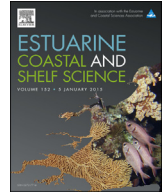




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The invasive barnacle species, *Austrominius modestus*: Its status and competition with indigenous barnacles on the Isle of Cumbrae, Scotland



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ABSTRACT

The invasive barnacle *Austrominius* (= *Elminius*) *modestus* has been present in Europe since the 1940s, and has recently been recorded to outnumber native barnacle species at some locations, including an Irish marine nature reserve. It has been suggested that these increases in abundance following a lag phase since establishment, represent the awakening of an 'ecological sleeper', due to changes in environmental conditions. *Austrominius modestus* was first recorded on the Isle of Cumbrae, Scotland in 1955, and was reported to be well established on the island by 2007. Since this location is close to the northern limit of the invaded range of *A. modestus*, it has been chosen as a site for the long term monitoring of this species. Quantitative and semi-quantitative surveys of the abundance of *A. modestus*, together with the native barnacle species *Chthamalus montagui* and *Semibalanus balanoides*, have been made on the island on a biannual basis since 2009. This study examined changes in the abundances of these three species from 2009 to 2013, and reports on the present status of this invasive species on the island. *Austrominius modestus* was found at all sites surveyed, but did not outnumber native barnacle species at any site. *Semibalanus balanoides*, a cold water boreal species, was the most abundant barnacle species at most sites from 2009 to 2013. All three barnacle species underwent a decline in 2011, but had increased in abundance by 2013. Despite undergoing the smallest increase in abundance between 2011 and 2013, *S. balanoides* remains the dominant barnacle species on the Isle of Cumbrae. Nearly sixty years after its initial discovery on the island, *A. modestus* is widespread, however it has not outnumbered native species, which continue to recruit at high densities. This competitive pressure makes it unlikely that *A. modestus* will outnumber native barnacle species at this location, close to its northern limit, in the near future.

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1. Introduction

The invasive barnacle *Austrominius* (= *Elminius*) *modestus* (Darwin, 1854) is native to subtropical and temperate coasts of Australasia (Moore, 1944). This species was accidentally introduced to the UK (at Chichester Harbour; 50°47'N, 0°57'W) around 1943 (Bishop, 1947; Stubbings, 1950). It is now widespread in European

waters (Crisp, 1958; Crisp and Southward, 1959; Lawson et al., 2004; Allen et al., 2006; Gomes-Filho et al., 2010), present on sheltered shores in the Atlantic, North Sea and Western Mediterranean (Witte et al., 2010; O'Riordan and Ramsay, 2013) and has been described as a 'naturalised' member of European intertidal habitats (Tøttrup et al., 2010).

The establishment of non-native species in new ranges has become a common occurrence, due to the widespread availability of anthropogenic vectors such as shipping and aquaculture (Bax et al., 2003; Witte et al., 2010). While introduced species have been found to coexist with native species (Buschbaum et al., 2006; Sax and Gaines, 2008; Heard and Sax, 2013) and even contribute to

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an increase in biodiversity at some locations (Mooney and Cleland, 2001; Sax and Gaines, 2008), these non-native species are more often associated with a reduction in biodiversity, which can produce changes in ecosystem structure and functioning (Baird et al., 2012; Bracewell et al., 2012). Some non-native species exhibit a 'lag phase' during which they persist within their invaded range, but do not become abundant until there has been a favourable environmental change which promotes their abundance over native species (Bax et al., 2003; Witte et al., 2010). One such environmental change is increasing temperatures, which promote invasive species originating from warmer climates (Occhipinti-Ambrogi, 2007; Reise and van Beusekom, 2008). Witte et al. (2010) suggested that there are non-native 'sleepers' present in cold temperate waters. It is believed that *Austrominius modestus* is such a 'sleeper' (Witte et al., 2010) as, despite being present in Europe since the 1940s, increases in abundance of *A. modestus* at a number of locations within its invasive range have only been recorded relatively recently (Franke and Gutow, 2004; Reichert and Buchholz, 2006; Herbert et al., 2007; O'Riordan et al., 2009; Witte et al., 2010), including Lough Hyne Marine Nature Reserve, Ireland (51°30'N, 9°18'W) where it now dominates much of the lough intertidal area (Lawson et al., 2004).

In its native range *Austrominius modestus* is capable of growing on most substrata and is a common fouling organism in harbours and estuaries, generally inhabiting the upper intertidal zone (Moore, 1944). Within its invaded range, *A. modestus* has been recorded at various shore heights, and has been found to be abundant in the mid-low tidal regions at some sites (Bracewell et al., 2012). *A. modestus* apparently occupies a similar niche to the native barnacles *Semibalanus balanoides* and *Chthamalus montagui* (Bracewell et al., 2012). However, as summarized by Harms (1999), this species displays a number of traits which contribute to its invasion success including eurythermal and euryhaline larval and adult stages and high cirral rates to effectively utilize food. *A. modestus* is also highly fecund with a short generation time (Crisp and Davies, 1955) and is capable of reproducing throughout the year (O'Riordan and Murphy, 2000) as opposed to the more discrete breeding seasons shown by native species (Rainbow, 1984; Burrows et al., 1992; Anderson, 1994). It is believed that these factors (Gomes-Filho et al., 2010), together with climatic changes (Witte et al., 2010), have contributed to the recent increase in abundance of *A. modestus* within its invaded range in North West Europe.

