Boats or Tides: Tidal Streams as Dispersal Vectors for Invasive Marine Species

by M.J.Simons. Published online by Boat Owners' Response Group, July 2015

Summary:

Concern has been expressed at the possibility of the spreading of invasive non-native marine species by recreational boats. This article proposes that the vigorous tidal streams which flow along the southern English coasts can offer a far greater capacity for spreading marine species over short and medium distances than the hulls of small vessels. Examples are given of tidal flows, of published studies modelling the tidal spread of Manila clams between Poole and Southampton, and of the tidal distribution of radionuclides between Cherbourg and Dover. Published reports of the distribution of the invasive carpet sea squirt *Didemnum vexillum* fail to support the hypothesis that it is being spread by recreational vessels. It is concluded that, in the several cases considered, tidal streams appear to be more potent dispersal vectors than the hulls of recreational boats over short to medium distances.

1. Introduction:

The possibility of the spreading of invasive non-native marine species by recreational boats is being raised in some quarters. For example, as part of the programme to designate Marine Conservation Zones in England, the advisory body Natural England states in respect of intertidal rock in the Yarmouth to Cowes area "*Current risk from risk of introduction or spread of non-indigenous species from recreational sailing and powerboating."* **(1)** Six further similar "risks" are alleged (without any substantiation) in the same document. This raises the spectre of conservation activists campaigning to restrict the movement of recreational vessels in some areas - but such restrictions would be futile and pointless if invasive species were being widely distributed by natural water flows anyway. Here, we examine in outline the scope for the natural dispersion of marine species in the tidal waters of southern England as reflected in the published literature, and interpreted from the perspective of the author as a practical yachtsman and a physical scientist.

Ships are widely acknowledged to have been responsible for transporting invasive marine species over long distances across oceans, in their ballast water, sea chests, or as fouling on their hulls. The transfer of marine species between isolated lakes via recreational craft or their trailers has been reported, particularly in the USA and Canada. However when it comes to dispersal over short or medium distances between bodies of water connected by significant tidal flows, the question arises whether any dispersal via the hulls of recreational vessels matters at all when compared with the mass transport of vast quantities of sea water, and the life forms it contains, through the twice-daily tidal cycle.

2. Fouling on Hulls:

Smaller boats, usually up to around 20 ft length, which are kept out of the water (eg dinghies, trailer-sailers, motor boats kept in "dry stacks") will usually be free of fouling anyway, and so free of any non-native marine species, although there may be a risk of tufts of weed being caught and transported on launching trailers.

Boats which are kept afloat and are in use are usually protected by antifouling paint, usually applied annually, and generally remain free of fouling apart from sometimes a thin layer of slime and a fringe of silky green weed *(Ulva flexuosa)* around the waterline. Most boats are also kept out of the water for a period each year, killing off most species on the hull. Mineur et al (2008) **(2)** surveyed yachts in marinas in France and Spain and reported that "The hull survey showed that many in-service yachts were completely free of macroalgae." (Out of 67 yachts sampled, 28 were completely free of fouling, and the vast majority of the rest had only one species, usually of the *Ulva* genus, and that at a low level).

An underwater survey of boat hulls in Holyhead Marina, North Wales, conducted in 2008 as part of an investigation of an invasion by the carpet sea squirt reported: "At the time of the survey the marina was only half full (130 boats out of a capacity of approximately 250 boats when full). Of those present, only two boats were found to have heavily fouled hulls." (Holt et al 2009 (**3**)). That is just 1.5% of hulls were heavily fouled.

It is in a boat owner's own interest to minimise fouling, as it severely reduces boat speed and increases fuel consumption. Pictures of severely fouled boats, with streamers of kelp metres long, have been posted in some reports, perhaps by environmental alarmists, or researchers desperately seeking funding, but such cases of extreme fouling are unusual and are probably on boats which have been neglected or abandoned by their owners for unavoidable reasons. No sane person would attempt to navigate such a vessel, unless to the nearest yard for remedial work. So while there will always be a small number of heavily fouled boats, they are unlikely to travel far at all, because of the effects of the fouling itself. They are thus unlikely to be significant vectors in the spread of invasive species.

The key point of this section is that fouling on the hulls of boats which are in use, which might possibly carry invasive species, is normally at a low level, and so any invasive species on the hull would be expected to be at an overall low level too. The question is, does this low level of fouling on recreational boat hulls in tidal waters add anything to the dispersal of invasive marine species which is not already being done by tidal flows, by the tidal conveyor belt around British coasts?

3. Propagation and Dispersal

To propagate themselves, all life forms must be able to reproduce, and to disperse the new growth spatially, to spread out. Invasive species must be particularly good at dispersal, for that is what makes them invasive. On a local scale, invasive marine species must be able to disperse through the water column, whether by swimming or drifting, or perhaps being carried in the gut of an animal or fish. They cannot rely on hitching a ride on passing boats: in many places, there just are not many boats anyway, and once upon a time, there were no boats at all. Of course, to attach themselves to a boat, or to leave a boat for their new home, they have to pass through the water column anyway.

