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REVIEW ARTICLE

A review of the potential effects of recreational wind-powered craft on coastal habitats and wildlife

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Wind-powered recreational (WPR) activities are increasingly popular and occur in many areas of high conservation value. Possible impacts are poorly understood; existing reviews do not generally include recent widespread forms of WPR or have narrow taxonomic/ecological scopes. We identify the coastal ecosystems/wildlife that may interact with WPR and potential impacts: a) noise, movement and other stimuli, b) direct contact, c) disruption of substrates, and d) transport of pests. Almost all available evidence on impacts involves coastal birdlife, specifically their escape responses. Most studies are a) non-peer reviewed, largely anecdotal or otherwise limited in scope and b) from temperate locations. Sustainable use of WPR craft is required despite the prevailing information gaps. We suggest a precautionary, proactive approach which likely requires a combination of site-based management, plus policy and education initiatives.

Keywords: coastal ecosystems; collision; disturbance; kite board; sailing; wind surfing

1. Introduction

Recreational activities using wind-powered craft, such as windsurfing and kiteboarding, are increasing in popularity and visibility as materials technologies have advanced the variety of equipment available and improved the affordability and capabilities of the craft themselves (Global Kitesports Association 2017). These activities often require specific environmental conditions, namely large open stretches of water with limited obstructions and bottom features, and prevalent crosswinds. As with many outdoor recreational activities, this can lead to most activity occurring in a relatively small number of locations that offer the required combination of environmental characteristics, as well as other factors such as convenience (e.g. proximity to urban centres), ease of

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access, and availability of open space to set up and prepare equipment (Krüger 2016; Global Kitesports Association 2017).

Prime areas on coasts often overlap with tidal flats, seagrass beds, saltmarsh, fringing reef, and other coastal ecosystems that provide important habitat for a wide variety of terrestrial and marine, shoreline and coastal wildlife, including threatened or protected species, or species with socioeconomic importance (Table 1; Online Supplementary Material). These coastal ecosystems provide habitat for a wide variety of plants, birds, fish, mammals, reptiles, amphibians, and invertebrates (Gomon, Bray, and Kuiter 2008; Palmer 2019; Schafft *et al.* 2021). This has put kiteboarding and similar activities in conflict with areas of importance for wildlife and conservation worldwide (e.g. Morrison *et al.* 2020). Wind-powered craft use could inadvertently affect coastal ecosystems *via* a number of pathways, processes, and mechanisms, changing the behaviour of associated species and altering the habitats on which they rely (Krüger 2016; Global Kitesports Association 2017; Schafft *et al.* 2021). For instance, noise and movement may alter the behaviour of feeding or roosting birds (Francis, Ortega, and Cruz 2009), use in very shallow water may disturb underlying substrates or water conditions (Orth, Lefcheck, and Wilcox 2017), and site access may damage fragile coastal plant communities (Thomsen, Adam, and Silliman 2009).

1.1. A conceptual framework for assessing interactions between wind-powered craft and ecosystems, and defining impact pathways

While the type of craft used varies, the process of using these can be generalised into several key stages, which can then inform the identification of ecosystems within which they occur (Figure 1). All of the ecosystems that have the potential to host wind-powered recreational craft are home to a wide variety of marine, shoreline and terrestrial wildlife, providing important habitats for feeding, roosting and breeding, and shelter from predators and environmental extremes (Online Supplementary Material 1). These ecosystems provide critical habitats for a variety of protected species, as well as critical life stages of many commercially and recreationally important fishery species. As such, they maintain biodiversity, natural heritage, and socioeconomic values. Many of these ecosystems also offer passive recreational opportunities such as fishing, bird-watching and nature study. Thus, there is potential for wind-powered recreationists to be in conflict with some of these other users.

1.2. Aims

Reviews offer useful insights into underappreciated or emerging recreational pressures on ecosystems, including in marine environments (see, for example, Giglio, Luiz, and Ferreira 2020). While reviews exist of the effects of water-based recreation – which includes wind-powered craft – on ecosystems, they combine powered and "unpowered" craft, focus on freshwater ecosystems, or otherwise do not specifically deal with the full breadth of impact pathways or taxa concerned with use of wind-powered craft (Carney and Sydeman 1999; Schafft *et al.* 2021). Thus, while concerns regarding the potential effects of recreational wind-powered craft persist (Battley 2018), the broader impacts of these activities on coastal environments have yet to be comprehensively reviewed. Here, we review the current literature on the effects of wind-powered craft on coastal wildlife and habitats. We aim to describe current usage

Table 1. Conceptual representation of key coastal habitats favoured by wind-powered recreational activities and overlap with key faunal groups.

	Coastal habitats								
Activity	Terrestrial vegetation	Beach	Tidal flats	Saltmarsh and mangroves	Seagrass (and aquatic plants/macroalgae)	Shallow inlets	Fringing reef	Open water	Faunal group
Kiteboarding (land)	*	✓	✓	*					Terrestrial fauna
Kiteboarding (water)	*	*	*	*	✓	✓	*	*	Shore and waterbirds
Windsurfing						*	*	✓	Fish
Wing boarding	*	*	*	*	✓	✓	*	*	Marine invertebrates
Sailing						*	*	✓	Marine megafauna

*Unintended or minor intersection between activities and habitats.
✓Primary favoured habitats of activities. Gray shading indicates habitats which are critical for corresponding faunal groups.

