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Research Article

Monitoring temporal changes in the early phase of an invasion: *Undaria pinnatifida* (Harvey) Suringar using the abundance and distribution range method

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Abstract

The status of the Asian kelp *Undaria pinnatifida,* was determined using the abundance and distribution range method during a rapid assessment survey. This kelp was first found on the northeast coast of Ireland at Carrickfergus Marina in Belfast Lough, Northern Ireland in 2012. It was not known in Ireland in 2006. *U. pinnatifida* was one of a set of target species searched for during 2012, and initially it occurred at low levels. By 2013 its population had expanded within this marina. In 2014, some tens of individuals were found for the first time over a hundred kilometres to the south in the Republic of Ireland at Carlingford Lough. Both senescent and young plants were found at these sites. In 2015, the kelp appeared at Glenarm Marina 40 km to the north of Carrickfergus; and in the following year, the population had increased marginally. The kelp was not found at a marina on the south side of Belfast Lough, most probably due to fluctuations of salinity. This account discusses the value of the ADR method for evaluating the recent arrival of this large and easily recognised species.

Key words: RAS, marina, exotic species, Ireland, introduction, marine, macroalga

Introduction

Monitoring of invasive species is a requirement under various national and international requirements, such as the Water Framework Directive (2000/60/EC) and the Marine Strategy Framework Directive (2008/56/EC; EC 2010). However, approaches by different member states within the European Union may vary (Boyes and Elliott 2014). There is often an overlap of responsibility within the coastal zone for these different requirements that range from hypersaline lagoons to freshwater. Monitoring of non-indigenous species (NIS) needs to be rapidly undertaken to provide practical results, and should cover sites where NIS may be found including the early stages of an invasion.

Rapid assessment surveys (RAS) for non-indigenous species (NIS) have been undertaken in ports, covering a wide range of habitats (Hewitt et al. 2004). Marinas have also been examined by sampling the floating units of boardwalks (Pedersen et al. 2005; Arenas et al. 2006). These studies involved the examination of a wide range of taxa by several specialists. Surveys targeting easily identified NIS are more efficient, and can service management needs using less field staff and can be undertaken within a short period of time enabling a greater number of localities to be sampled. Targeting a single easily identified species is a more selective approach (Minchin 2012);

and can be undertaken following the finding of an impacting species during general surveys (Minchin and Nunn 2013).

The kelp *Undaria pinnatifida* (Harvey) Suringar 1873 is native to coasts of the northwest Pacific Ocean from southeast Russia, China, Japan and Korea (Saito 1975; Kitayama et al. 1995). It has a heteromorphic life-cycle, alternating between the diploid sporophyte, which is easily recognised and a microscopic haploid gametophyte stage. *U. pinnatifida* has expanded its range worldwide, and was first recognised in Europe in 1971 in the Etang du Thau, on the Mediterranean coast of France (Boudouresque et al. 1984). This species was probably introduced as the gametophyte stage with consignments of the Pacific oyster *Crassostrea gigas* (Thunberg, 1793) arriving from Japan (Floc'h et al. 1991). It then appeared in the Venice Lagoon in the northern Adriatic Sea in 1992 (Curiel et al. 1998), and from southern Italy to Taranto in 1998 (Cecere et al. 2000). The kelp was cultivated at sites along the west coast of France in the 1980s and 1990s (Pérez et al. 1984; Castric-Fey et al. 1996), having been introduced for this purpose from the Etang du Thau. It was in cultivation in Spain at Santander in 2000 (Peteiro 2008) and in Galicia (Peteiro and Freire 2011). It then appeared at other sites in northern Spain (Santiago Caamaño et al. 1990; Cremades et al. 2006) and in 2008 was found in Portugal (MACOI 2008). The kelp also spread northwards to Calais in northern France in 1997, to Zeebrugge, Belgium in 1999 (Leliaert et al. 2000); and in the same year to Yerseke in The Netherlands (Stegenga 1999).

In June 1994 it was found in the Hamble, Southampton Water, on the south coast of Britain (Fletcher and Manfredi 1995), spreading to Torquay on the southwest coast by 1996 (Fletcher and Farrell 1999). Since then, this kelp has spread to form isolated populations occurring as far north as the Humber Estuary in the North Sea and on the west coast of Britain to the Wyre Estuary and to the Isle of Man (NBN Gateway 2013).

