Focus Article

Marine litter as a vector for non-native species: what we need to know

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Abstract

Plastic debris and other floating materials endanger severely marine ecosystems. When they carry attached biota they can be a cause of biological invasions which extent and intensity is not known yet. This article focuses on knowledge gaps and research priorities needed for, first, understanding and then preventing dispersal of alien invasive species attached to marine litter.

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Alien invasive species (AIS) are a major threat to biodiversity and ecosystem services, as well as human health and economy (Regulation (EU) No 1143/2014). Plastic debris and other floating materials contribute to the transfer of non-native species (Vegter et al., 2014). Although there are frequent anecdotal reports of rafting non-native biota on marine anthropogenic litter, the extent of this phenomenon and its impact on ecosystems and biodiversity is not well known yet. Here we revise current literature and identify knowledge gaps by addressing four main questions. Based on this, we suggest urgent research needs for the close future, with the final objective of enhancing management actions to prevent the spreading of AIS by floating litter (Figure 1).

1) How important is marine litter in the transport of non-native species?

Floating debris is a vector for both first introductions (long distance transport) in a new region, and secondary spread (short-distance transport) within an already affected region. However, as rafting is usually referred to as "other routes of introduction" (Katsanevakis and Crocetta, 2014), the actual contribution of floating litter to the introduction and spreading of AIS is largely unknown (Vegter et al., 2014). Katsanevakis and Crocetta (2014) suggest rafting to be a potentially important vector of both primary AIS introductions via corridors in the Mediterranean, as well as of secondary spread of already introduced species, meaning that its importance might be seriously underestimated. In fact, more than 80% of alien species in the Mediterranean might have arrived on floating debris or used this vector for further dispersal (Galgani et al., 2014).

Floating debris is the third most common vector of alien species introductions in British brackish and marine waters (Minchin et al., 2013). There are many examples of long and medium-distance transport of biota along the prevailing oceanic currents in different regions (Thiel and Haye, 2006; Gregory, 2009; Kiessling et al., 2015), like successful kelp-rafting occurring between islands about 500 km distance (Nikula et al., 2012); exotic molluscs and barnacles reaching British and Irish waters by trans-Atlantic rafting on anthropogenic litter (Minchin et al., 2013; Holmes et al., 2015); big anthropogenic rafts, detached by a tsunami, transporting non-native species from Japanese to North American western coasts (Calder et al., 2014). On floating litter close to Brazil, the vast majority of taxa were exotic and cryptic species (Farrapeira, 2011).

The importance of marine litter for near-shore AIS dispersal, where the first introduction occurred due to another vector (secondary spread) has also been emphasized by several authors (e.g. Winston et al., 1997). The relative frequency of each type of transport (long- or short- distance), and especially the contribution of litter on regional AIS spread remains to be quantified.

2) Which litter items are the main carriers of biota?

Barnes (2002) estimates that anthropogenic litter more than doubles rafting opportunities. Biota can attach to glass, metal and paper surfaces, and indeed to more frequent and persistent plastic items (Kiessling et al., 2015). The type of artificial polymer seems to influence the composition of the bacterial fouling community (Carson et al., 2013b; Zettler et al., 2013). Positively buoyant polypropylene (PP), polyethylene (PE) and expanded polystyrene (EPS), commonly used in food packaging and single-use everyday items, are the main polymers found in marine litter (e.g. Carson et al., 2013b; Zettler et al., 2013). EPS is often used in aquaculture and a known carrier of attached biota (Hinojosa and Thiel, 2009).

Buoyancy and persistence are key characteristics of potential rafts. Initially, the attached fouling community may enhance these traits on rather porous or unstable objects, but with increasing weight it reduces the buoyancy, especially of smaller objects (Bryan et al., 2012; Engler, 2012; Kiessling et al., 2015; Fazey and Ryan, 2016). Surface roughness and size, and floating behaviour of an object seem to influence its biotic colonization (Carson et al., 2013b; Goldstein et al., 2014), as well as the species or taxonomic group preferentially attached (Bravo et al., 2011; Kiessling et al., 2015). It is then necessary to assess the influence of artificial polymers, surfaces and buoyancies of marine litter items on the successful patterns of invasions mediated by them, and learn from case studies to improve risk predictions and to establish effective prevention campaigns.