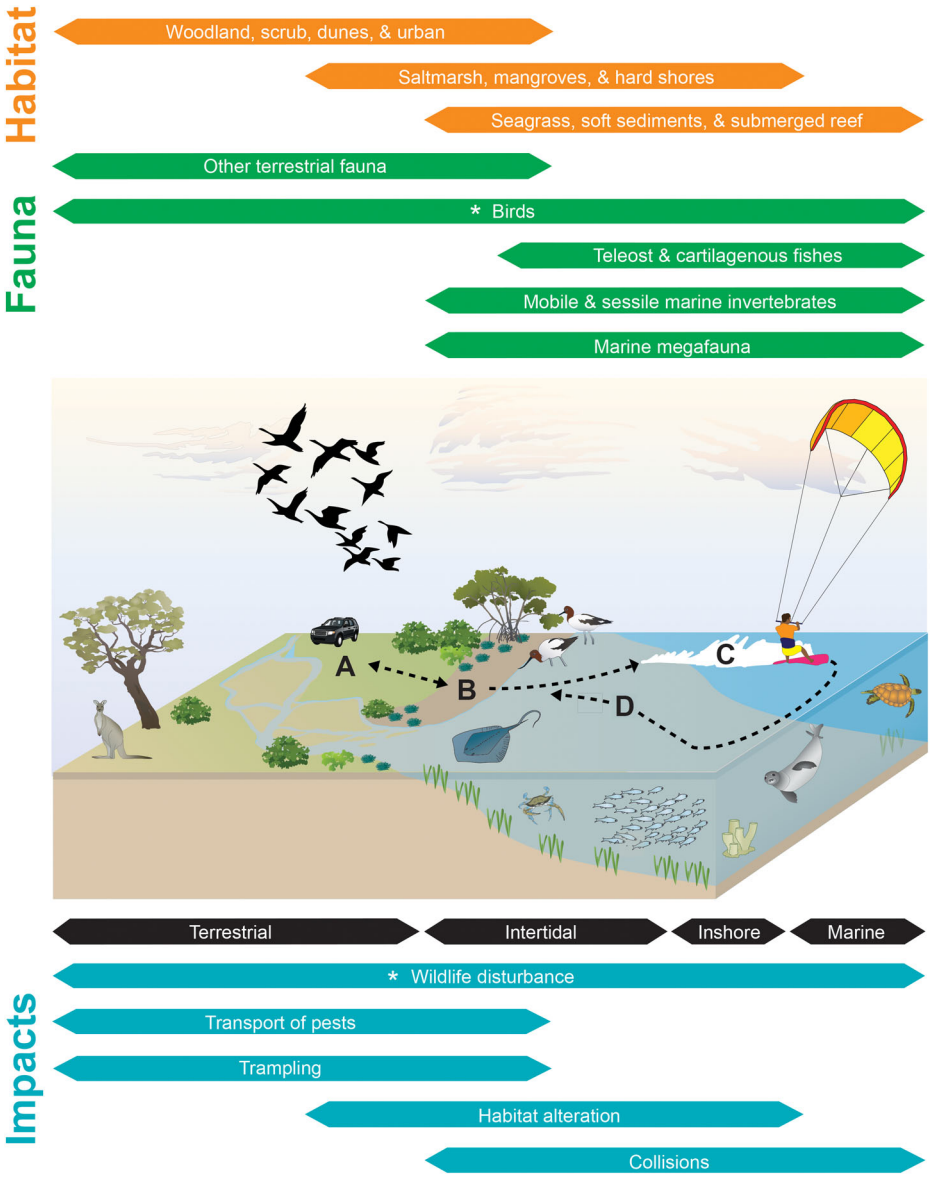


Figure 1. Zonation of wind-powered craft use, in this case kiteboarding, indicating a generalised account of the coastal ecosystems and fauna likely to be encountered at each stage of activity depending on location (here represented as South-Eastern Australia). zones of possible impacts are also shown. The sequence used by participants is: A) Arrival at site and gear assembly in open area (often grass interspersed with coastal scrub and woodland). B) transport of gear from assembly area to shoreline (e.g. coastal scrub and woodland, mangroves, saltmarsh, soft-sediment intertidal, intertidal seagrass beds). C) The recreational activity in nearshore coastal environments (e.g. soft-sediments, seagrass beds, submerged reef). D) Transport of gear back to assembly area, gear breakdown and storage (all ecosystems). Each of these steps creates distinct opportunities for interactions between the user and different ecosystems and constituent parts thereof. Ecosystems are defined in Online Supplementary Material. *indicates processes which have received some study specifically regarding wind-powered craft.

patterns of wind-powered craft to identify possible impact pathways on coastal ecosystems. We then review what is known regarding impacts on coastal ecosystems. By identifying information gaps, and areas of particular concern, we suggest a general set of recommendations to maximise the likelihood of sustainable use of wind-powered craft.

2. Methods

The relative dearth of information available in the literature precluded a systematic literature review, instead we use a "traditional" review methodology (Haddaway *et al.* 2015). We compiled literature on wind-powered craft, and possible impacts, which included primary research articles located using the Web of Science database and Google Scholar, accessed *via* Deakin University, as well as publicly available government and industry reports located using Google searches. We used the following search terms: kite, kiteboard, kite and board, windsurf, wind and surf, windboard, wind and board, wingboard, wing and board, sailing, boat, watercraft, and combinations of these terms with distance, disturbance, impact, birds, birdlife, and wildlife. To limit bias, we defined our initial search strategy and scope to only include the range of activities we had classified as "wind-powered" (see Section 2.1) and made the predetermined decision to include grey literature in our analysis (Haddaway *et al.* 2015). This scope was then extended for instances where components of activities were determined as not unique to the use of wind-powered craft, i.e. the transport of pests on equipment. Once located, both primary and grey literature was critically appraised with regards to data quality, scope, and potential conflicts of interest, and relevant information extracted (Bilotta, Milner, and Boyd 2014). Where literature included data on both wind-powered and non-wind-powered craft, information regarding impacts was only included in our analysis if those resulting from wind-powered craft could be clearly identified. We identify and describe potential impact pathways, and review what is known about each.

Given that we first aim to describe the current state of knowledge, our uneven treatment of different taxonomic groups reflects the uneven treatment we uncovered in the literature, and which is well described in general (i.e. most notably there was a publication bias towards birds; see also Phaka *et al.* 2022). We use birds, as a relatively well-studied group, to illustrate general processes which may apply to wildlife more broadly, simply because most study on wind-powered craft and wildlife has focussed on birds. We explicitly acknowledge this bias (after Haddaway *et al.* 2015).

2.1. Defining wind-powered craft on coasts

The vast majority of coastal and near shore wind-powered activities can be classified as either kiteboarding, wing boarding, windsurfing and small craft sailing, thus we exclude paddled craft such as paddle boards, kayaks and canoes, as well as large yachts which require deeper waters. Each activity we consider uses unique sets of equipment, with different spatial "footprints", movement characteristics, participation rates, and suitable areas for use. Thus, each also varies in the type and extent of potential environmental impacts. Here we provide an overview of each activity and outline the process by which each activity generally occurs.

2.1.1. Kiteboarding

Coming to prominence in the late 1990s, kiteboarding (or kitesurfing) is an increasingly popular sport where participants are propelled across the water or land using a large power kite (Gratwick 2015). Most water-based kiteboarding set-ups consist of a leading edge power kite, connected to a control bar and harness by around 20 m of flying line. Thus, a kiteboard has a large three-dimensional "footprint" (i.e. the space around the kiteboard within which it may interact with ecosystems) relative to many other wind-powered craft. A variety of boards are used, including highly specialised foil boards and surf boards; however, bidirectional kite boards are also common. Kiteboarding boards have relatively short fins and this, combined with the pulling power of the kite, means that kiteboarders can operate in shallow waters and light winds which would not be amenable to other wind-powered craft. As a result, they are able to access areas particularly close to shorelines where there is sufficient open space. A number of styles are practised including wave riding, foiling, wake skating, and jumping. Each uses slightly different equipment set-ups and is best suited to certain weather or water conditions. For example, wave riding uses a surfboard and occurs along beaches where there is a surf break, while jumping requires higher wind conditions and shorter lines. However, most participants use the bidirectional board, with a general set-up suited to a wide range of conditions and environments (Gratwick 2015).

2.1.2. Windsurfing

Wind surfing has a longer history than kiteboarding, coming to prominence in the 1970s (Gadd, Boothroyd, and Durrell 1985). Windsurfing boards can be traditionally classified as either long or short boards. Long boards ($>$ 3 m in length) are equipped with a daggerboard underneath, making them best for light winds or competitive courses. Short boards are designed for planing over the water's surface. However, as with kiteboards, there are now a wide range of board types available, each suited to certain environmental conditions or types of activities (Currer 2004). The presence of a daggerboard restricts windsurfers to deeper waters than kiteboarders, generally hip or chest deep, and thus generally windsurfing takes place further away from the shoreline to avoid hitting substrate or being entangled in seagrass or algae. However, specialised anti-weed fins are available which allow access to shallower water or areas with vegetation. Many popular windsurfing sites are the same as those that are suitable for kiteboarding due to the prevalent wind conditions, open space, and relatively featureless seafloor.

2.1.3. Sailing

Sailing is a popular activity worldwide. Sailing boats come in a wide range of sizes and classes, from small dinghies for use in coastal and other sheltered waters through to large ocean-going vessels. Here, we consider small single or multi-hulled dinghies, which are most likely to interact with inshore coastal ecosystems and wildlife due to their size and ability to operate in relatively shallow water (Pickthall 2021). These craft are classed as off-the-beach sailing yachts. However, as with windsurfing boards, the presence of a centre keel restricts the operating depth to deeper waters and so most activity takes place in suitably deep water.