In 2012, three individual sporophyte stage individuals were found in Carrickfergus Marina, Belfast Lough, in Northern Ireland during a coastal monitoring study (Minchin and Nunn 2013). In 2014, the kelp was found almost over a hundred km to the south at the Carlingford Marina in the Republic of Ireland, and in 2015 it appeared 40 km northwards at the Glenarm Marina.

The Abundance and Distribution Range (ADR) is based on part of the biopollution assessment method (Olenin et al. 2007). This approach has been used to evaluate the relative impact of a single species over a wide area (Olenina et al. 2010) or for many species (Zaiko et al. 2011). Sessile biota are often first recorded on marina pontoons, as these are readily accessed at all tidal stages using a small amount of equipment providing cost-effective monitoring for sessile biota (Ashton et al. 2006; Minchin 2007, 2012). The evaluation of the ADR at a site provides some indication of the impact of a target species. While the measurement of impact itself may take a considerable time to evaluate, the ADR can be undertaken over a short period of time and provides a practical monitoring approach which has been used previously in assessments of freshwater invasive bivalves (Minchin and White 2014; Zaiko et al. 2014; Minchin 2014), coastal marinas (Minchin and Nunn 2013; Marchini et al. 2015), lagoons (Wittfoth and Zettler 2013) and ports (Minchin et al. 2016).

The method requires the assessment of the size of the study area, which in this investigation is an individual marina for a specific time periods.

Here we examine the usage of the Abundance and Distribution Range (ADR) for the early invasion stages of *U. pinnatifida* at three marinas on the island of Ireland and examine the usefulness of this method in evaluating its early appearance and expansion.

Methods

The method requires the assessment of the size of each study area; here this an individual marina and for a specific time period, August September in each year surveyed. The assessment is based on the abundance associated with the number of individual floating pontoons (used to support a boardwalk) that are infested. Abundance can be *"low"* where the target species makes up only a small part of a community (in this case up to two sporophytes on a pontoon side), *"moderate"* where it is frequent but less than half of the abundance of the native community and *"high"* should it exceed half of the overall abundance and dominates. The distribution scales for each assessment unit range from *"local"*, where it occurs at one pontoon, *"several localities"* where it is present in less than half of the pontoons selected, "*many localities"* where it is found in more than half of the pontoons selected, and *"all localities"* where it occurs on all studied pontoons. Combinations of abundance and distribution provide a scale that ranges from *"A"* few individuals on one pontoon, to *"E"* where a species occurs in high numbers on all pontoons (Table 1).

One, or more, of four marinas, Glenarm (54º58.15′N; 05º57.04′W), Carrickfergus (54º42.59′N; 05º48.66′W), Bangor (54°39.86′N; 05°40.19′W) and Carlingford (54º03.10′N; 06º11.47′W) on the northern Irish coast were sampled in August/September 2006, 2012, 2014,

Table 1. ADR classes of abundance and distribution according to Olenin (2007).

	DISTRIBUTION SCALE			
ABUNDANCE	One locality	Several localities	Many localities	All localities
Low	A	A	B	C
Medium	B	B	C	D
High	B	C	D	E

Table 2. ADR levels for September 2014 for *U. pinnatifida.* Numbers indicate the sites where sporophytes were found.

	Carlingford	Carlingford +	Bangor	Carrickfergus
Low	1	4	0	8
Moderate	0	4	0	17
High	0	0	0	0
Pontoons sampled	30	45	30	30
ADR level	A	B	--	C

2015 and 2016. These marinas have berths for 280, 500, 40 and 300 craft respectively.

Up to five samples were obtained from the immersed surface along one side of each of the selected pontoons using a 15cm wide scraper and pocket net attached to an extendable pole, as well as by direct observation. Thirty or more pontoons were sampled, distributed throughout the entire marina and were selected semi-randomly. Pontoon surfaces devoid of kelps were avoided, as some of these had been recently cleaned. Following the observation of *U. pinnatifida* at a single pontoon float, a more complete study of the pontoons close to the find took place at Carlingford Marina involving a further fifteen stations.

During September 2014, sporophytes sampled in Carlingford and Carrickfergus marina pontoons were measured for their overall length of the sporophyte and for the length of the sporophyll. Some specimens were removed from boat hulls.

Water temperatures were measured using an oceanographic reversing thermometer accurate to 0.1 °C at a depth of 0.3 m. Salinities were determined using a refractometer with an accuracy of ± 1. Sampling equipment was disinfected between sites using an iodine preparation (*Iosan® CCT*: Ciba Geigy Agro Ltd, Waterford, Ireland).