In the case of the seaboard of southern England, there is a relatively large tidal range, and often powerful tidal streams. These can provide a tidal conveyor belt, a dispersion vector, for species within the water column, and examples will be given in later sections of this article. To be dispersed by water movement, the species must be in a form which can be carried along in, or swim in, the water column. The duration of the mobile phase or phases is an important factor in determining the distance over which the species can be dispersed by water flow. A limited number of examples will be considered below.

Extended or indefinite mobile phase:

Fish, shrimps and many other crustaceans, and other swimming creatures can remain in the water column indefinitely. Seaweeds (algae) can be dispersed as vegetative fragments which can settle elsewhere, or as much smaller entities such as spores or zygotes etc. during reproduction processes. The invasive Japanese wireweed, *Sargassum muticum,* first found at Bembridge in 1972, in now widely spread around the coasts, and clumps of this buoyant seaweed (it has small spherical flotation sacs) may frequently be found floating on the surface. Its spreading could be in very large part be through natural dispersal by water currents, tidal flows, wind and waves. The occurrence of natural dispersal of seaweeds by tide, wind and wave is beyond doubt.

Shellfish have a mobile larval or pelagic phase which eventually settles to turn into the adult shellfish: in the case of the Manila clam, discussed below, the larval phase lasts around three weeks, sufficient for tidal dispersal of tens of kilometres as explained below.

Short mobile phase:

Sea squirts (tunicates) have a larval phase which is short lived, perhaps a few hours to one to three days. This will clearly limit the range in which they can be dispersed in the larval phase by water currents, although even in a few hours tidal currents could transport larvae a number of kilometres. However, other means of natural dispersal are possible:

Detatched fragments and rafting:

An invasive sea squirt which has recently raised concern is the carpet sea squirt, *Didemnum vexillum.* In mature form it forms cohesive sheets which can fragment and disperse in water currents. Small fragments of *D. vexillum* can tolerate suspension in the water column for weeks without reattaching, suggesting that it can be transported medium distances by tidal and storm currents (Morris and Carman 2012) (**4**). Carman et al (2014) studied the re-attachment of separated fragments of *D. vexillum* to eelgrass (*Zostera marina)* and to plastic substrates, finding a 77% success rate (**5**). It is clear that *D. vexillum* has the potential for long-range natural dispersal in the water column via detached fragments.

A further route for water-borne dispersal of marine species is by rafting onto floating objects, including seaweeds. A press release by the Woods Hole Oceanographic Institution (**6**) shows pictures of carpet sea squirt growing on a bladder-wrack type of seaweed: clearly if a portion of the seaweed were to be broken free by wave action, there would be potential for long range water-borne dispersal.

WHOI researcher Mary Carman points to sea squirts on the rocks in a tide pool in Sandwich, MA. (Tom Kleindinst, WHOI)

https://www.whoi.edu/main/news-releases/2005?tid=3622&cid=4098

The invasive carpet sea squirt, shown here growing on seaweed, often looks like scrambled eggs but comes in all shapes and colors. (Tom Kleindinst, WHOI)

The wide-spread water-borne dispersal of the non-indigenous Japanese wireweed has already been mentioned above, and this species itself has the potential to act as a vector for further non- indigenous species associated with, or rafting on, it. *Sargassum muticum* can act as host to a wide range of epibiota: Withers et al (1975) found 80 animal, 52 plant and 9 fungal species from S. muticum plants collected at four different localities around the Eastern Solent (**7**). Buschbaum et al (2006) (**8**) found 105 species associated with *Sargassum muticum* from two different sites in the North Sea in Germany. They covered 12 phyla or sub-phyla, and included 6 species of tunicates, including *Didemnum* species. Although the only associated species identified as alien to the area was the leathery sea squirt *Styela clava*, the principle remains that Japanese wireweed, and other seaweeds, can act as host to a multiplicity of organisms, and there seems no reason in principle why it, and other macro algae, might not host a range of non-indigenous varieties.

Davis et al (2007) (**9)** report of *Styela clava,* the leathery sea squirt, “It has been found attached to seaweed, e.g. *Laminaria saccharina* and *Sargassum muticum*, but in general a hard substratum is required.” They cite Lutzen (1999) (**10**) as proposing two natural methods of dispersal of *Styela clava*, as planktonic eggs and larvae, carried by tidal and other horizontal currents;and (ii) as sessile adults attached to drifting flotsam, e.g. *Sargassum muticum.*

A common and widely spread non-native species is the orange tipped sea squirt, *Corella eumyota*, and the Natural History Museum website carries the following description:

“Corella eumyota is an invasive solitary sea squirt. ……..