2.1.4. Other wind-powered activities

There are a range of other niche wind-powered activities that also occur. For instance, wing boarding is a relatively new hybrid sport which involves the user holding a smaller kite directly for propulsion. Wing boarding kites are increasingly popular due to their versatility and relative ease of use as the same kite can be used in a wide range of water conditions, using a range of different boards, and can also be used on land and snow. Finally, small sails are also available that are designed for attachment to personal non-powered craft which traditionally would not have them, such as kayaks and canoes. These small sails allow the user to rely less on their own energy for propulsion and so are popular with users traveling long distances or operating in difficult conditions.

3. Results

Recreational activities involving wind-powered craft have the potential to impact the ecosystems and wildlife *via* a number of pathways (Figure 1). To date, most research into the effects of modern wind-powered craft, such as kiteboards, on wildlife are found in the non-peer-reviewed "grey" literature. In addition, while these activities occur in locations worldwide, almost all research has focussed on temperate environments. For several of the predicted impacts there is no information available which is specific to these activities. In these cases, we have drawn from studies on activities which we consider ecologically comparable, i.e. the transport of aquatic and pests on recreational equipment and trampling of terrestrial wildlife at entry sites.

3.1. Wildlife disturbance

Kiteboarding, windsurfing and other similar activities represent stimuli in an animal's environment which need to be assessed by an animal regarding whether or not they require a response on the part of that animal (after Weston *et al.* 2012). Many vertebrates have nuanced responses to the same stimulus, demonstrating that they also assess stimulus attributes i.e. perceptible elements available for wildlife to judge the degree of threat posed (after Weston *et al.* 2012). Wind-powered craft often appear as a large three-dimensional object at water level, and in the case of kiteboards, as a separate independently moving object in the air (the kite) (Figure 2). These craft can move rapidly at high speeds close to shore and can often change course unpredictably. Depending on the time of day, the sun's angle can project large shadows from these craft further increasing their "sensory footprint," and potentially evoke escape or hiding responses in marine animals (Drewes and Fourtner 1989; Buskey and Hartline 2003; Lukas *et al.* 2021). In addition to producing visual cues, these craft generate noise, either as kites or sails cut through the air, or suddenly if these hit the water or from the vocalisations of the operators. The aforementioned attributes (among other factors) influence the responses of wildlife, in terrestrial contexts using other stimuli (Smith 2004; Møller and Tryjanowski 2014; Lethlean *et al.* 2017; Weston *et al.* 2020). To our knowledge, the exact levels of stimulus produced by wind-powered craft have not been formally quantified. For example, speeds, track length and noise levels above and below the water appear to be unrecorded; however, these can and should be measured (see Weston *et al.* 2020). Nonetheless, the stimulus attributes of different wind-powered activities can be estimated and ranked based on the relative frequency or intensity of stimuli produced relative to other activities (Bötsch, Tablado, and Jenni

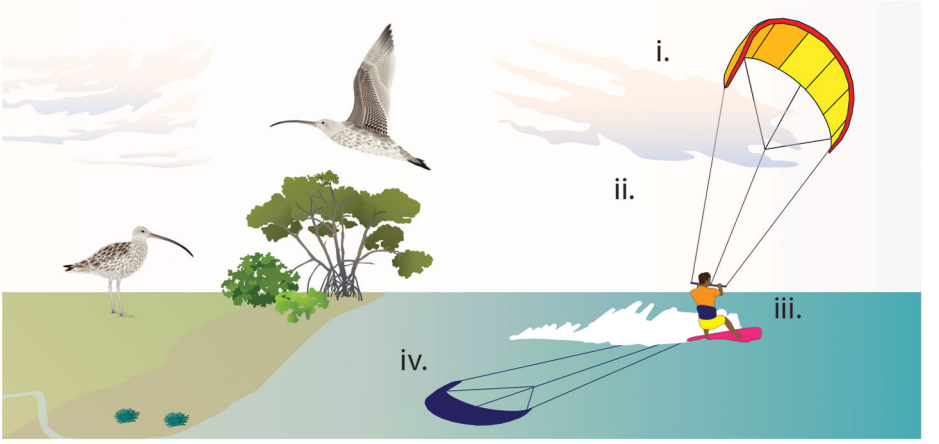


Figure 2. Stimulus attributes of kiteboarding and other wind-powered craft which could evoke a response in nearby wildlife, causing disturbance. i) Visual cues from the kite and rider, ii) noise from the kite and rider, iii) cues resulting from speed and unpredictable movement of kite and rider, iv) shadow and silhouettes created by the kite extend the three-dimensional footprint of the kite.

Table 2. Relative on-water stimulus attributes for different types of recreational craft common in coastal areas.

Craft	Noise	Unpredictability	Speed	Visibility	Cumulative stimulus attribute
Jet ski	3	3	3	2	11
Kiteboarder	2	3	2	3	10
Motorboat	3	2	3	2	10
Windsurfer	2	2	2	2	8
Wing boarder	2	2	2	2	8
Sailing boat	2	2	2	2	8
Kayak	1	1	1	1	4

Note: Cumulative stimulus attribute is calculated as the sum of all component attribute scores across the four categories of attribute. Noise represents a combination of sound emission and range, unpredictability is the relative capability for craft to rapidly change direction or appear suddenly, speed is the relative average speed capable towards a location, and visibility represents the relative three-dimensional footprint (i.e. size, height, and openness of operating environment). wind-powered craft are in bold. Methods adapted from Krijgsveld, Smits, and Van Der Winden (2008) and Krüger (2016). estimated scores (1-3) indicate the relative prominence of that attribute compared to the other activities listed, with lower numbers indicating less of that attribute. Craft are listed in descending order of cumulative stimulus attribute.

2017). Based on these criteria, wind-powered craft, most notably kiteboarding and windsurfing, have the potential to provide strong cues to wildlife, similar to those of powered craft such as jet skis (Laursen *et al.* 2017; Table 2).

A further consideration is the presence of naturally occurring stressors when wind-powered recreational activities take place. For example, most activity is likely to occur during periods of moderate to high winds. At these times, some fauna species may already be stressed and highly alert due to their compromised ability to hear over the noise of wind or due to a reluctance or inability to move freely due to wind conditions (Carr and Lima 2010; McBlain, Jones, and Shannon 2020). This may be more severe in cool climates where the conservation of warmth and energy is important for

