remain, particularly if they occur in areas that are sensitive for biodiversity and or shellfish aquaculture. The most suitable and cost effective method should be chosen that allows for a rapid response to the occurrence, for example drying out of marina pontoons.

4. Continued surveillance and monitoring is an important part of any strategy to determine its effectiveness, or whether new populations have occurred. While this represents an ongoing cost any monitoring program could be stratified to monitor only the most at risk, or sensitive sites. Partnership working with owners of marinas would assist this surveillance.

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Colonies of *Didemnum vexillum* overgrowing gravel substrate on Georges Bank off New England, USA. Page Valentine and Dann Blackwood, US Geological Survey

APPENDIX 1 – GIS Modelling

1. Predicting the spread of *D. vexillum* and GIS mapping

   1.1. Predicting the spread of an invasive species is crucial when assessing possible management actions. The impacts of the species on both biodiversity and commercial interests need to be studied and a cost-benefit approach taken to decide on the best course of management for that species.

   1.2. Geographic Information System (GIS) offers a fast, efficient way to map this predicted spread. The results of this mapping can then be used to focus on areas where *D. vexillum* may conflict with conservation and commercial interests.

   1.3. For this project, all the GIS spatial processing was carried out in ArcMAP 9.3 and used the ArcMAP toolbox along with Hawth's Tools and ET Geowizzards toolboxes.

   1.4. In order to predict the potential spread of *D. vexillum* a simple modelling approach can be used, which uses the species biological limits and current known populations to estimate the positions of future colonies. Whilst this approach quickly produces results, it is limited as the model is not quantitative and cannot be adequately tested (see section 5.3).

2. Data Collation

   2.1. Data for the project came from a variety of sources as outlined in table 2.1. In many cases the data had to be extracted to an appropriate format for ArcMAP 9.3. This extracting was carried out in Microsoft Excel using the Visual Basic Editor and other MS tools.

3. Data processing

   3.1. Temperature data was averaged into four periods (Jan – Mar, Apr – Jun, Jul – Sep and Oct - Dec) using the Calculate Raster function in ArcMAP 9.3.

   3.2. Salinity data for the offshore area were interpolated using the Inverse Distance Weighting (IDW) method as shown in Herborg *et al.* 2009 using annual averages. Salinity data specific to each marina was paired to the marina to give a specific salinity reference for those areas.

	Data	Source
	Sea Currents	SeaZone
	Bathymetry	SeaZone
	Sediment	SeaZone
	Salinty (Offshore)	www.nodc.noaa.gov
	Salinty (Marinas)	Supplied by Natural England
	Temperature	Met Office
	RYA cruising routes	Royal Yachting Association (RYA)
	RYA marinas	Royal Yachting Association (RYA)
Biodiversity Concerns	SSSI areas	Supplied by Natural England
	SPA	Supplied by Natural England
	SAC	Supplied by Natural England
	Mudflats	Supplied by Natural England
	National Nature Reserves	Supplied by Natural England
	Local Nature Reserves	Supplied by Natural England
Commercial Concerns	Aquaculture	SeaZone
	Shellfish Beds (Farmed)	Supplied by CEFAS
	Shellfish Beds (Natural)	Supplied by CEFAS
	Bi-valve Classification Regions	Supplied by CEFAS
	D. vexillum locations (England)	Supplied by Natural England
	D. vexillum locations (Abroad)	http://woodshole.er.usgs.gov/project-pages/stellwagen/didemnum/index.htm

Table 2.1. Sources of data used in the project. RYA = Royal Yachting Association.

3.3. All data on biodiversity concerns (table 2.1) were clipped to show only coastal areas (i.e. removal of inland biodiversity concerns). This allowed for increased speed in display of the map and in any spatial analysis.

3.4. RYA marinas were clipped to show only those that were within 1km of the coast or within 1km of an RYA cruising route. It was assumed that any marinas outwith these bounds would not be affected by *D. vexillum* as inshore marinas would have a salinity level that would be outside the biological limits of *D. vexillum*.