- it often forms large clumps of tightly packed aggregations on floating pontoons, piers, ropes, ship hulls, and other submerged structures
- individuals can be so tightly adherent to one another that it is usually not possible to separate them without tearing the external covering (tunic)
- this species can grow over other organisms, including other invasive species”

(http://www.nhm.ac.uk/nature-online/species-of-the-day/biodiversity/alien-species/corella-eumyota/index.html)

So, like *Didemnum vexillum,* the orange tipped sea squirt would also seem to have potential for dispersal via detatched fragments of a cluster, or like both *Didemnum vexillum* and *Styela clava,* by rafting on seaweeds.

Bryozoans are another class of non-native species often found in marinas. Like the sea squirts (ascidians, tunicates) they also have a short-lived larval stage. Here again rafting of the mature phase on seaweeds (or other floating matter) offers a waterborne route for dispersal. The tufty buff bryozoan *Tricellaria inopinata* has been found to grow on brown seaweeds by Johnson et al (2012) (**11**), and the orange ripple bryozoan *Watersipora subtorquata* has been reported as growing on floating seaweeds which could provide a comparatively long range means of natural dispersal (Kuhlenkamp and Kind (2013) (**12**). It is worth reproducing in full their abstract:

"This is the first report about the arrival of the encrusting cheilostomatid bryozoan *Watersipora subtorquata* on floating seaweeds in German coastal waters of the North Sea. During summer 2012, drifting or stranded thalli of the non-indigenous brown macroalga *Himanthalia elongata* were investigated on the island of Helgoland showing numerous benthic species covering the holdfast of *Himanthalia*. Out of the 120 basal structures investigated, 8.3% had viable colonies of the invasive, non-native *W. subtorquata* attached to them. *Himanthalia* and *W. subtorquata* have both their nearest origin reported to be in the English Channel (La Manche), approximately 800 km away from Helgoland. Now we found *W. subtorquata* as a rafting species in the eastern part of the North Sea, showing its ability to distribute easily over very large distances using floating algae as a natural transport vector. This event might constitute the first step in the potential introduction of this alien species into German coastal waters."

It is clear that floating seaweed can act as a natural dispersal pathway for at least some bryozoans. Of the two examples given, one is a branching species which grows outward from its substrate, the other is a relatively flat-growing encrusting species.

This section has established that the published literature supports waterborne dispersal pathways for a number of classes of non-native marine species, and we will now turn our attention to tidal flows.

4. Flow into Marinas

The pontoon floats of marinas, which are usually made of a concrete shell enclosing an expanded polystyrene core, have proved to be a favourable substrate for many native and non-native marine species. Two obvious explanations are that they are sheltered from any strong wave action, and that because they are floating, they do not dry out when the tide falls. They are always (just) sub-tidal.

It is possible to draw the facile conclusion that the non-native species present must initially have been transported there on boat hulls, but boats are not the only possible vectors, especially as the vast majority of boats which are in use, the boats which actually come and go, are effectively anti-fouled.

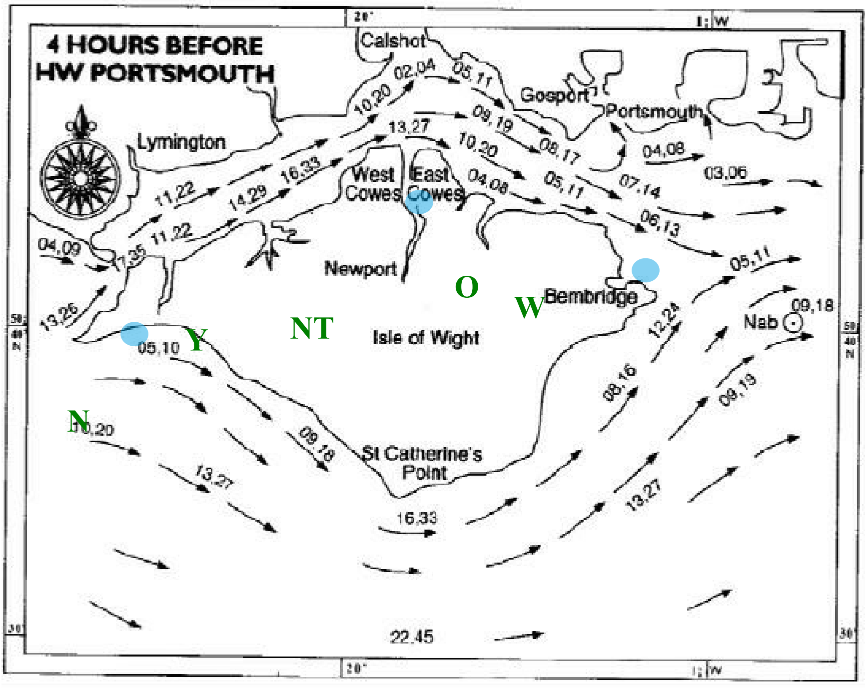
A tidal marina with which the author is familiar has a capacity of about 220 pontoon berths and a surface area of 36,700 m^2, excluding the shallow tidal lagoons which flank it and dry out at each tide. A tidal range of 4.0 m at springs means that at each spring tide more than 150,000 m^3 of water will flow out of the marina through the entrance channel, and more than 150,000 m^3 of different water will flow back in again. At neap tides this volume will be about half, and the mean volume over the tidal cycle will be about 112,500 m^3 per tide, or twice that, 225,000 m^3, or nearly a quarter of a million cubic metres per day. Over the course of a year, which is not a long time-scale in the context of establishing a non-native species, that is 82 million cubic metres, or 373,000 m^3 per boat. There would seem to be scope for waterborne species, even at very low concentrations per cubic metre, to enter the marina in significant numbers.