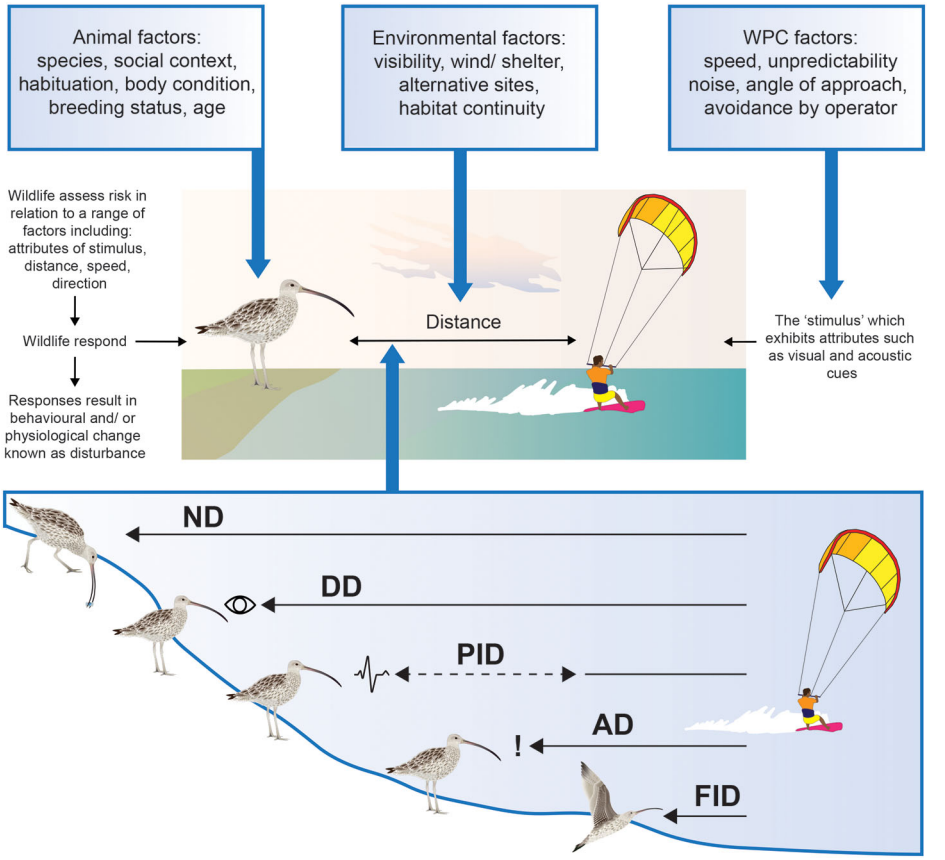


Figure 3. Relationship between stimuli indicative of a threat and direct disturbance of wildlife (centre panel). the upper panel presents candidate factors affecting the distance of wildlife response. The lower panel shows the relationship between distance to stimulus and escalating response by wildlife, in this case shorebirds on a shoreline. ND is distance beyond which no response is observed, DD is the detection distance by an individual, PID is the physiological-initiation distance at which a physiological response is observed, and can precede or lag after the AD as indicated by the dotted line. AD is the alarm-initiation distance at which individuals exhibit an alarm response, and FID is the flight-initiation distance at which individuals exhibit an escape response. Figure adapted from Weston *et al.* (2012) and Charuvi *et al.* (2020). dashed lines indicate the variation recorded by Charuvi *et al.* (2020).

individual animals and forced movements during cold, windy conditions are undesirable (Ojanen 1979). Furthermore, the degree of disturbance can vary depending on the activity of sensitive species. For example, a flock of shorebirds foraging on a mudflat may experience a short-term disturbance associated with short distance movements, whereas a flock disturbed at a high tide roost may experience longer disturbance and greater energy costs, especially if other suitable roosts are distant or non-existent (Weston *et al.* 2012). Migratory birds may be especially sensitive to energy lost to disturbance (Weston *et al.* 2012).

While we primarily discuss birdlife here (because it is most studied), many concepts regarding disturbance are broadly applicable to other mobile wildlife such as fish and marine mammals (Andersen *et al.* 2012; Kennedy, Lonhart, and Stachowicz 2019). For coastal birds, responses (whether they occur, and their intensity) to a

stimulus such as a kiteboard generally depends on the distance between the stimulus and the individual, among other factors (Weston *et al.* 2012; Figure 3). Wildlife responses are generally conceived as several escalating stages, ranging from increased vigilance, physiological stress, to rapid escape responses (Weston 2019). There is a clear inverse relationship between the distance to the stimulus and the intensity or likelihood of the response (Weston *et al.* 2012). While the relationship between distance and response can be generalised, the actual distances that evoke responses are dependent on a wide range of factors including species, group size, time of day, the structural complexity of the environment, the value of the habitat to the responder, the size and shape of the stimulus, how fast the stimulus is approaching, and how habituated individuals are to the stimulus (Møller 2014; Samia *et al.* 2017; Mayer, Natusch, and Frank 2019).

In general, anthropogenic "direct disturbance" refers to alteration of the behaviour or physiology of wildlife, caused by responses to human proximity (Figure 3; Weston *et al.* 2012). Consequences of disturbance include decreased condition, reproductive fitness, distribution or abundance of wildlife (Weston *et al.* 2012). Here, we also recognise "biophysical disturbance," the alteration of habitats or resources on which biodiversity rely, and the diversity of consequences which may result (e.g. Larson *et al.* 2016). Both direct and biophysical disturbance have long been identified as potential problems for wildlife and a wide range of studies have examined the effects of recreational activities on the behaviour and ecology of coastal birds and other animals (for example, see reviews by Hardiman and Burgin 2010; Steven, Pickering, and Castley 2011; Larson *et al.* 2016). These effects can range from reducing the amount of time animals spend feeding to complete abandonment of the habitat (Krüger 2016).

Kiteboarding has a greater visibility effect than windsurfing or sailing due to the kite itself, although in other aspects they can be considered comparable in terms of potential to cause disturbance. An assessment of the available literature on the effects of kiteboarding on birds identified a range of general disturbance effects but suggests that the impact of these is highly context dependent (summarised in Table 3). The most consistent effect reported was the evocation of distinct FIDs, with birds generally leaving the area completely and returning later. However, the distance at which birds initiated an escape response was highly dependent on the species present, the environment, whether birds were on the shore or wading versus swimming, and the level and frequency of kiteboarding, windsurfing or sailing activity (Table 4). Motorised craft can, for some birds, elicit longer FIDs than those in response to walkers (Scarton 2018); whether wind-powered craft do the same is unknown. Wind-powered craft have the potential to exclude wildlife from substantial areas; studies of other mobile stimuli, which buffer movement paths of stimuli with the FID they likely impart to wildlife, show that little habitat may remain in which wildlife are undisturbed (Petch *et al.* 2018; Schneider *et al.* 2020).

Linking wildlife response to broader consequences of disturbance is difficult, yet all responses have some degree of cost to the individual. One of the difficulties is disentangling the cumulative effects of disturbance from all stimuli, and whether WPC would substantially change the level of human disturbance already occurring. For instance, Battley (2018) found that, while kiteboarding increased the number of bird responses, disturbance was substantial in general due to other human activities near roosting sites. In contrast, in some locations these activities represent the primary

Table 3. Summary of reported effects on birdlife due to kiteboarding, windsurfing and sailing (X = effect reported).

Study	Activity	Country	Site Protection	Regulations	No of spp.	Habitat	Movement	Escape response	Reduced numbers	Temporary site abandonment	Permanent site abandonment	Other effect
Andretzke *et al.* (2011)	Kiteboarding	DK	NP, SAC, SPA	N	>20	Offshore						X[1]
Beauchamp (2009)	Kiteboarding	NZ	WR	N	17	Coastal		X		X		X[2]
Bergmann (2010)	Kiteboarding	DK	NP, SAC, SPA	Y	>20	Coastal		X				
Blüml *et al.* (2013) in Krüger (2016)	Kiteboarding	DK	NP, SAC, SPA	Y	>20	Coastal		X		X		
Figueiredo de Almeida Silva (2020)	Kiteboarding	NZ	N	N	2	Coastal		X				
Hüttemann (2013)	Kiteboarding	DK	NSG, SAC, SPA	Y	>20	Coastal		X				
Jansen (2008)	Kiteboarding	NL	N	N	2	Lake		X		X	X	
Jansen (2011)	Kiteboarding	NL	N	Y	15	Lake		X				
Keller and Stark (2012) in Krüger (2016)	Kiteboarding	CH	partially BLN	Y	>20	Lake				X		
Lewis and Adcock (2017)	Kiteboarding	IE	NR, SAC, SPA	Y	>15	Coastal	X	X		X		
Liley *et al.* (2011)	Kiteboarding, Sailing, Windsurfing,	GB	RS, SAC, SPA	N	>20	Coastal		X		X		
Liley and Fearnley (2012)	Kiteboarding	GB	RS, SPA	N	>20	Coastal		X		X		
Linaker (2012)	Kiteboarding	GB	RS, SPA	N	>20	Coastal		X		X		
Schikore *et al.* (2013)	Kiteboarding	DK	NP, SAC, SPA	Y	>20	Coastal		X				
Smith (2004)	Kiteboarding	GB	RS, SAC, SPA, SSSI	N	9	Coastal			X			
van Rijn, Krijgsveld, and Strucker (2006)	Kiteboarding	NL	N	N	>20	Lake		X		X		X[3]

(*Continued*)

Table 3. (*Continued*).