4. Model building

4.1. Two models were developed for predicting the spread of *D. vexillum*. The first was designed to show all possible areas around the English coast that could support *D. vexillum* (i.e worse case scenario). The second model aimed to show the most likely areas that *D. vexillum* could spread to over the short term.

4.2. Model 1.

4.2.1. All the areas that were ecologically suitable for *D. vexillum* growth were highlighted. To do this the following variables were considered; temperature, salinity, depth and substrate. The biological limits of the species are set out in table 4.2.1. The presences of hard artificial substrate in marinas was assumed

4.2.2. SeaZone data on depth and sediment were clipped to show the areas around the UK coast that were suitable for *D. vexillum* growth. Anything above the subtidal zone was removed from the data set as unsuitable for *D. vexillum* growth. Data on positions of natural and farmed shellfish beds were included in the model as *D. vexillum* is known to survive on these.

Table 4.2.1. Biological limits of *D. vexillum* used in the modelling process.

Variable	Biological Limits
Temperature	-2 to 25℃ (larval development ceases at 10℃)
Salinity	25-36 psu
Substrate	Only hard substrates [Gravel, Rock and Shells]
Depth	Down to a depth of 50m but not intertidally

4.2.3. The offshore salinity raster and the four groups of temperature rasters were then studied. Temperature and salinity were never outwith the biological limits of *D. vexillum* (at all times of the year). Therefore, it was assumed that temperature and salinity would not limit the spread of the species around the English coast.

4.2.4. The resulting layer (created in section 4.2.2) contained all the areas that were biologically suitable for *D. vexillum* growth around the UK coastline.

4.3. Model 2a and 2b

4.3.1. The models looked at several variables to try and predict the spread of *D. vexillum* in the short term. These variables are shown in table 4.3.1. Model 2a was developed to try and predict the hypothetical spread of the sea squirt, from France, to areas along the south coast of England. If model 2a was able to make accurate predictions then model 2b would be developed using the same variables and would predict the spread of *D. vexillum* from all known colonies in the UK (Wales, Scotland, Northern Ireland and England) and surrounding EU countries (Ireland, France, Holland).

Table 4.3.1. Variables used in the second model to predict short term *D. vexillum* spread.

Variables considered
1. Number of cruising routes in 5km buffer
2. Distance to nearest *D. vexillum* colony
3. Number of possible infected routes entering the marina
4. Suitable depth and substrate
5. Suitable salinity

4.3.2. Number of cruising routes (vector density): Firstly, buffers of 5km were created around each of the RYA marinas. A size of 5km was selected for the buffers arbitrarily. Within each of these buffers, the number of RYA cruising route line nodes (i.e. the beginning and ends of cruising routes) were counted. These cruising routes can be split in to high, medium and low recreational yachting use, using data supplied by the Royal Yachting Association (RYA).

4.3.3. Distance to the nearest *D.vexillum* colony was calculated using point to point distance in ArcMAP 9.3. All known colonies were used, including those in England, other areas of the UK (Scotland, Wales and Northern Ireland) and Europe (Ireland, France and The Netherlands) (see Figure 4.3.3). However, colonies that had been eradicated were not included.