Results

Water temperatures ranged from 15.3 °C at Carrickfergus to 15.9 °C at Carlingford during 2012. No *U. pinnatifida* were found at Bangor Marina which is subject to storm water inflow. At the time of study, surface salinities here ranged from 19 to 34 psu. All other sites had salinities of ~34 psu.

Three sporophytes of *U. pinnatifida* with sporophylls were observed from Carrickfergus Marina in 2012 to provide an ADR level "A". This marina was re-visited in the following year on 29 August, and many small sporophytes were seen near the surface attached to pontoon floats to provide a level "C". In 2014, many sporophytes were recorded to provide the same level "C" (Table 2). Specimens collected at this site varied in size, with many small individuals and several senescent sporophytes (Figure 1). Four sporophytes were removed from a yacht and two cruisers (Figure 2). In 2015, *U. pinnatifida* was found on all pontoons except for one sampled site furthest away from the entrance to give a value of "D".

At the Carlingford Marina in 2014, a senescent and two young plants were found on a single pontoon close to the sea-entrance from a total of 30 pontoons sampled throughout the marina. This gave an ADR of level "A" (Table 2, Carlingford). A further fifteen pontoon surfaces were then examined in the adjacent area to the original find. *U. pinnatifida* was present on seven of these sites. This provided an overall ADR for the 45 samples at the level "B" (Table 2, Carlingford +). During further visit on 9 June 2015, it was observed that *U. pinnatifida* had spread throughout the marina (hundreds of individuals). On many pontoons, it had formed thick clusters and appeared to be the dominant species present (even on some pontoons far from the entrance site where it was originally found in 2014). Many of the individuals were in a reproductive state with some more than a metre in length, with the largest being near the entrance where there was water movement. An ADR of "C" was determined.

No *U. pinnatifida* were found at Glenarm Marina during 2012, and the Marina was not visited in 2013 or 2014. However, on 18 September 2015, 20 sporophytes were found in the central region of pontoons supporting the landward boardwalk, and during 2016 there were 37 sporophytes located over a wider area;

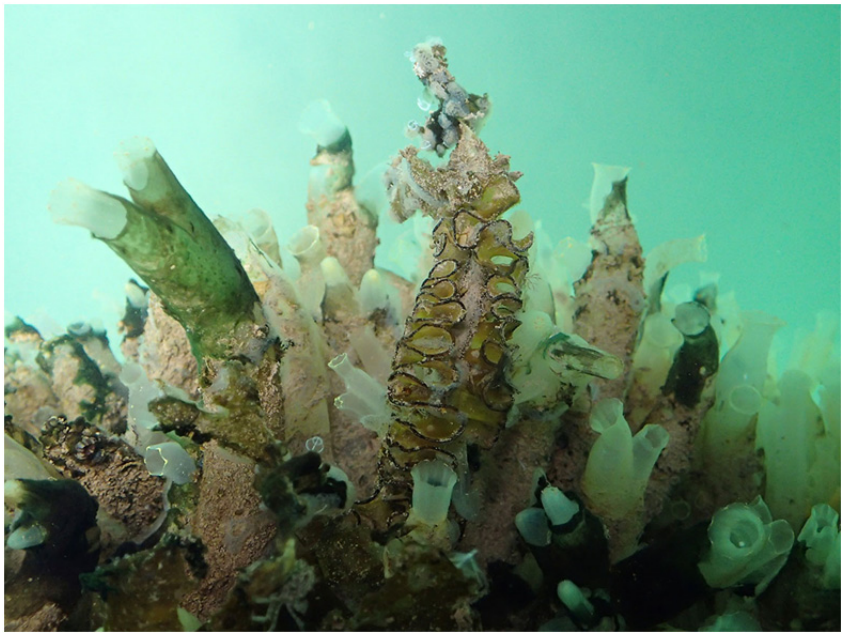

Figure 1. Senescent plant showing sporophyll (centre) attached to pontoon surface together with the tunicate *Ciona intestinalis* at Carrickfergus Marina, 3 September 2014 (Credit D. Minchin).