Study	Activity	Country	Site Protection	Regulations	No of spp.	Habitat	Movement	Escape response	Reduced numbers	Temporary site abandonment	Permanent site abandonment	Other effect
Verdaat (2006)	Kiteboarding, Windsurfing	NL	SAC, SPA	Y	1	Coastal		X	X	X		
Batten (1977)	Sailing	GB	LNR	N	2	Lake		X	X			
Hübner and Putzer (1985)	Sailing, Windsurfing	DK	N	N	1	River		X				
Koepff and Dietrich (1986)	Sailing, Windsurfing	DK	NP, RS	Y	6	Coastal	X	X				X[4,5]
Madsen (1998)	Windsurfing	DM	RS, SPA	N	3	Coastal		X				

Note: Data adapted from Krüger (2016) which focussed on kiteboarding., incorporating additional data sources and available equivalent data for other types of wind-powered craft. Site protections are BLN = 'bundesinventar der landschaften und naturdenkmäler,' being a site listed in the federal inventory of habitats and natural monuments of National importance (Switzerland), LNR = local Nature Reserve (GB), N = no specific protection identified, NP = National Park (Denmark/ Germany), NR = Nature Reserve (Ireland), NSG = 'naturschutzgebiet,' being a Nature Conservation area (Germany), RS = Ramsar site, being a wetland of international importance under the Ramsar convention, SAC = Special area of Conservation as defined in the EU habitats Directive, SPA = Special protection area as designated under the (EU) Directive on the Conservation of wild Birds, SSSI = site of Special scientific interest (United Kingdom), WR = wildlife refuge (New Zealand). regulations indicates whether restrictions on wind-powered craft use in the area were identified. No. of species indicates the number of focal species in the study. Disturbance effects are: Movement = birds moved slightly away from immediate site of disturbance, escape response = birds forced into flight (i.e. FID), reduced numbers = less birds recorded following kiteboarding, temporary site abandonment = birds left the areas for a short period of time, permanent site abandonment = no birds now recorded in area, other effects are: 1 = flying birds changed direction when approaching land away from kiteboards, 2 = near mid-air collision between birds and kites, 3 = "domino" effect of FID, with birds startled by kites causing birds outside of FID to also leave en-masse, 4 = small noticeable changes in behaviour i.e. increased vocalisations, and 5 = physically attacking the craft while underway.

Table 4. Summary of reported flight initiation distances (FID) of coastal birds in response to kiteboarding, windsurfing and sailing.

Common name	Species	Family	Activity	FID (m)	N	References
Tundra swan	*Cygnus colombianus*	Anatidae	Kiteboarding	350, 700	?, 1	Jansen (2008); Laursen *et al.* (2017)
			Windsurfing	190, 700		Jansen (2008); Laursen *et al.* (2017)
Mute swan	*Cygnus olor*	Anatidae	Windsurfing	450-700		Madsen (1998)
Brant goose	*Branta bernicla*	Anatidae	Windsurfing	300	1	Küsters and Von Raden (1986)
Common shelduck	*Tadorna tadorna*	Anatidae	Windsurfing	275, 400	5, ?	Koepff and Dietrich (1986); Laursen *et al.* (2017)
Gadwall	*Anas strepera*	Anatidae	Kiteboarding	550		Jansen (2008)
			Windsurfing	90		Laursen *et al.* (2017)
Eurasian wigeon	*Anas penelope*	Anatidae	Windsurfing	450-700		Madsen (1998); Laursen *et al.* (2017)
			Kiteboarding	550		Jansen (2011)
Mallard	*Anas platyrhynchos*	Anatidae	Kiteboarding	40, 300	1, ?	Schikore *et al.* (2013); Laursen *et al.* (2017)
			Sailing boat	100	1	Batten (1977)
			Windsurfing	280		Laursen *et al.* (2017)
Eurasian wigeon	*Anas penelope*	Anatidae	Windsurfing	450-700		Madsen (1998)
Northern pintail	*Anas acuta*	Anatidae	Kiteboarding	550		Jansen (2011)
Northern shoveler	*Anas clypeata*	Anatidae	Kiteboarding	550		Jansen (2011)
Common eider	*Somateria mollissima*	Anatidae	Windsurfing	150 and 500	2	Fraser (1987)
			Kiteboarding	157	3	Blüml *et al.* (2013) in Krüger (2016)
Common goldeneye	*Bucephala clangula*	Anatidae	Kiteboarding	500, 650, 740		Van Rijn, Krijgsveld, and Strucker (2006); Jansen (2011); Laursen *et al.* (2017)
			Sailing boat	300 – 400		Hume (1976); Batten (1977); Laursen *et al.* (2017)

(*Continued*)

Table 4. (*Continued*).

Common name	Species	Family	Activity	FID (m)	N	References
Smew	*Mergellus albellus*	Anatidae	Kiteboarding	550		Jansen (2011)
			Sailing boat	100		Batten (1977)
Common merganser	*Mergus merganser*	Anatidae	Kiteboarding	540, 550		Jansen (2011); Laursen *et al.* (2017)
			Sailing boat	280, 350		Laursen *et al.* (2017)
Red-breasted merganser	*Mergus serrator*	Anatidae	Kiteboarding	> 500		Van Rijn, Krijgsveld, and Strucker (2006)
Tufted duck	*Aythya juligula*	Anatidae	Sailing boat	275 – 450		Batten (1977)
Pochard	*Aythya ferina*	Anatidae	Sailing boat	275 – 450		Batten (1977)
Great cormorant	*Phalacrocorax carbo*	Phalacrocoracidae	Kiteboarding	120	2	Blüml *et al.* (2013) in Krüger (2016)
			Windsurfing	233	12	Hübner and Putzer (1985)
Red-throated Loon	*Gavia stellata*	Gaviidae	Windsurfing	1000 – 2000		Verdaat (2006)
			Kiteboarding	1400, 1000 – 2000		Verdaat (2006); Laursen *et al.* (2017)
Great-crested Grebe	*Podiceps cristatus*	Podicipedidae	Sailing boat	90		Laursen *et al.* (2017)
			Kiteboarding	340		Laursen *et al.* (2017)
Black-eared Grebe	*Podiceps nigricollis*	Podicipedidae	Kiteboarding	< 200	1	Van Rijn, Krijgsveld, and Strucker (2006)
Eurasian coot	*Fulica atra*	Rallidae	Windsurfing	430-700	2, ?	Madsen (1998); Laursen *et al.* (2017)
Eurasian oystercatcher	*Haematopus ostralegus*	Haematopodidae	Kiteboarding	53, 80, 100, 130, 180	8, ?, 1, ?, ?	Bergmann (2010); Blüml *et al.* (2013) in Krüger (2016); Laursen *et al.* (2017)
			Windsurfing	150, 160, 170		Koepff and Dietrich (1986), Laursen *et al.* (2017)
			Sailing boat	130		Laursen *et al.* (2017)
Eurasian curlew	*Numenius arquata*	Scolopacidae	Windsurfing	350, 395, 400	1, 1, ?	Koepff and Dietrich (1986); Schikore *et al.* (2013); Laursen *et al.* (2017)

(*Continued*)

Table 4. (*Continued*).