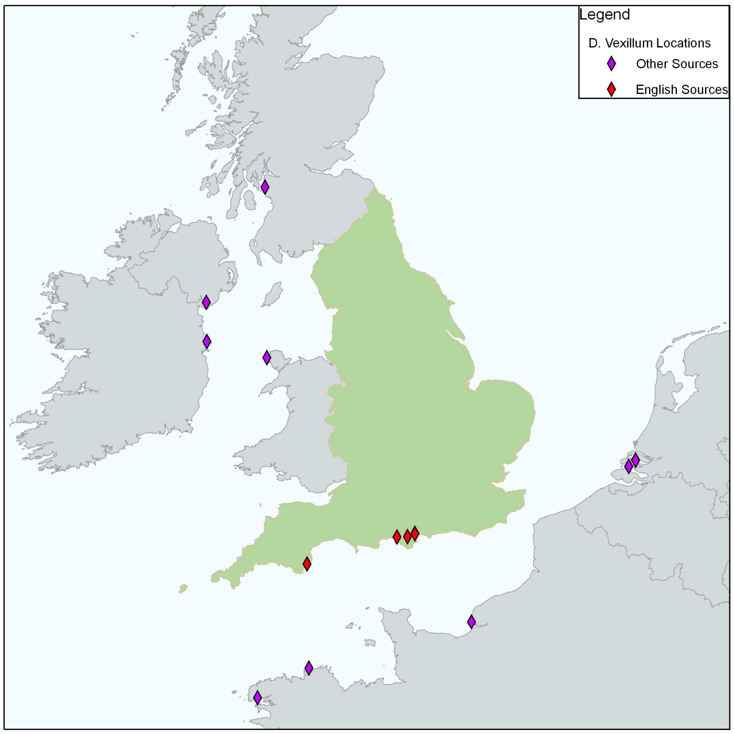


Figure 4.3.3. Known locations of *D. vexillum* colonies that were used to model its possible spread across England.

4.3.4. Number of possible infected routes entering a marina: For the south coast, it was assumed that all routes entering a marina were possibly infected with *D. vexillum*. This assumption is valid because of the extremely high level of yachting activity along with the high number of *D. vexillum* colonies in the area. These two factors would enable ships to become infected in a number of places and subsequently to move anywhere along the coast.

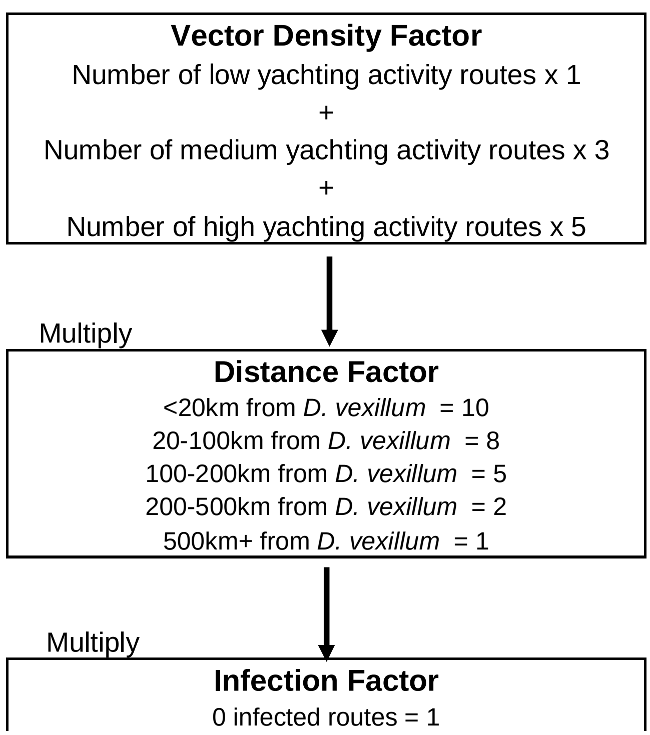
4.3.5. Number of possible infected routes entering a marina: For areas around the North West coast of England, the numbers of infected routes were calculated by sequentially 'selecting by location'. Any routes that came into contact with an infected marina, and subsequently headed for the English coast were selected. This was possible due to the lower levels of yachting activity in the area.

4.3.6. Suitable depth and substrate: It was assumed that all marinas would have artificial substrate that would be capable of supporting *D. vexillum* and would be within the depth range of the species.

4.3.7. Suitable salinity: Salinity data specific to each marina was used to establish if an individual marina had salinity levels within those of the species biological limits.

4.3.8. All the variables in table 4.3.1 were also collected for possible *D. vexillum* originating from France and colonising the south coast of England (i.e. distance from southern marinas to the closest *D. vexillum* source in France, and number of infected routes [calculated as in section 4.3.5]). These values would be fed into model 2a.