Austrominius modestus was first found on the Isle of Cumbrae, Clyde Sea (55°46'N, 4°55'W) in 1955, when a single specimen was recorded by Connell (1955). Despite becoming widespread in the UK, *A. modestus* was not recorded on the Isle of Cumbrae again until 1959, even though surveys were carried out in the intervening years (Powell, 1960). Thereafter it was generally regarded as a rare member of the island's intertidal fauna (J. Atkinson, University Marine Biological Station, Millport, pers. comm.). However, by 2007 *A. modestus* was recorded to be widespread on the island (O'Riordan et al., 2009).

The lag phase exhibited by *Austrominius modestus* within its invaded range has resulted in a paucity of information regarding the impacts of this species on native communities. The Isle of Cumbrae is located close the current northern limit of *A. modestus* within its European invaded range. Given recent increases in the abundance of this species, and predictions for increases in global sea surface temperatures, an understanding of the interactions between this invasive warm water species and native species is required. This study provides an overview of the changes in abundance of *A. modestus* and two native barnacle species, towards the northern limit of the invasive range of *A. modestus*, from 2007 to 2013.

Table 1

Name, location and exposure of thirteen sites surveyed on the Isle of Cumbrae, Scotland in 2009, 2011 and 2013. Site numbers are used in Figs. 1 and 2. Sites marked with an asterisk (*) are replicate sites.

Site number	Site name	Latitude, longitude (GPS)
1*	White Bay	55°47.50'N 4°54.88'W
2	Ferry Slipway	55°47.91'N 4°53.90'W
3	Watersports slip (North)	55°46.58'N 4°53.55'W
4	Watersports slip (South)	55°46.58'N 4°53.55'W
5*	Butter Lump	55°45.55'N 4°56.42'W
6	Farland Bight	55°44.44'N 4°54.41'W
7*	Farland Point	55°47.05'N 4°54.84'W
8	Kames Bay	55°42.01'N 4°55.00'W
9*	Millport Harbour Wall	55°45.08'N 4°55.95'W
10	West Bay	55°44.95'N 4°56.10'W
11	Sherriff's Point	55°45.16'N 4°57.02'W
12*	Fintray Bay	55°45.60'N 4°56.42'W
13	Skate Point	55°47.05'N 4°55.39'W

2. Materials and methods

Surveys of the abundance (semi-quantitative) of the invasive barnacle species *Austrominius modestus* were carried out at thirteen sites, representing a range of exposure levels (Table 1) around the perimeter of the Isle of Cumbrae, Scotland (Fig. 1), biannually from 2007 to 2013. The exposure level of each shore had previously been estimated using the Ballantine scale (Ballantine, 1961). Surveys from 2009 onwards also recorded the abundance of two other barnacle species, *Semibalanus balanoides* and *Chthamalus montagui*. In 2009, 2011 and 2013 quantitative surveys were also carried out. Five replicate sites, representative of the various exposure and habitat types on the island, were established on the island in 2011 (Table 1), in order to allow for a standardized comparison of species abundance in future monitoring.

2.1. Quantitative surveys

In March 2009, a single line transect was carried out at the survey sites. The start point of each transect was taken as the point on the shore where barnacles first appeared and transects ended at the low tide mark. In the case of piers and slipways, transects were

Table 2

Abundance of *Austrominius modestus* (AM), *Chthamalus montagui* (CM) and *Semibalanus balanoides* (SB) at thirteen survey sites on the Isle of Cumbrae, Scotland in 2009, 2011 and 2013. Sites are ranked in order of increasing exposure, which was measured using the Ballantine scale (Ballantine, 1961). Abundance estimates were made using the SACFOR scale as described in O'Riordan et al. (2009). S = Super-abundant, A = Abundant, C = Common, F = Frequent, O = Occasional, R = Rare and N = None. N/A indicates that the site was not surveyed in that year.

Site	Exposure	2009			2011			2013		
		AM	CM	SB	AM	CM	SB	AM	CM	SB
White Bay	Very sheltered	C	A	A	F	F	C	O	F	A
Watersports slip (North)	Sheltered	A	A	A	C	O	C	F	R	A
Watersports slip (South)	Fairly sheltered	N/A	N/A	N/A	C	F	C	C	O	A
Ferry Slipway	Semi exposed	F	A	A	F	C	C	F	F	A
Butter Lump	Semi exposed	C	C	S	F	O	C	C	F	A
Farland Bight	Semi exposed	C	S	S	C	C	C	F	C	A
Kames Bay	Semi exposed	N/A	N/A	N/A	F	C	C	F	C	A
Millport Harbour Wall	Semi exposed	C	A	S	F	C	C	C	C	C
Fintray Bay	Semi exposed	A	N	S	F	O	C	O	F	C
Skate Point	Semi exposed	R	C	S	O	C	C	O	F	A
West Bay	Exposed	C	C	A	O	F	C	O	F	C
Sherriff's Point	Exposed	C	A	S	F	F	C	F	A	A
Farland Point	Very exposed	C	S	S	F	C	C	F	A	A

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