Common name	Species	Family	Activity	FID (m)	N	References
Bar-tailed godwit	*Limosa lapponica*	Scolopacidae	Windsurfing	230, 240		Koepff and Dietrich (1986); Laursen *et al.* (2017)
Common redshank	*Tringa totanus*	Scolopacidae	Kiteboarding	87	3	Blüml *et al.* (2013) in Krüger (2016)
			Windsurfing	260, 290		Koepff and Dietrich (1986); Laursen *et al.* (2017)
Red knot	*Calidris canutus*	Scolopacidae	Windsurfing	280		Koepff and Dietrich (1986)
Gulls	*Larus* spp.	Laridae	Windsurfing	100-120		Koepff and Dietrich (1986)
Black-headed gull	*Larus ridibundus*	Laridae	Kiteboarding	57	6	Blüml *et al.* (2013) in Krüger (2016)
Herring gull	*Larus argentatus*	Laridae	Kiteboarding	<50		Andretzke *et al.* (2011)
Lesser-black backed gull	*Larus fuscus*	Laridae	Kiteboarding	<50		Andretzke *et al.* (2011)
Sandwich tern	*Sterna sandvicensis*	Laridae	Kiteboarding	200		Andretzke *et al.* (2011)

Note: Common and species names are provided, along with their respective family. Activity indicates whether the reported FID is in response to either kiteboarding, windsurfing or sailing (sources featuring only "non-motorized watercraft" or those involving mixed species flocks are excluded). FID is the estimated distance in m between the craft and birds when the escape response was initiated. n is the number of observations, if provided. Means are presented where replication occurred, otherwise individual values are given. Response distance of mixed flocks, or those of unspecified species, are omitted. Reference indicates the source. Data adapted from Krüger (2016). Note that the data in this table is largely anecdotal and non-peer reviewed, and we note it primarily involves European species.

Table 5. Summary of assumed impacts (Dark grey = moderate to high, light grey = low to moderate, white = minor/NA) and level of evidence (1 = assumed impacts with little quantitative evidence, 2 = impact documented in grey literature or qualitative evidence, 3 = impact documented as for 2, plus some quantitative studies/literature) of wind-powered activities on different faunal groups.

Faunal group	Kiteboarding (land)	Kiteboarding (water)	Windsurfing	Wing boarding	Sailing
Terrestrial fauna	1	1	1	1	1
Migratory shorebirds	1	2	2	1	3
Resident shore and waterbirds	1	2	2	1	2
Fish	1	1	1	1	2
Marine invertebrates	1	1	1	1	1
Marine megafauna	1	1	1	1	2
Aquatic vegetation (Seagrass, macroalgae, macrophytes)	1	1	1	1	1

Note: Interactions between low evidence scores and higher potential impacts indicate key knowledge gaps.

source of direct human disturbance, due to these location's unsuitability for other forms of recreation. In these cases, the novel stimulus wind-powered craft produce may have a particularly large effect due to the lack of habituation to human activities in resident animals.

Nevertheless, water-based recreation might have population-level consequences, for example through disruption of demographic processes whereby substantial disturbance may cause breeding birds to fail to mate, reduce vigilance, or abandon nests leading to lower breeding success (Carney and Sydeman 1999). Kiteboarding disturbance has been associated with reductions in the number of birds and the temporary abandonment of roosting sites (sites used by sub- or inter-tidal foraging species while they wait for suitable tidal conditions). For example, regular kiteboarding by up to 12 riders at the Dee Estuary, United Kingdom, correlated with dramatic declines in the abundance of several coastal species, most notably common redshanks (*Tringa totanus*) and Eurasian oystercatcher (*Haematopus ostralegus*). Offshore, flying birds were seen to change direction away from kiteboarders, suggesting that flocks may avoid nearby habitats entirely (Andretzke *et al.* 2011).

To our knowledge, the effects of wind-powered craft use on other types of wildlife, for instance marine mammals and fish, have not been formally assessed. However, responses to human activities in coastal areas more generally often indicate a negative, but context dependent, response to disturbance. For example, dolphins, seals, and sirenians often display avoidance behaviours towards motorised boats (Tripovich *et al.* 2012; Filby *et al.* 2014, 2017; Rycyk *et al.* 2018), and studies of disturbance by wind-powered craft are required (Table 5).

3.2. Direct contact with wildlife

The large three-dimensional footprint, high potential speeds, and shallow water in which kiteboards and other wind-powered craft can operate mean that direct contact between these craft and both marine and terrestrial wildlife is possible. In some circumstances, these craft can be harder to control than boats, kayaks or jet skis which

can make unintended contact with wildlife more likely. Beauchamp (2009) observed near contact between birds and kites. While no direct accounts are known to us, the fact that many birds die through collisions with moving vehicles (perhaps analogous to hulls or boards) and powerlines (analogous to kite wires) might suggest collisions occur at least sometimes (see Loss, Will, and Marra 2015). In addition to birds, larger marine animals such as marine mammals, turtles, and rays could theoretically come into contact with riders, especially slow-moving species (e.g. manatees) or at shallow depths where the ability to dive is restricted. While we were unable to find any published reports of this occurring with kiteboarders or windsurfers, small and unpowered craft can hit marine wildlife due to their low noise, erratic movements, and potential for high speeds (Schoeman, Patterson-Abrolat, and Plön 2020). In general, it is likely that these animals would move away from where kiteboarders or other wind-powered craft are active, or will exhibit a rapid escape response if a rider approaches suddenly and so the chances of interaction are likely low. The challenge of quantifying infrequent collisions could draw upon methods used to examine the analogous situation of drone collisions with wildlife, namely analysis of social media (Rebolo-Ifrán, Grilli, and Lambertucci 2019) or surveys of riders (Gray and Weston 2021). In some instances where collisions with small subsurface species are involved, riders may be unaware of what has occurred, making it especially difficult to quantify these impacts.

3.3. Physical disruption of substrates

Interactions between equipment and marine and coastal substrates, i.e. a board, fin or keel hitting the seabed, could cause localised biophysical disturbance to the environment, and damage seagrass, macroalgae, and aquatic vegetation, and sessile and mobile invertebrates (i.e. habitat alteration; Figure 1). While these types of interactions could result from all types of wind-powered craft, we suggest they are theoretically most likely to occur during kiteboarding. Kites operating on land have the potential to cause rutting on beaches and sandflats, disturbing feeding and nesting areas. On water, kiteboarding set-ups have the ability to operate in very shallow depths relative to standard windsurfing boards or sailing dinghies due to the small standard fins, lack of daggerboard or keel, and the pulling power of the kite. Kiteboarding fins can also be removed allowing the operator to access even shallower waters. As a result, there is the potential for contact between the board and the substrate, especially for novice riders or those operating in unfamiliar areas. The impact of any biophysical disturbance will depend on a number of factors, including the underlying substrate, and the number, frequency, and skill level of kiteboarders operating within the given area. For instance, a novice kiteboarder operating over a shallow seagrass bed may bottom out frequently, causing localised disturbance to plants and increased turbidity. Individual effects of this activity on the overall ecosystem would be minimal; however, if a large number of kiteboarders are operating within an area on a frequent basis (e.g. training schools), these effects may cause more substantial changes. This is similar to propeller damage to seagrass beds from powered craft observed in high use areas which can lead to fragmentation of habitats (West 2012; Orth, Lefcheck, and Wilcox 2017), which can in turn reduce the biodiversity of these ecosystems (Burfeind and Stunz 2006).