The marina example given can be considered as enclosed, with the one narrow channel connecting it to the sea or estuary. Some are also enclosed but are entered through lock gates or over a tidal sill, and clearly these will have less interchange of sea water from outside - although some will always occur when water flows in to or out of the lock. Others may be within a larger sheltered harbour, or within a tidal river, such as those on the Rivers Hamble and Medina, and the pontoons and boats may be subjected to an ongoing tidal flow through the marina area, which will give a greater volume of exchange of sea water (through-flow marinas). The last class of marina might be expected to be more exposed to water-borne non-native marine species. In estuary rivers in particular, such as the Hamble, Medina and Dart, the marinas are often close to each other, and the spaces in between may be filled with harbour pontoons, so as to form in effect one very large elongated marina within the river, with the possibility of dispersal of all species, even those with very short larval phases, along its entire length by tidal and river flow.

The scope for tidal transport of marine species into and out of marinas will then vary with the particular circumstances of each marina.. Some examples of enclosed of lock-gated marinas, including some large ones, with unusually low levels of non-native marine species are discussed in section 7 below.

5. Tidal Streams

Shown right is a diagram illustrating the tidal streams flowing round the Isle of Wight. The numbers show the speed of the stream flowing in the direction of the arrow: they are in pairs, the smaller number shows the speed during mean neap tides, the larger during mean springs. The rates can be significant: for example the 33 near West Cowes means 3.3 knots, which is 3.3 nautical miles per hour, or 6 km/hr, or 1.7 m/s.



The progress of a hypothetical floating object caught in the principle tidal streams in the Solent was worked out using data from the tidal stream atlas by Peter Bruce (**13**), a publication widely used by yachtsmen, and giving more detail than the illustrative chart shown.

Starting points, shown as pale blue circles on the above chart, were, left to right, Hurst Narrows, South Brambles buoy, and No Man's Land Fort. Green letters on the chart denote places referred to in the table: N: The Needles, Y: Yarmouth, NT: Newtown, O: Osborne Bay, W: Wooton. The flow rates are for Mean Spring Tides, and the times are in hours relative to High Water Portsmouth. Flow rates (and distances) for neap tides will be approximately half the values in the table, and average values three quarters of the values given in the table below.

Eastbound	W.Solent from Hurst				E.Solent from S. Bramble		
Time	Rate, kts	Total dist, NM	Off of:		Rate, kts	Total dist, NM	Off of:
HW -7 hr	2	2	Yarmouth		0.8	0.8	
HW -6	3	5	Newtown		1.5	2.3	Osborne Bay
HW -5	3	8			1.7	4	
HW -4	2.8	10.2	Cowes		1.5	5.5	
HW -3	2.6	12.8			0.8	6.3	Portsmouth
Westbound	W.Solent from S.Bramble				E.Solent from NML Fort		
Time	Rate, kts	Total dist, NM			Rate, kts	Total dist, NM	
HW -2					0.8	0.8	
HW -1	1.5	1.5			1.1	1.9	
HW	3	4.5	Saltmead		1.6	3.5	Wooton
HW +1	3.3	7.8			2.1	5.6	Osborne Bay
HW +2	3.5	11.3	Hurst		2.2	7.8	Cowes
HW +3	3	14.3	The Needles		2	9.8	

Thus an object floating or immersed in the tidal stream, including marine species, can be transported the length of the West Solent in just four hours. Flow rates are lower in the East Solent, but even so significant distances can be covered in the duration of a tide. The distances are for movement along the main streams of flow, and movement towards the shores will be a more random affair, involving eddies, especially around the turn of tide, and the effects of wind and waves. The dispersal of non-native marine species, many of which have a prolonged viability in the water column as discussed above, by tidal flows throughout the Solent area must be considered a very real possibility, indeed probability.

The flow rates in the Solent are rather unusual in being relatively high close inshore. Rates similar to or greater than the Solent rates occur in the central areas of the English Channel, and near headlands. Closer inshore (within a mile or two of the coast) tidal flows along the coast between Devon and Kent are generally of the order of one knot at Springs, which would give perhaps 3 or 4 miles of travel on a tide.

