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Artificial coastal lagoons at solar salt-working sites: A network of habitats for specialised, protected and alien biodiversity

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ABSTRACT

There are concerns that novel structures might displace protected species, facilitate the spread of non-indigenous species, or modify native habitats. It is also predicted that ocean warming and the associated effects of climate change will significantly increase biodiversity loss within coastal regions. Resilience is to a large extent influenced by the magnitude of dispersal and level of connectivity within and between populations. Therefore it is important to investigate the distribution and ecological significance of novel and artificial habitats, the presence of protected and alien species and potential vectors of propagule dispersal. The legacy of solar salt-making in tropical and warm temperate regions is regionally extensive areas of artificial hypersaline ponds, canals and ditches. Yet the broad-scale contribution of salt-working to a network of benthic biodiversity has not been fully established. Artisanal, abandoned and historic salt-working sites were investigated along the Atlantic coast of Europe between southern England (50°N) and Andalucía, Spain (36°N). Natural lagoons are scarce along this macrotidal coast and are vulnerable to environmental change; however it is suspected that avian propagule dispersal is important in maintaining population connectivity. During bird migration periods, benthic cores were collected for infauna from 70 waterbodies across 21 salt-working sites in 5 coastal regions. Bird ringing data were used to investigate potential avian connectivity between locations. Lagoonal specialist species, some of international conservation importance, were recorded across all regions in the storage reservoirs and evaporation ponds of continental salinas, yet few non-indigenous species were observed. Potential avian propagule transport and connectivity within and between extant salt-working sites is high and these artificial habitats are likely to contribute significantly to a network of coastal lagoon biodiversity in Europe.

1. Introduction

It is predicted that ocean warming and the associated effects of climate change will significantly increase biodiversity loss within coastal regions (Hawkins, 2012, 2016). Transitional waters, which include estuaries, rias and lagoons, are highly productive and extremely important ecosystems that support a wide range of vital services (Munari and Mistri, 2008; Basset et al., 2013). Resilience to biodiversity loss is, to a large extent, influenced by the magnitude of dispersal and level of connectivity within and between populations. Yet transitional waters are relatively closed environments and therefore particularly vulnerable and exposed to environmental change. Associated with the development of coastal regions is the creation of novel structures and artificial habitats that become colonised by species assemblages that can differ with native populations. Interactions between native and artificial habitats in coastal regions and their potential contribution to species population resilience are poorly understood and mostly consider hard structures communities (Airoldi and Beck, 2007; Bulleri and Airoldi, 2005; Airoldi et al., 2009; Mineur et al., 2012; Herbert

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et al., 2017). Here we consider the importance of soft-sediment benthic communities within artificial lagoons at salt-working sites along the Atlantic European seaboard and whether they contain species of biodiversity importance and contribute to a network of Coastal lagoon habitat.

1.1. Coastal lagoons

Coastal lagoons are important features and habitats within transitional water ecosystems where connectivity is particularly constrained. They have been defined as ‘shallow bodies of enclosed, brackish or salt water separated from an adjacent coastal sea by a barrier of sedimentary material’ (Barnes, 1980, 1989a), and artificial coastal lagoons also occur (Bamber et al., 1992). Globally, lagoons comprise 13% of the coastline, yet only 5% of the European coast is lagoonal, the smallest proportion of any continent (Cromwell, 1971: Barnes, 2000). In the Mediterranean region lagoons are relatively numerous and of significant area (Chauvet, 1988; Tagliapietra and Volpi Ghirardini, 2006; Zaldivar et al., 2006). However, in macro-tidal regions, such as the North-east Atlantic, natural lagoons are unusual and particularly restricted in distribution (Barnes, 1980, 1989a, 1995). In a changing climate, coastal lagoons may experience significant variation in rainfall, temperature and fluctuations in sea level that could change the salinity and thermal regime of the habitat. The rate of colonisation and establishment of populations at new and potentially distant habitat will be very low as water exchange between lagoons and with the open sea can be infrequent (Ghezzo et al., 2015) and propagule dispersal distance in the water column is small. Establishing mechanisms of connectivity between lagoonal habitats is a conservation priority (Barnes, 1988) and for isolated habitat generally has been an enduring problem in biogeography (MacArthur and Wilson, 1967; Lomolino, 2000; Nolby et al., 2015).