In addition to potential effects on marine substrates, wind-powered craft activities could also impact terrestrial and intertidal ecosystems such as coastal scrub and saltmarsh at sites where gear assembly and entry sites are not well defined, and so require

users to cross areas of natural vegetation to access the water or create informal walking tracks (i.e. trampling; Figure 1) (Thomsen, Adam, and Silliman 2009). As with physical disturbance to marine substrates, any effects on fragile plant communities and associated biodiversity (e.g. ground nesting birds' nests) will likely be highly localised and will depend on the plant community present at the site, ease of access, and how frequently it is crossed (Ross 2006). Kiteboarders generally need a clear area of open space to assemble and launch their gear, further reducing the number of locations appropriate for accessing the water.

3.4. Transport of pest species

Invasive plants and animals pose a major threat to coastal ecosystems, with most invasive marine species arriving as larvae or propagules in the ballast water of commercial shipping boats or *via* aquaculture (Hewitt *et al.* 2004; Richardson *et al.* 2016). However, there has been increased recognition of the role that recreational craft can play in transport of pest species, coupled with targeted education campaigns (Rothlisberger *et al.* 2010). Once introduced to an area, invasive species can quickly outcompete natives for space, food or other resources, or reduce populations directly though predation or herbivory. In addition to established invasive species in many waters, there are a large number of algae, crustaceans, molluscs and other invertebrates with the potential to become established under the right circumstances (Hewitt *et al.* 2004). There is increasing recognition that the most effective approach to minimising environmental and socioeconomic impacts of invasive species is to prevent their initial establishment and spread (Caplat and Coutts 2011).

While invasive marine species likely arrive in a country *via* commercial means, transportable recreational craft can play an important role in their spread following their initial establishment (Rothlisberger *et al.* 2010). The majority of research on this risk has examined larger craft such as motorboats carried on trailers; however, the pathway indicated in these cases could logically apply to smaller craft and equipment such as kiteboards, windsurfers, small sailing dinghies, or indeed any equipment that is transported between sites without thorough cleaning and inspection, such as wetsuits (Bacela-Spychalska *et al.* 2013; Smith *et al.* 2020).

Many invertebrates have a planktonic larval stage, while marine algae often disperse *via* propagules with even small pieces of tissue often able to remain reproductively viable in some species. If larvae, propagules, or small pieces remain on wet equipment, such as a kite or the soles of booties, they may be able to survive during transport to other sites. While the chances of this may be small, it may only take a small amount of material to survive for an invasive species to successfully enter a new area and the consequences can be profound and long lasting (Giakoumi *et al.* 2019).

4. Information gaps and synopsis

Management authorities are under increasing pressure to manage wind-powered craft, as they do for powered craft, yet there is currently an information void in which to make decisions. Here, we identify information gaps to clarify prevailing uncertainty for managers, and to highlight these to applied scientists who may address some of these gaps. We outline several impact pathways through which wind-powered craft may detrimentally affect coastal ecosystems and their constituent components, and

which span terrestrial, shoreline and nearshore marine systems. These are chronically understudied for wind-powered craft, but often some research is available on these pathways for powered craft and their impacts (e.g. Scarton 2018). With the exception of bird responses, which can occur at substantial distances and cause decreased numbers or use of habitat, disturbance by wind-powered craft on other fauna (including that which occurs on the surface or under the water) has not been examined. The stimulus attributes - which may exceed some powered craft in terms of intensity – have not been documented. Any impacts on terrestrial or marine substrates, or quantification of collision rates or capacity to transport pests, are unavailable. Similarly, associations with population or assemblage level impacts have not been attempted.

We propose the following steps to help build a way forward for the sustainable use of wind-powered recreational craft and enable co-existence with environmental values:

1. Address existing knowledge gaps using baseline methods developed for monitoring other vectors of disturbance and apply them for wind-powered craft (*sensu* Giglio *et al.* 2020). This will involve engaging appropriately experienced ecologists but should also involve the various craft users to better understand the human dimensions (including values, attitudes, beliefs and behaviours) of this group. Perceptions of impacts among the users is likely important to any behaviour change campaign, and a critical underpinning of effective social marketing (Decker, Brown, and Knuth 2021). Other areas to target include impacts on non-avian values such as vegetation (including macroalgae), substrates, megafauna, fish and invertebrates.
2. While conducting Step 1, take a precautionary principle approach and assume these activities do exert negative environmental and conservation pressures (see, for example, Diogo *et al.* 2020). This is necessary, as it may take several years for knowledge gaps to be addressed during which long-lasting environmental harm can occur, especially in areas where these activities have not occurred previously.
3. Encourage coastal managers to be pro-active and develop clear guidelines for these new and emerging recreational activities. This can include legislative amendments, compliance, engaging with stakeholders, provision of guidelines and community outreach (Giglio *et al.* 2020). Much of this can be informed by Step 1.
4. Reform coastal, terrestrial and marine legislation, management planning and procedures to enable a more seamless approach to managing activities which intersect all these areas (e.g. Powell *et al.* 2019). Currently there can be blunt or ambiguous demarcations of management, jurisdiction and tenure on the coastal fringe based on features such as high water mark. This can make holistic and effective management of recreational activities difficult and inconsistent. Planning which avoids overlap between WPC and areas of high natural value could be based on spatially explicit modelling (e.g., Laursen *et al.* 2021).
5. Develop educational campaigns aimed at the wind-powered craft recreational community consisting of the following elements, and based upon foundational human dimension research yet to be undertaken, and developed in collaboration with the users of wind-powered craft (Decker *et al.* 2021):
    a. Awareness raising of key environmental values and conservation issues that intersect with their activities (Buonocore *et al.* 2021).
    b. Promotion of minimal impact techniques and methods (Decker *et al.* 2021).
    c. Highlight the importance of maintaining equipment hygiene to curtail the spread of foreign organisms, pests and pathogens (Cunningham *et al.* 2019).

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Supplemental data

Supplemental data for this article can be accessed here.

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References

Andersen, S. M., J. Teilmann, R. Dietz, N. M. Schmidt, and L. A. Miller. 2012. "Behavioural Responses of Harbour Seals to Human-Induced Disturbances." *Aquatic Conservation: Marine and Freshwater Ecosystems* 22 (1): 113–121. doi:10.1002/aqc.1244.

Andretzke, H., J. Dierschke, F. Jachmann, K. Normann, J. Herrmann, and S. Hagen. 2011. *Auswirkungen Des Kitesurfens Auf Den Vogelzug Im Seeseitigen Meeresgebiet Vor Norderney 2010/2011*. Norderney, Germany: Nationalparkverwaltung Niedersächsisches Wattenmeer, BIOS and Gavia Eco Research. https://loveitlikealocal.de/wp-content/uploads/2016/02/kite-surfer-bericht_bios_gavia_2011.11.23_end.pdf

Bacela-Spychalska, K., M. Grabowski, T. Rewicz, A. Konopacka, and R. Wattier. 2013. "The 'Killer Shrimp' *Dikerogammarus Villosus* (Crustacea, Amphipoda) Invading Alpine Lakes: Overland Transport by Recreational Boats and Scuba-Diving Gear as Potential Entry Vectors?" *Aquatic Conservation: Marine and Freshwater Ecosystems* 23 (4): 606–618. doi:10.1002/aqc.2329.