A study by Perianez (2000) (**14**) has modelled the rate of marine dispersal of radionuclides from the nuclear reprocessing plant on the Cherbourg peninsula and concluded that the transit time for dissolved radionuclides from Cherbourg to the central Dover Strait , about 160 nm or 300 km, was 3 months under average wind conditions. Tidal transport only (no winds) increased the time to 4 months, and under easterly wind conditions the time increased to 7 months, suggesting that wind also plays a significant role. Thus longer distance dispersal of marine species by tide and wind is viable provided that the material concerned has sufficient longevity under pelagic conditions. An example of this has already been given in Section 3.

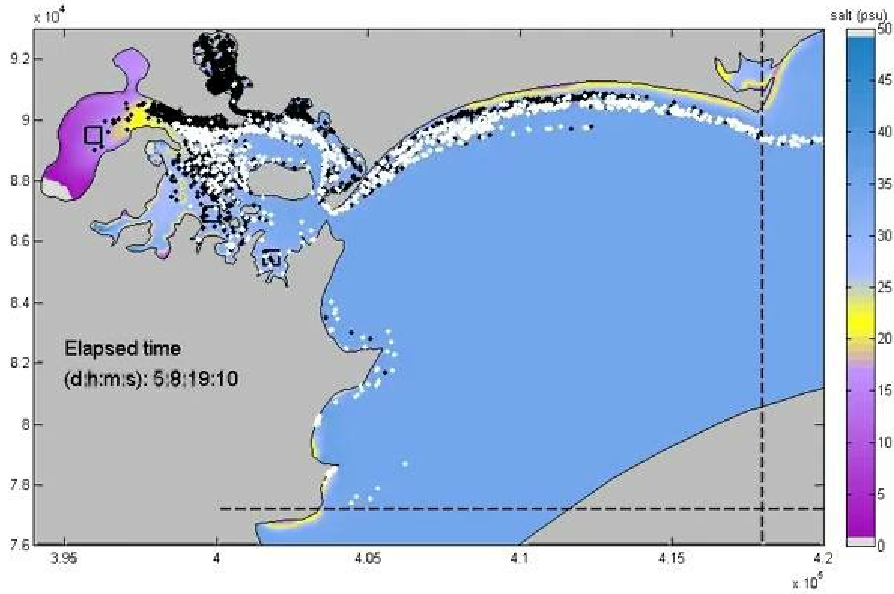
At the wider western end of the English Channel tidal streams are slower, especially inshore, and wind and wave effects from the prevailing southwesterlies stronger, so waterborne westward natural dispersal will be less likely. This may account for the non-arrival of some non-native species in the Isles of Scilly (section 7) and perhaps western Cornwall.

6. A study of the tidal dispersal of Manila clam larvae from Poole Harbour

This study was carried out by the environmental hydraulics consultancy HR Wallingford, who modelled the water flows, and a team from Bournemouth University who studied then behaviour of the larvae. The synopsis on the HR Wallingford website (**15)** is quoted here in part:

"Larvae behaviour studies carried out at Bournemouth University, part-funded by HR Wallingford, indicated that the larvae of the manila clam are able to swim vertically through the water column and that they do so in conjunction with the state of the tide i.e. as the tide comes in they swim up, and as it goes out they swim down. This behaviour allowed them to move through the harbour (rather than stay where placed as was previously believed). We combined our existing hydrodynamic model of Poole Harbour with an ecological model of larval movement to consider whether this new mechanism would result in dispersion of the larvae to Southampton Water. Particles were added to the model and coded with the behavioural characteristics of the clam larvae. The model indicated that the larvae were able to move out of the mouth of Poole Harbour into open water and, once out of the harbour, the prevailing currents and tides eventually swept the larvae to Southampton Water." The modelled timescale for arrival in Southampton Water was reported to be 10 days (D.Jones, pers. Comm.). Full details are given in Herbert et al (2012) (**16**), including a description of the mediation of the larvae's drift behaviour by their response to varying salinities. The modelled drift patterns are graphically shown in a Youtube video at http://www.youtube.com/watch?v=17ezKfP0a34)

A screen capture of the video is shown (right): the larvae are represented by black and white dots, which originated from two different regions in Poole Harbour. The model indicates them breaking out from Poole Bay and into Christchurch Bay towards the end of day 4, from where tidal streams can sweep the larvae into the Solent.and onwards.



The video shows a complex set of tidal flows out of Poole Harbour during different parts of the tidal cycle: during the first four days the flow along the coast is predominantly southward towards Studland Bay and Swanage, then for days 4 - 10 it is predominantly north-eastward towards and past Bournemouth, then from day 10 - 14 it starts to flow southward again. This may be of interest in the context of the dispersal of other species in the tidal flow, for instance sea horses which are found in varying numbers in Studland Bay. (Note: the flow patterns are fascinating: this short 72 second video is well worth viewing).

The foregoing draws attention to possibilities of natural dispersal of marine species through tidal flow mechanisms. We will now turn our attention to some cases where dispersal of non-native marine species did not occur, despite significant recreational boat traffic passing through the area.