4.3.9. The final model created is shown in figure 4.3.9.1 Vector density is likely to be a good predictor of *D. vexillum* spread (Herborg et al. 2009) and is therefore given a high weighting in the model. It was decided that distance would heavily affect the spread of *D. vexillum*, as the majority of yachts are unlikely to travel large distances (unless racing / international yachting). From the RYA data it can be seen that most yachting movement is localised around the South coast of England and the Severn Estuary, with very low numbers of well used, long distance routes extending only part of the way around the coastline (figure 4.3.9.2). This indicates fewer long range movements and more localised movements. Also any effect of larval movement in currents would be highly local (no data on direction of currents is included in the model). The number of infected routes was given a lower weighting in the model, as the probability of a yacht on a route becoming contaminated is unknown.



1 infected route = 2
2 -10 infected routes = 3
10+ infected routes = 4

Multiply

Substrate and Depth Factor
Suitable area = 1
Not suitable area = 0

Multiply

Marina Salinity Factor
Suitable salinity = 1
Not suitable salinity = 0

Equals

RESULTING RISK

Figure 4.3.9.1. Flowchart showing the modelling steps for models 2a and 2b.

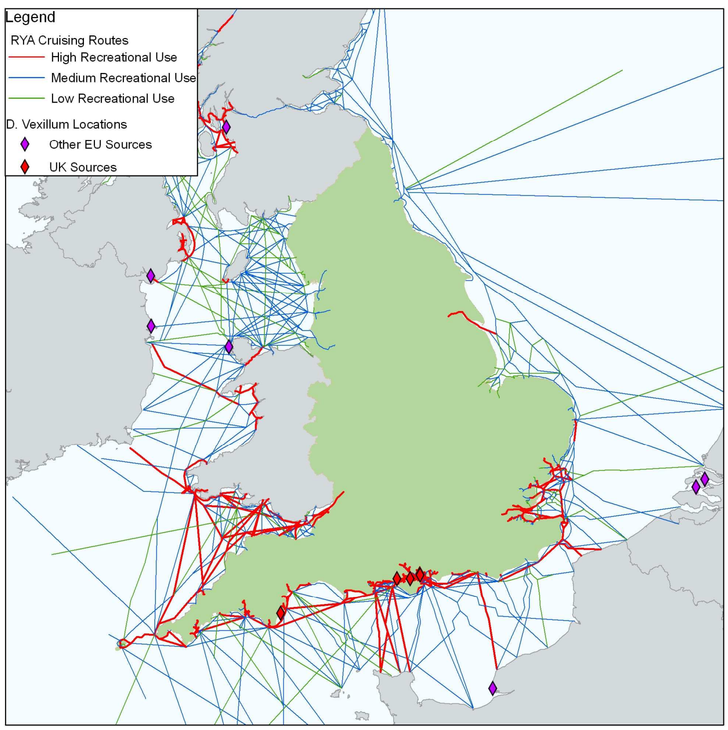


Figure 4.3.9.2. Map of the RYA cruising routes showing high concentration of well used routes along the Southern coast and the Severn Estuary. Most well used routes, regularly come into land at marinas and very few extend from the Southern coast around to the Severn Estuary or the Thames Estuary. This suggests localised movements rather than well used long ranging yachting routes extending around the coast of Britain.