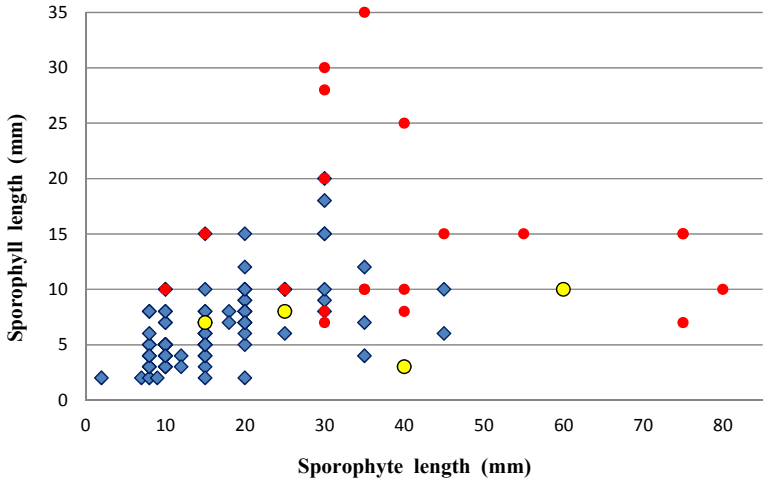

Figure 2. Relative sizes of sporophyll to total plant length; blue from Carrickfergus pontoons, red from Carlingford pontoons and yellow from boat hulls at the Carrickfergus Marina in September 2014.

but not found within the most sheltered regions, nor attached to the hulls of any leisure craft (Figure 3). This gave an ADR of level "B" for both years (Table 3).

Discussion

There is a need for a consistent approach for both the methodology and management for monitoring for selected species. Such monitoring needs to be cost-effective, rapid and practical, and frequent with the ability to report directly new information on species of concern. In this study, the sampling of thirty stations provided an early indication of the arrival of *U. pinnatifida* in the north of Ireland. However, since such sampling does not necessarily provide complete coverage, the finding of a target species at one station may require further study of the locality close to the single observation. Indeed it is possible that target species soon after an arrival may be entirely missed. Marine species are not always readily recognised when they first appear, when not specifically searched for, due to a general similarity with other native species; in this case the kelps *Saccharina latissima* together with the less frequent *Laminaria digitata* and *Alaria esculenta.* These also attach to pontoon floats, and may obscure the presence of *U. pinnatifida*. As a result, when sampling, the removal and examination of all kelps

Table 3. ADR levels for five separate years. "0" refers to no sporophytes being found.

Locality	2006	2012	2013	2014	2015	2016
Carlingford Marina	0	0	0	B	C	Not sampled
Bangor Marina	0	0	0	0	Not sampled	Not sampled
Carrickfergus Marina	0	A	C	C	D	Not sampled
Glenarm Marina	0	0	Not sampled	Not sampled	B	B

Figure 3. *Undaria pinnatifida* sporophytes growing from the lowest point of the pontoon surface at Glenarm Marina, 18 September 2015 (Credit H. Edwards).

should be undertaken. The number of pontoons surveyed should be practical for general monitoring purposes, as thirty stations may require approximately four hours of sampling. In the case of the Carlingford Marina, the ADR based on thirty samples was level "A", but following an increase in the number of sampling stations, close to where the single find took place near the entrance to the marina breakwater, an ADR of "B" was obtained. Clearly a single find requires a more thorough search. Species found and recorded at ADR levels of "C" or greater most probably reflect a real result, as in the case of a study of a large bryozoan (Minchin 2012).

We first recorded the presence of *U. pinnatifida* at Carrickfergus Marina, with the subsequent appearance in the following years in Carlingford Marina and Glenarm Marina. This indicates that the seminal site of its invasion may be Carrickfergus Marina.

At Carrickfergus Marina, situated on the north side of Belfast Lough, *U. pinnatifida* was present at most of the sampled pontoons in 2015 which included the most sheltered regions, where there were small sporophytes. The specimens removed from the hulls of craft in the more sheltered region were more complete plants. This ability to foul vessels (Hay 1990) may depend upon the age, type, and condition of the antifouling on the vessels and the presence of untreated hull surfaces (Campbell and Hewitt 2013). Should antifouling paint be applied and maintained, it can be effective in reducing *U. pinnatifida* settlements (Burridge and Gorski 1997). The gametophyte stage readily settles on rope, and the movement of infected ropes and cage netting may also be a vector responsible for further range expansion.