There is variation in the degree of specialisation to transitional waters, with euryhaline and eurythermal species being adapted to cope with a wide range of salinity and temperature, respectively. Yet with increasing specialisation and adaptation to a narrower range of abiotic conditions, such as those that can be experienced within lagoonal habitats, there is an increasing risk of population decline and extinction. There has been much debate about the existence of specialisation and diversity within transitional and brackish waters (Remane, 1934, 1940; Barnes, 1989a,b, Bamber et al., 1992; Barnes, 1994; Cognetti and Maltagliati, 2000; Telesh et al., 2011); however for coastal lagoons of the British Isles, Barnes (1989b) recognised the presence of 38 specialist lagoonal species i.e. species more characteristic of lagoon-like habitats than of freshwater, estuarine brackish waters or the sea. These comprise a wide range of invertebrate groups, including insects, algae and plants belonging to the charophyceae. In a survey of 166 British coastal lagoons, Bamber et al. (1992) found that lagoons showed greater environmental variability than estuarine waters and the open sea and identified six suites of species that included euryhaline lagoonal specialists, and stenohaline marine lagoonal specialists common in southern Britain. Invertebrate and plant lagoonal specialists differ from estuarine species in their adaptation to the stresses associated with reduced tidal exchange, including hypoxia, thermal and pH stratification, and more extreme temporal variation in temperature and salinity. Tolerance to these conditions ensures their survival in these habitats where competition and predation from marine and estuarine species is reduced (Bamber et al., 1992).

In the United Kingdom and Ireland, sites containing stenohaline marine lagoonal specialist species are particularly scarce and given high conservation status (Barnes, 1989a; Bamber et al., 1992 Gilliland and Sanderson, 2000; Joyce et al., 2005; Beer and Joyce, 2013; JNCC, 2015). As these sites are vulnerable to being lost as a result of coastal development and climatic changes there is an imperative to establish mechanisms of dispersal of lagoonal specialists and the distribution of potential habitat to ensure adequate population connectivity. Many of these lagoonal species may have found refugia in southern Europe and the Mediterranean basin during the last glacial period (Barnes, 1994). Literature searches of the distribution of six ‘specialised’ lagoonal invertebrate species of conservation importance in the UK (Table 1) indicated that they also primarily occupy lagoonal habitat and brackish waters throughout their range, which extends from the Mediterranean and Baltic Sea north and west to the British Isles. If larger source populations of these species are present on European coasts then it is important to identify habitats and evidence of potential dispersal vectors that could facilitate species colonisation, establishment and range expansion in a changing climate.

Table 1
Results of literature search for habitat preferences and European distribution of selected ‘specialist’ lagoonal invertebrates of conservation importance in the UK, plus the non-native *A. franciscana.* Searches conducted in Web of Science (Web of Science, 2017) using terms: ‘Lagoon’ ‘Estuary’, ‘Brackish’, ‘Seas’, ‘Intertidal’ and ‘Habitat’.

Group	Species	No. of Sites (Studies)					Region (No. different sites of each habitat type)
		Lagoons (a)	Salt pans (exc. Salterns) (b)	Brackish bays and fjords (c)	Estuary (d)	Intertidal (e)	
Cnidaria	*Nematostella vectensis*	20 (4)	0	0	0	0	England (20[a])
Crustacea: Anostraca	*Artemia franciscana*	0	4 (3)	0	0	0	Atlantic Spain (3[b]), Portugal (1[b])
Crustacea:Amphipoda	*Gammmarus insensibilis*	27 (16)	0	2 (2)	1 (1)	1 (1)	England (19[a]), Portugal (2[a],1[e]) Mediterranean Sea (5[a],1[b], 1[e]), Black Sea (1[a],2[c])
Crustacea:Amphipoda	*Monocorophium insidiosum*	7 (10)	0	1 (6)	0	1 (1)	Mediterranean Sea (7[a],1[c],1[e])
Crustacea:Isopoda	*Idotea chelipes*	5 (4)	0	1 (6)	1 (1)	0	England (3[a]), Mediterranean Sea (2[a]) Baltic Sea (6[c]), Wadden Sea (1[d])
Crustacea: Isopoda	*Lekanespaheara hookeri*	35 (10)	0	0	1 (1)	1 (1)	England (28[a]), Mediterranean Sea (5[a]), Atlantic Spain (1[d,e]), Portugal (2[a])
Mollusca:Gastropoda	*Ecrobia ventrosa*	32 (17)	1 (1)	5 (5)	0	0	England (20[a]), Atlantic Spain (1[b]), Mediterranean Sea (6[a]), Portugal (2[a]), Denmark (1[a],1[c]) Baltic Sea (3[a],3[c]), Skagerrak (1[c])
Mollusca:Bivalvia	*Cerastoderma glaucum*	81 (40)	1 (1)	11 (12)	6 (4)	13 (2)	England (39[a],10[e,f]), Scotland (2[a]), Wales (2[a]), Ireland (13[a], 2[e,f]), Portugal (4[a],3[d]), Mediterranean (21[a],1[b], 1[c], 1[d],1[e]), Baltic (10[c]), Wadden Sea (2[d]),
	Total	**207 (101)**	**6 (5)**	**20 (31)**	**9 (7)**	**16 (5)**	