7. Cases where the spread of invasive species did not occur

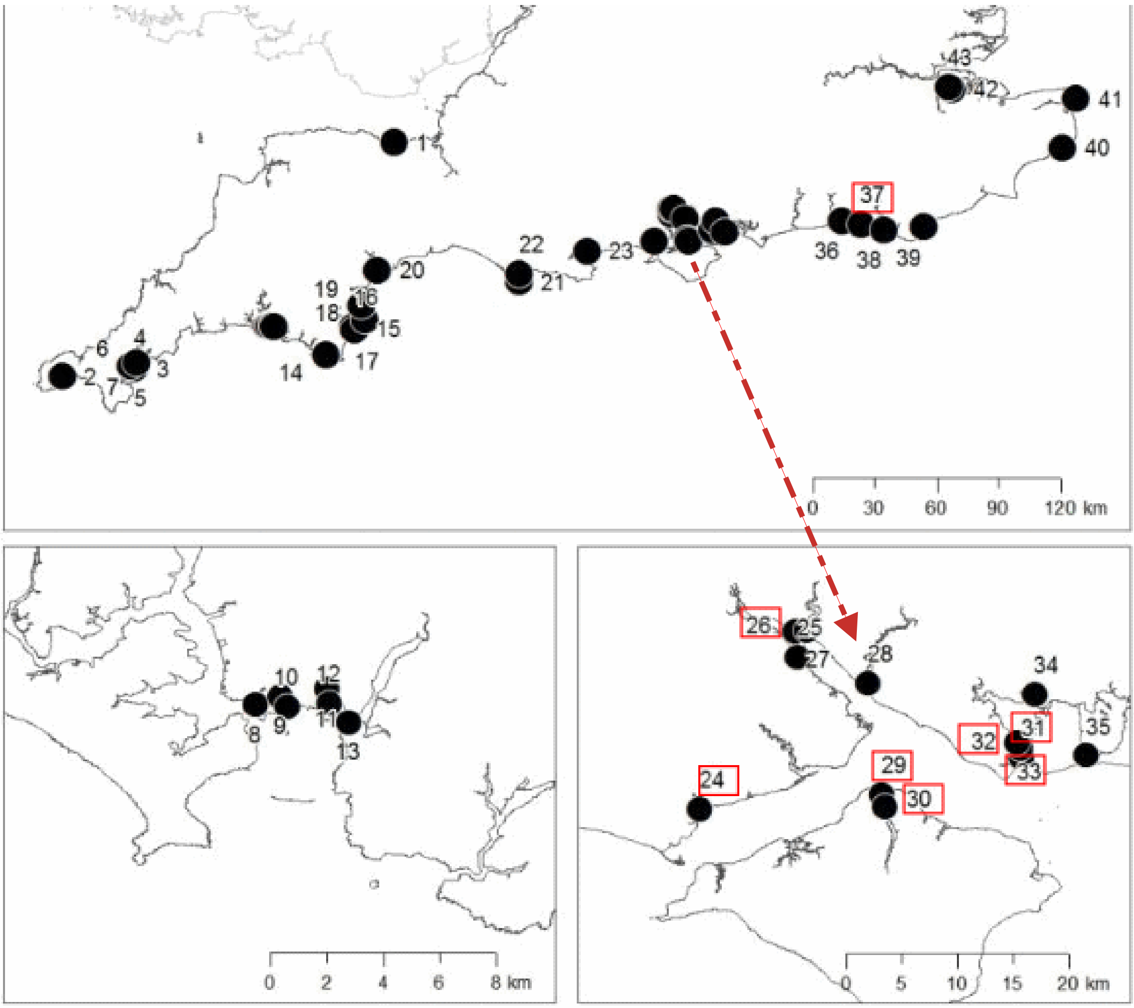
In the course of researching this article, it was noted that in a number of cases, despite significant recreational boat traffic into the area concerned, certain key non-native invasive species had not been found, suggesting that transport by recreational boats is a less effective vector than commonly assumed.

The Carpet Sea Squirt, Didemnum vexillum

The invasive non-native sea squirt *Didemnum vexillum* was found in Holyhead Marina, North Wales, in summer 2008, and a diving survey in winter 2008/09 showed it to be present in much of the Marina, but not in the wider harbour outside the Marina (Holt et al 2009 (**3**)). Efforts to eradicate it were quite successful, but it reappeared after treatments, and was still found to be present in a comprehensive survey of Welsh marinas in summer 2014 (Wood et al (2015) (**17**). However in the same survey, *Didemnum vexillum* was not found to be present in any other Welsh marina, six years after the initial identification at Holyhead. While a number of nearby marinas may not be suitable for sea squirts (ascidians) for reasons of low salinity, the report noted three reasonably close marinas, Port Dinorwic , Victoria Dock and Hafan Pwllheli, which had other ascidians present but not *D. Vexillum,* indicating that boat traffic from Holyhead had not transported *D. Vexillum* to these ascidian-receptive marinas within a period of six years.