5. Results and Discussion

5.1. Model 1.

5.1.1. Model 1 shows suitable areas for *D. vexillum* colonisation all around the UK coastline (Figure 5.1.1).

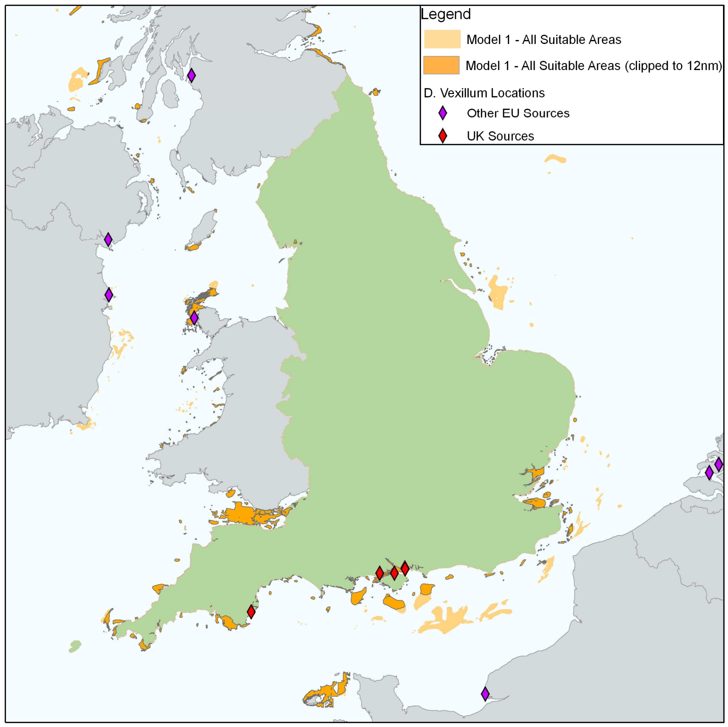


Figure 5.1.1. Model 1 output showing suitable areas for *D. vexillum* growth.

5.1.2. From January to March, the temperature around the UK coast drops below 10℃, therefore limiting the development of *D. vexillum* larvae.

5.1.3. The biologically suitable areas for *D. vexillum* include areas of commercial (Figure 5.1.3) and biodiversity interests.

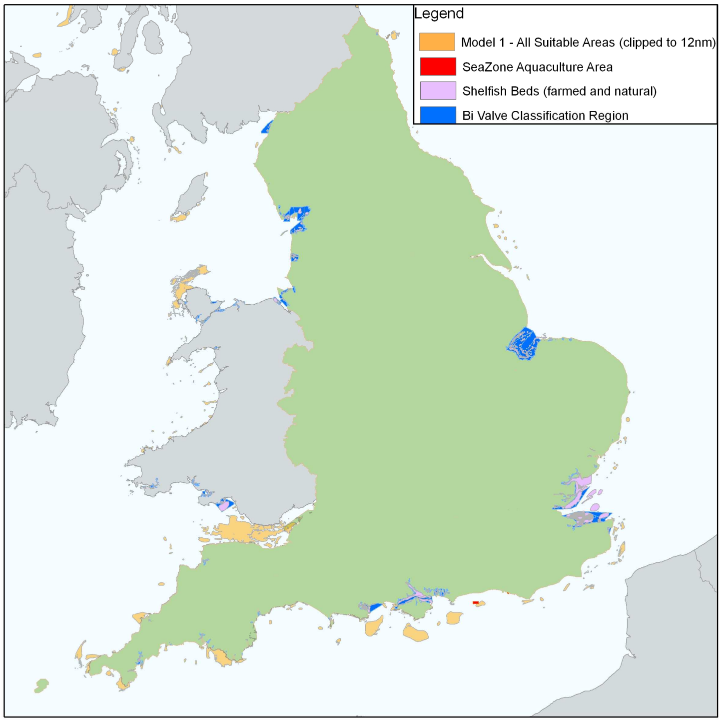


Figure 5.1.3. Model 1 output showing all the possible areas (clipped to 12nm), around the UK coast, that are suitable for colonisation by *D. vexillum* and the areas of commercial interests that may be affected.

5.2. Model 2.

5.2.1. The model shown in figure 4.3.9 accurately predicted the spread of *D. vexillum* along the south coast of England from France (Figure 5.2.1). Hotspots of likely sea squirt spread were shown around the Isle of Wight & Southampton Water (several confirmed *D.vexillum* sites), Torbay & Dartmouth (one confirmed *D.vexillum* sites) and around Plymouth (colony not located in most recent surveys, but a colony was located and removed in 2008). Therefore the model is capable of making accurate predictions based on the variables selected.