3) **Which areas are donors of litter and attached biota?**

The identification of source areas is a priority for the prevention of debris input and subsequent rafting by AIS (Goldstein et al., 2014). How much litter is released from a certain area depends on the type and intensity of anthropogenic activities (e.g. industry, fishing, aquaculture), on the efficiency of waste disposal and treatment facilities, and on the frequency of accidental releases caused by natural or anthropogenic disasters (hurricanes, shipwrecks etc.) (Ebbesmeyer and Ingraham, 1994; Derraik, 2002; Doong et al. 2011; Browne, 2015).

High-risk areas are those where intense littering coincides with a high occurrence of potential invasive species. Estuaries typically suffer from a high burden of litter, both from land-based as well as from marine sources (e.g. Acha et al., 2003). Aquaculture, often located in estuaries, is economically and ecologically affected by fouling organisms and plastic pollution (Williams and Grosholz, 2008; Rius et al., 2011; Sussarellu et al., 2016). At the same time it is a major source of AIS, due to escapes -and sometimes active releases- of exotic farmed individuals (Rius et al., 2011; Crego-Prieto et al., 2015; Habtemariam et al., 2015; Semeraro et al., 2015). The floating devices used in aquaculture often provide optimal conditions for fouling AIS (Rius et al., 2011), especially when they are detached (Katsanevakis et al., 2013; James and Shears, 2016). Considerable amounts of detached buoys with attached AIS, as well as floating litter from aquaculture activities was reported from some locations, especially related to extreme climatic events (Astudillo et al., 2009; Hinojosa and Thiel, 2009; Macfadyen et al., 2009; Liu et al., 2015).

Other AIS shelters are ports and marinas, especially those located in densely populated zones with a high amount of litter (Ashton et al., 2006; Seebens et al., 2013; Peters et al., 2014; Wells et al., 2014; Pejovic et al., 2016). They receive biota from vessels and recreational boats and their artificial structures are a suitable habitat for AIS (Glasby et al., 2007; Tyrrell and Byers, 2007). Ports are frequently disturbed habitats which offer permanent and sheltered spaces to AIS, especially if they are partially enclosed (Peters et al., 2014). Therefore ports are at the same time recipients of AIS coming from outside regions, and donors for neighboring areas (Ardura et al., 2015).

Once afloat, rafts and attached organisms accumulate in marine convergence areas, most importantly the five subtropical marine convergence zones, known as oceanic gyres, where they may interact or change rafts (Thiel and Haye, 2006; Cózar et al., 2014; Eriksen et al., 2014; Goldstein et al., 2014; Ryan, 2014). Some rafting species may be travelling within these gyres for several years before reaching land (Hoeksema et al., 2012). Determining the contribution of ports and aquaculture zones to regional AIS dispersion of floating litter, as well as the role of oceanic accumulation areas in trans-oceanic litter rafting are urgent research needs.

4) Which areas are at special risk to receive floating litter and host its attached biota?

All natural sink areas receive floating litter and, if present, attached biota. The long-distance transport of floating marine debris is determined offshore by the prevailing upper-ocean currents and winds. Ekman currents direct the litter towards the five gyres and their neighbouring coastal areas and oceanic islands (Barnes, 2005; Lebreton et al., 2012; Maximenko et al., 2012; Cózar et al., 2014; Eriksen et al., 2014), where dense accumulations of floating or stranded litter have been reported (eg. Hidalgo-Ruz and Thiel, 2013). Storm events aggravate the deposition of marine debris in sink areas (Doong et al., 2011; Lebreton and Borrero, 2013; Holmes et al., 2015).