Recent information on the distribution of *D. Vexillum* in marinas in southern England is found in a series of surveys conducted in 2013/2014, reported by Wood et al (2015A) (**18**) . Prior to these surveys, *D. Vexillum* had been reported in the Darthaven Marina, River Dart, in 2009 and 2010, possibly as early as 2005, and in a marina in Plymouth in 2008: however the 2013/2014 surveys did not report the species in the marinas in Plymouth or Dartmouth.

The locations of marinas surveyed by Wood et al are shown in the maps below, copied and adapted from their report. The reference numbers of the marinas at which *D. Vexillum* was found have been identified by the present author by red boxes.



On the map, the position of marina 37 corresponds to Brighton Marina, a very large marina with 1600 berths. Large numbers of recreational vessels will leave that marina, many will visit other marinas along the coast, but the carpet sea squirt was not found at the marina to the west (Shoreham), nor at those to the east (Newhaven, Eastbourne, Dover, Ramsgate). The conclusion may be drawn that recreational vessels have not proved to be an effective means of transferring *Didemnum vexillum* from Brighton to those other marinas.

Six marinas in the Solent area were found to contain *D. Vexillum*: from west to east, one in Lymington, one at Hythe (Southampton), two in Cowes and three in Portsmouth Harbour. Southampton is a major cargo and passenger ship port (Hythe being the closest marina to the docks) and Portsmouth is a port for Channel ferries and naval ships: both are plausible entry points for *D. Vexillum* in ballast water or ships' sea chests (recessed areas in the hull behind gratings from which the ship draws sea water). The affected marinas are all within a plausible range for tidal dispersal of *D. Vexillum,* whether as larvae or detached fragments, as discussed above. It was reported to be present in Lymington, Cowes and Gosport in late 2009 (**19**), although anecdotal evidence in the article reported it had already been in Gosport for "some time".

Between them, the affected marinas have approximately 2400 berths, and in total there are some 6000 berths in the area, not counting moorings on piles and buoys. It is the largest concentration of recreational craft in the UK, and large numbers of boats every year voyage westwards along the English coast, as well as across the English Channel towards France. As the boats travel westwards along the coast, many will stop at marinas and harbours on the way. A popular weekend trip for Solent-based boats is to cruise to Poole or to Weymouth or Portland, stay in a marina overnight, and return to the Solent next day.

Yet the survey by Wood et al (2015A) shows none of the 23 marinas in the study which are west of Lymington to contain *D. Vexillum*, nor do there appear to be any other records of *D. Vexillum* ever being observed anywhere in between Lymington and Dartmouth. The conclusion appears inescapable that recreational vessels have so far proved ineffective as dispersal vectors for this particular non-native invasive marine species, over a period of five years.

It also follows that natural dispersal mechanisms for the species have not been effective over distances of greater than several miles.

The Leathery Sea Squirt, Styela clava

Styela clava was first found in Britain in 1953, and is now widespread: it was found in 33 out of the 41 southern England marinas surveyed by Wood et al (2015A). It will tolerate fairly low salinity (Davis et al (2007)) (**9**), down to 22 psu.

Davis et al (2007) surveyed a large number of British harbours for *Styela clava,* and comment:

"We have found *S. Clava* growing on un-maintained boats in harbours; but neither we, nor the boatyards that we have approached, have found *S. clava* attached to the hulls of well maintained small boats. In this respect, it is interesting that we found no specimens of *S. clava* on the Isles of Scilly (south-west UK), yet numerous small pleasure craft sail to the islands from a variety of infested European ports."

The current map for *S. Clava* on the National Biodiversity Network Gateway still shows no presence of the species in the Isles of Scilly. It appears that that recreational vessels have so far proved ineffective as dispersal vectors over medium distances for this second non-native marine species, which has now been present in Britain for over sixty years.

Other species

The survey by Wood et al (2015A) shows that certain marinas, including some large and busy ones, were free of some generally widespread non-native species. We have selected two of the commonest non-native sea squirts (ascidians or tunicates), the leathery sea squirt, *Styela clava,* and the orange-tipped sea squirt, *Corella eumyota*, and two common non-native bryozoans, the widespread tufty-buff bryozoan, *Tricellaria inopinata*, which has a small, bushy habit rather like a small seaweed, and is reported to have been found on propellers and keels, and the red ripple bryozoan, *Watersipora subatra*, which forms flattish encrusting colonies, and is also widespread.