The occurrence of senescent *U. pinnatifida* which had lost most of their lamina, at Carlingford Marina in 2014 suggests it may have been present in 2013, but was probably absent in 2006 and 2012 (Table 3). Furthermore the size of the sporophyll clearly indicated the plants were capable of reproducing,

even those attached to leisure craft hulls (Figure 2). Recruitment during 2014 was indicated by the larger complete sporophytes to 75 cm in length with few attached epibiota. Recruitment success may depend upon the cover of other biota attached to each floating pontoon because suspension feeders might remove kelp propagules. *U. pinnatifida* also competes with the native kelps for space with different settlement periods (Valentine and Johnson 2003). *U. pinnatifida* can persist within native species assemblages and, when the community is disturbed, can become a dominant species (Forrest and Taylor 2002; Valentine and Johnson 2003).

Undaria pinnatifida was absent from Glenarm Marina in 2012, but was found there in 2015. It was only observed around the middle of the large sheltered landward pontoon where there was good water clarity, relatively deep water and a current flow. None were present in either the more exposed areas, or those subject to high turbidity with a community dominated by the green alga *Ulva* sp. By September 2016, *U. pinnatifida* was present at half of the sites in low to moderate levels of abundance. The pontoons were regularly cleaned by scraping the pontoon sides in 2015 and again in April/May 2016 but not subsequently. The sporophylls found in September 2016 were of small plants ~30cms in overall length. The cleaning may have had some effect in reducing what might have otherwise been an expected increase in their abundance. Although the number of plants since 2015 had increased, this was not reflected in the method used to evaluate an ADR. Removal of sporophytes in a marine reserve in Tasmania did not result in a decline of plants even after regular removal over a two and half year period (Hewitt et al. 2005). Most probably this was due to a continued presence of the inconspicuous life-history stages of this plant.

The absence of *U. pinnatifida* at Bangor Marina on the south side of Belfast Lough, is probably due to freshwater discharges, although it can endure occasional exposure to levels of 27 psu (Santiago Caamaña et al. 1990), or perhaps 23 psu (Wallentinus 2007). Since the floating pontoons do not become immersed to depths of more than ~ 40 cm from the surface, the freshwater run-off from storm drains is likely to suppress establishment at some marina sites, as may have been the case at Bangor Marina. This is because salinities of 19 psu were obtained at the Bangor Marina despite several rain free days preceding the 2014 survey. Discharges are weather event dependent, and the biota on pontoons at this marina will have varied in concert with seasonal amounts of rainfall and rainfall events in the past (J. Nunn pers. ob.).

In Britain, sporophytes were found mainly during the spring and summer and occurred most frequently at marina sites (Minchin and Nunn 2014). *Undaria pinnatifida* is known to be capable of tolerating a range of exposure levels from different levels of shelter within marinas to moderately exposed coastal areas (Sanderson 1997). The number of new records on the coast of Britain has increased since the species was first recorded in 1994 by Fletcher and Manfredi (1995) (NBN Gateway 2013). The preponderance of *U. pinnatifida* at marina sites strongly implicates recreational craft in its spread. In Carrickfergus Marina, we found specimens attached to boat hulls. Indeed, elsewhere at one marina site in New Zealand, almost a quarter of the berthed leisure craft were fouled with sporophytes (Floerl et al. 2005). The high frequency of records in Britain from marina sites is consistent with observations in Europe and elsewhere. While several vectors may be responsible for this kelp's distribution, leisure craft dispersal can be classified as being very likely (Minchin 2007). Small sporophytes, or sporophytes with a remnant sporophyll, may be able to colonise, as may the smaller gametophyte stage. The highly localised occurrence of *U. pinnatifida* at Carlingford and Glenarm Marinas may result from being imported on the hull of a relatively recent visiting leisure craft. *U. pinnatifida* spores are thought to be naturally capable of spreading over tens to hundreds of metres (Forrest et al. 2000). These spores, confined under the sheltered conditions of a marina site, could lead to highly localised occurrences. Recreational craft within the studied marinas undertake visits to the west coast of Scotland; consequently this species may be expected to appear at marinas there over the coming years and to areas further to the north (James et al. 2015). It is recognised as being a target species for this region, while not having been recorded in this region to 2016 (Cook et al. 2015). The species is tolerant of seawater temperatures ranging between 2–27°C (Akiyama and Kurogi 1982) but freshwater discharges may restrict its distribution.

Conclusion

The ADR is a useful method for evaluating the status of *U. pinnatifida*. The method provides for five different levels and once established provides a method for examining temporal changes in a rapid and consistent way. However, at an early invasion stage, small numbers of specimens could be missed. If a target species is found at a single site, an immediate follow-up study should take place in order to obtain a more reliable result.

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