Along coastlines, near-shore currents and winds, tidal dynamics, wave motion and the coastal geomorphology are the main drivers of litter accumulation (Araújo and Costa, 2007a, 2007b; Browne et al., 2010; Doong et al., 2011; Carson et al., 2013a; Critchell and Lambrechts, 2016). Drift models help to estimate the pathways and sinks of floating litter (e.g. http://www.adrift.org.au/). However, AIS arrivals are not synonymous of biological invasions in a location. Several factors determine the vulnerability of a habitat to invasion, like the habitat´s species richness (both native and non-native) and cover (Marraffini and Geller, 2015), and the propagule pressure (Lockwood et al., 2005). Marine spatial protection may thus mitigate the problem, either by decreasing debris accumulation and/or conferring protection against biological invasions (due to preserved native biodiversity and/or less degraded habitats). However, this aspect has rarely been considered in marine and coastal spatial planning, and should be investigated. There is a serious need for an international system to scoring coastal areas in terms of habitat conservation (or degradation), similar to the current European blue flags allocated to clean beaches.

Conclusions

This short review identifies several research needs for evaluating and preventing the imminent, biodiversity-threatening problem of AIS carried by marine litter. Donor and vulnerable recipient areas, high-risk litter items, and the relative contribution of marine litter to global biological invasions are main issues that need to be addressed, in order to design efficient management strategies.

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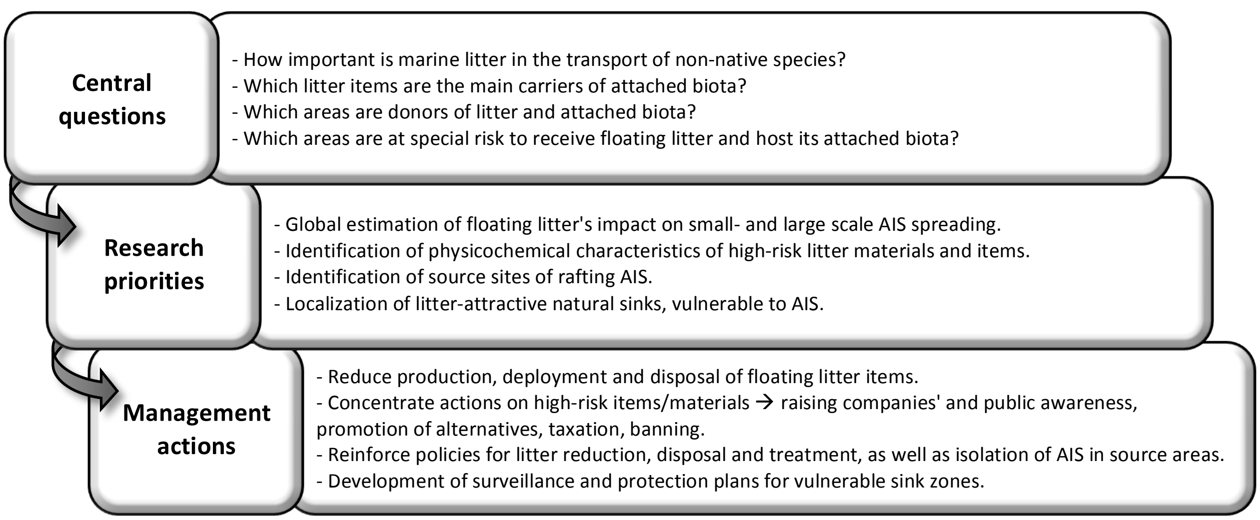
Figure legends

Figure 1. Schematic overview of the questions addressed in this review, consequential research needs and management actions.


Central questions
- How important is marine litter in the transport of non-native species?
- Which litter items are the main carriers of attached biota?
- Which areas are donors of litter and attached biota?
- Which areas are at special risk to receive floating litter and host its attached biota?
Research priorities
- Global estimation of floating litter's impact on small- and large scale AIS spreading.
- Identification of physicochemical characteristics of high-risk litter materials and items.
- Identification of source sites of rafting AIS.
- Localization of litter-attractive natural sinks, vulnerable to AIS.
Management actions
- Reduce production, deployment and disposal of floating litter items.
- Concentrate actions on high-risk items/materials → raising companies' and public awareness, promotion of alternatives, taxation, banning.
- Reinforce policies for litter reduction, disposal and treatment, as well as isolation of AIS in source areas.
- Development of surveillance and protection plans for vulnerable sink zones.