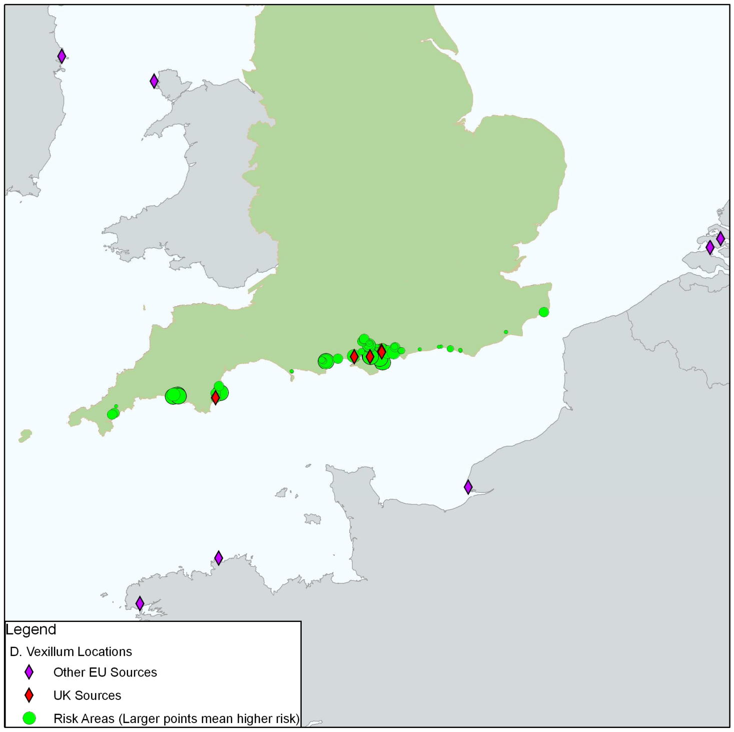


Figure 5.2.1. Predicted spread of *D. vexillum* from known colonies in France (model 2a).

5.2.2. The final model when applied to all English marinas also highlights the Isle of Wight as a major area of concern for *D. vexillum* colonisation (Figure 5.2.2a). It is likely that the species will spread to more marinas in this area due to the high degree of yachting activity and the high number of known *D. vexillum* sites in the area (Figure 5.2.2b).

5.2.3. In the Isle of Wight area, currents will also aid in the spread of the species during April to December when sea temperatures are high enough to allow larval growth.

5.2.4. The second area of the most concern is Plymouth. This area also has a high degree of yachting activity and is close to a known *D. vexillum* colony. The area previously had a colony that has since been removed.

5.2.5. The rest of England has a fairly low risk of *D. vexillum* spread, perhaps with the exception of the Thames area and Whitehaven marina. Although the risk posed to these areas is much lower than that along the South coast. Sources of the potential spread to Whitehaven marina are the infected sites in Wales, Northern Ireland and Ireland. The Thames area is most at risk from infected sites in the Netherlands and existing *D. vexillum* sites along the south English coast.

5.2.6. It would be FERAs suggestion that all marinas around the Isle of Wight and Plymouth be further surveyed for signs of *D. vexillum* spread, as these are the next likely areas to be colonised.

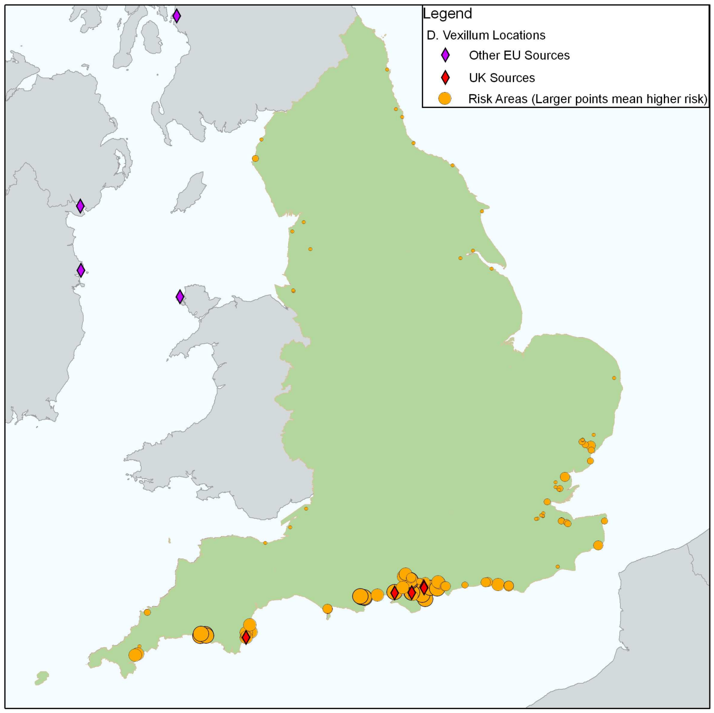


Figure 5.2.2a. Predicted spread of *D. vexillum* from all known colonies of the species to all areas of the English coastline (model 2b).