Three or more of these four species were not found in six marinas from 38 surveyed by Wood et al (2015A) (we have excluded from consideration the Somerset and the two northerly Kent marinas: the latter showed low salinity). Details are in the table:

Table showing marinas where species shown were not reported by by Wood et al (2015A):

	Approx.		**Category**	Leathery	OrangeTipped	Tufty Buff	Red Ripple
Code	**Location**	**Berths**	**(TF,Enc,L)**	Sea Squirt	Sea Squirt	Bryozoan	Bryozoan
CORN2	Newlyn	80	Enc	0	0	P	0
DEV13	Exmouth	172	Enc	0	0	0	0
HAMP2	Southampton	? 450	Enc	0	0	0	0
HAMP11	Port Solent	900	L	0	0	0	0
SUSS3	Newhaven	300	Enc (semi)	0	0	0	0
SUSS4	Eastbourne	860	L	0	0		P

Notes: the source document did not specify marina names. The Southampton marina is believed to be on the River Itchen, close to Southampton Water. P signifies species present in the survey, 0 signifies not present, and the blank entry for tufty-buff bryozoan in SUSS4 is described as "not looked for or noticed". Marina categories: as discussed in section 4 above, marinas are categorised as Through-Flow (TF), Enclosed, (Enc.) or behind lock gates (L).

All of these marinas would be expected to have a significant flow of boat traffic. Newlyn only has a limited number of berths for visiting yachts, but it has the biggest fishing fleet in the UK with 608 boats (**20**). Exmouth marina is of modest size, but the others could be considered large or very large. Many boats will leave and enter the marinas every year, but the marinas were found to be free of these key non-native species.

The absence of these species suggests either that they are not being brought into these marinas in sufficient numbers, whether by boats or by tidal flow, or else conditions are not suitable for them to flourish. The most likely unfavourable condition would be low salinity, but as noted above, the leathery sea squirt, *Styela clava*, is tolerant of quite low salinity, down to 22 psu, and Wood et al (2015A) report that at the time of survey, salinities for the above sites were between 30.4 and 35.1, which is within the marine salinity range. It is possible that periods of low salinity could occur if land water drains discharged large amounts of rain water into the marinas, or perhaps with the River Itchen in spate, but sufficient information is not available for meaningful conclusions.

So we simply draw attention to the fact that several busy marinas were found to be free of some otherwise widespread non-native marine species, and suggest that the circumstances of their absence would be well worth investigating to further the understanding of the spread of these species.

8. Summary and Conclusions:

Recreational boats and yachts which are in service are usually substantially free of fouling organisms through use of antifouling paint, reducing the probability of their acting as vectors for non-native marine species.

Marine organisms naturally employ natural dispersal means in their propagation, including water currents and tidal flows, and wind and wave. Some can swim, others float in the water column: seaweeds (algae) can disperse through viable floating vegetative fragments which can travel substantial distances. Some organisms (eg ascidians and bryozoans) have short-lived mobile larval phases before the larvae settle and form the adult phase on a substrate – which may be another marine species. Transport of the larval phase will be limited by the larval lifetime and the speed of water currents which transport them. However the adult phase can sometimes become mobile, in the form of fragments which break off from a settled colony, or by being attached to broken-off pieces of seaweed, or other floating debris, when longer distances may be achieved.

In coastal waters, the twice-daily rise and fall of tides makes water run into and out of marinas, and tidal streams can transport material along the coast. In the case of the West Solent, material can be transported the length of the West Solent, over ten nautical miles, within four hours, although timescales are much longer over longer distances. Modelling studies have shown the feasibility of tidal transport of Manila clam larvae from Poole Harbour to Southampton Water in ten days, or of material from Cherbourg to Dover in three months. The possibilities of dispersal of marine species through tidal effects are real and substantial.

The invasive non-native carpet sea squirt, *Didemnum vexillum*, was found in Holyhead, Marina in Anglesey in 2008. Despite attempts to eradicate it, traces were still present in 2014. However, a comprehensive survey of Welsh marinas in 2014 found no other marina in Wales to contain *D. Vexillum*, although three nearby ones supported another ascidian. Boat traffic from Holyhead had failed to establish *D. Vexillum* in any nearby marina within a period of six years.

A cluster of seven marinas in the Solent area were found to contain *D. Vexillum* in a 2014 survey, three of which were known to contain the species in 2009. The pattern is entirely consistent with tidal dispersal between them. Significantly, marinas west of the Solent, to which tidal dispersal would be less likely, were found to be free of *D. Vexillum* in 2014. These include Poole, Portland and Weymouth, which all receive heavy recreational boat traffic from the Solent region, yet this boat traffic had failed to establish *D. Vexillum* in those marinas, or indeed in any others further west as far as Cornwall. Again, recreational boat traffic had failed to act as a vector for *D. Vexillum* over a period of years.

The very widespread leathery sea squirt, *Styela clava*, present in British waters for 60 years, has still not been found in the Isles of Scilly, despite being a popular destination for British (and French) yachts, suggesting that yachts have failed to provide a transfer vector in that case. Also, certain large marinas having less than full tidal flow are free of key non-native species despite heavy boat traffic, although this could perhaps arise for reasons other than non-dispersal.

In conclusion, there are good reasons to believe that tidal flows can generally give more effective dispersal of invasive marine species than can transport on the hulls of recreational vessels, while there is clear evidence that the invasive carpet sea squirt *Didemnum vexillum* has **not** been spread by recreational vessels beyond its original areas in Anglesey and the Solent over periods of six and five years respectively.

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