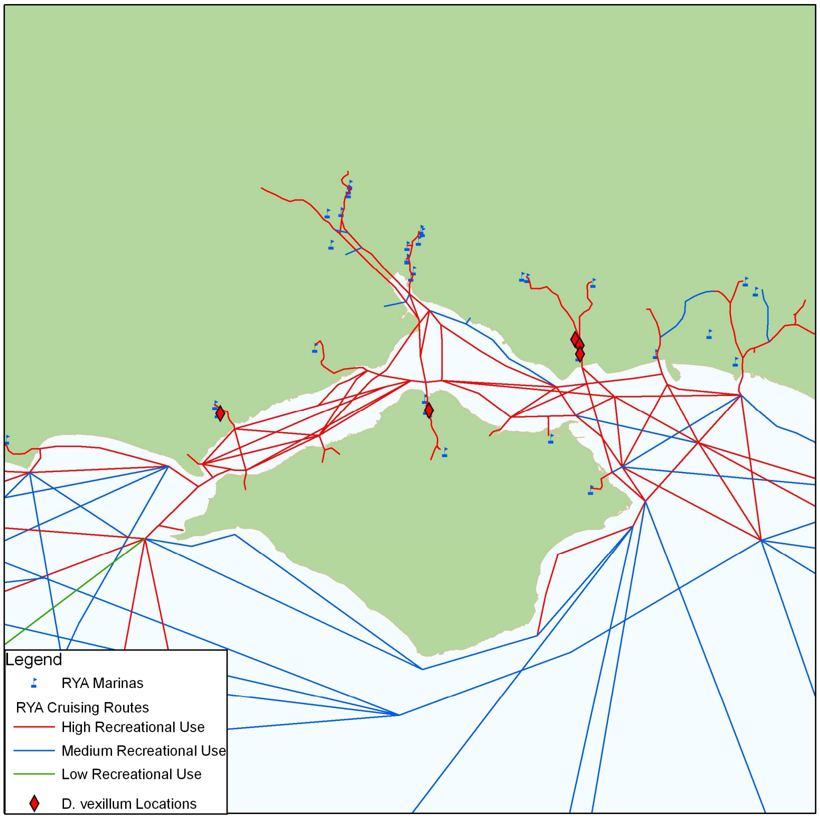


Figure 5.2.2b. Map showing the high degree of yachting around the area of the Isle of Wight.

5.3. Limitations of Model 2b

5.3.1. The model is limited due to a lack of quantitative data (i.e. probability of a ship/yacht being contaminated by *D. vexillum*, probability of the *D. vexillum* colonising a marina that a contaminated ship enters, numbers of yachts using the RYA cruising routes etc.).

5.3.2. The values of the factors assigned to each stage of the model are arbitrary, and whilst they seem to enable accurate prediction of the hypothetical situation of colonisation along the south coast of England from France, no real estimates of model efficacy have been undertaken.

5.3.3. The RYA cruising routes are not accurate. They have been created by the RYA by taking the average routes of ships that travel in the area, and so many ships will not follow these routes exactly.

5.3.4. The model could be ground-truthed by further surveying of marinas. However, before any long-term monitoring is put in place, further work should be undertaken to expand and improve the accuracy of this model, populating it with quantitative data. One possible direction would be to carry out ecological niche modelling (Herborg *et al.* 2009) on *D. vexillum*.

5.3.5. Despite the limits of the model, it is FERA's belief that the general trends predicted by model 2 are robust. The south coast of England and the Thames estuary are likely places for *D. vexillum* to colonise, given their proximity to colonies of the species and the level of yachting traffic in these areas.

6. References

Herborg, L. M., O'Hara, P. & Therriault, T. W. (2009) Forecasting the potential distribution of the invasive tunicate *Didemnum vexillum*. *Journal of Applied Ecology*, **46**, 64-72.