Batten, L. A. 1977. "Sailing and Reservoirs and Its Effects on Waterbirds." *Biological Conservation* 11 (1): 49–58. doi:10.1016/0006-3207(77)90027-1.

Battley, P. F. 2018. *An Evaluation of the Impact of a National Kite Boarding Championship on Shorebird Behaviour at the Manawatu Estuary. DOC Research and Development Series 351*. New Zealand: Department of Conservation. https://www.doc.govt.nz/globalassets/documents/science-and-technical/drds351entire.pdf

Beauchamp, A. J. 2009. *Distribution, Disturbance and Bird Movement during a Spring Tide and Kite Surfing Period at Ruakaka Estuary – 10–15 March 2009*. Whangarei, New Zealand: Northland Conservancy, Department of Conservation. https://www.researchgate.net/publication/322365014_On_the_effects_of_kitesurfing_on_waterbirds_-_a_review

Bergmann, M. 2010. *Auswirkungen Des Kite-Surfens Vor Upleward Auf Die Brut Und Rastvögel Im Nationalpark Niedersächsisches Wattenmeer*. Aurich, Germany: Gemeinde Krummhörn, Büro für Ökologie und Landschaftsplanung. https://www.researchgate.net/publication/322365014_On_the_effects_of_kitesurfing_on_waterbirds_-_a_review

Bilotta, G. S., A. M. Milner, and I. Boyd. 2014. "On the Use of Systematic Reviews to Inform Environmental Policies." *Environmental Science & Policy* 42: 67–77. doi:10.1016/j.envsci.2014.05.010.

Blüml, V., A. Degen, D. Frank, and A. Schönheim. 2013. *Auswirkungen Des Kite-Surfens an Den Standorten Dornumersiel Und Neuharlingersiel Auf Rastvögel Im Nationalpark Niedersächsisches Wattenmeer – Avifaunistische Begleituntersuchung 2012–2013*. Osnabrück, Germany: Nationalparkverwaltung Niedersächsisches Wattenmeer and BMS-Umweltplanung.

Bötsch, Y., Z. Tablado, and L. Jenni. 2017. "Experimental Evidence of Human Recreational Disturbance Effects on Bird-Territory Establishment." Proceedings of the Royal Society B: Biological Sciences 284: 20170846. doi:10.1098/rspb.2017.0846.

Buonocore, E., U. Grande, P. P. Franzese, and G. F. Russo. 2021. "Trends and Evolution in the Concept of Marine Ecosystem Services: An Overview." *Water* 13 (15): 2060. doi:10.3390/w13152060.

Burfeind, D. D., and G. W. Stunz. 2006. "The Effects of Boat Propeller Scarring Intensity on Nekton Abundance in Subtropical Seagrass Meadows." *Marine Biology* 148 (5): 953–962. doi:10.1007/s00227-005-0136-9.

Buskey, E. J., and D. K. Hartline. 2003. "High-Speed Video Analysis of the Escape Responses of the Copepod *Acartia Tonsa* to Shadows." *The Biological Bulletin* 204 (1): 28–37. doi:10.2307/1543493.

Caplat, P., and S. R. Coutts. 2011. "Integrating Ecological Knowledge, Public Perception and Urgency of Action into Invasive Species Management." *Environmental Management* 48 (5): 878–881. doi:10.1007/s00267-011-9747-8.

Carney, K. M., and W. J. Sydeman. 1999. "A Review of Human Disturbance Effects on Nesting Colonial Waterbirds." *Waterbirds: The International Journal of Waterbird Biology* 22 (1): 68–79. www.jstor.org/stable/1521995. doi:10.2307/1521995.

Carr, J. M., and S. L. Lima. 2010. "High Wind Speeds Decrease the Responsiveness of Birds to Potentially Threatening Moving Stimuli." *Animal Behaviour* 80 (2): 215–220. doi:10.1016/j.anbehav.2010.04.021.

Charuvi, A., D. Lees, H. K. Glover, A. R. Rendall, P. Dann, and M. A. Weston. 2020. "A Physiological Cost to Behavioural Tolerance." *Behavioural Processes* 181: 104250. doi:10.1016/j.beproc.2020.104250.

Cunningham, S., L. Teirney, J. Brunton, R. McLeod, R. Bowman, D. Richards, R. Kinsey, et al. 2019. "Mitigating the Threat of Invasive Marine Species to Fiordland: New Zealand's First Pathway Management Plan." *Management of Biological Invasions* 10 (4): 690–708. doi:10.3391/mbi.2019.10.4.07.

Currer, I. 2004. *Windsurfing: The Complete Guide*. York: Air Supplies.

Decker, D. J., T. L. Brown, and B. A. Knuth. 2021. "Human Dimensions Research: Its Importance in Natural Resource Management." In *Natural Resource Management*, edited by A. W. Ewert, 29–47. New York: Routledge.

Diogo, H., P. Veiga, C. Pita, A. Sousa, D. Lima, J. G. Pereira, J. M. Gonçalves, et al. 2020. "Marine Recreational Fishing in Portugal: Current Knowledge, Challenges, and Future Perspectives." *Reviews in Fisheries Science & Aquaculture* 28 (4): 536–560. doi:10.1080/23308249.2020.1777083.

Drewes, C. D., and C. R. Fourtner. 1989. "Hindsight and Rapid Escape in a Freshwater Oligochaete." *The Biological Bulletin* 177 (3): 363–371. doi:10.2307/1541596.

Figueiredo de Almeida Silva, L. 2020. *Effects of Human Disturbances on Birds at the Avon-Heathcote Estuary*. Christchurch, New Zealand: Avon Heathcote Estuary Trust (AHEIT).

Filby, N. E., F. Christiansen, C. Scarpaci, and K. A. Stockin. 2017. "Effects of Swim-with-Dolphin Tourism on the Behaviour of a Threatened Species, the Burrunan Dolphin *Tursiops australis*." *Endangered Species Research* 32: 479–490. doi:10.3354/esr00826.

Filby, N. E., K. A. Stockin, and C. Scarpaci. 2014. "Long-Term Responses of Burrunan Dolphins (*Tursiops Australis*) to Swim-with Dolphin Tourism in Port Phillip Bay, Victoria, Australia: A Population at Risk." *Global Ecology and Conservation* 2: 62–71. doi:10.1016/j.gecco.2014.08.006.

Francis, C. D., C. P. Ortega, and A. Cruz. 2009. "Noise Pollution Changes Avian Communities and Species Interactions." *Current Biology: CB* 19 (16): 1415–1419. doi:10.1016/j.cub.2009.06.052.

Fraser, M. W. 1987. "Reactions of Sea-Ducks to Windsurfers." *British Birds* 80: 424.

Gadd, M., J. Boothroyd, and A. Durrell. 1985. *The Book of Windsurfing: A Guide to Boardsailing Techniques*. Nelson, Victoria: Firefly Books Ltd.

Giakoumi, Sylvaine, Stelios Katsanevakis, Paolo G. Albano, Ernesto Azzurro, Ana Cristina Cardoso, Emma Cebrian, Alan Deidun, et al. 2019. "Management Priorities for Marine Invasive Species." *The Science of the Total Environment* 688: 976–982. doi:10.1016/j.scitotenv.2019.06.282.

Giglio, V. J., O. J. Luiz, and C. E. Ferreira. 2020. "Ecological Impacts and Management Strategies for Recreational Diving: A Review." *Journal of Environmental Management* 256: 109949. doi:10.1016/j.jenvman.2019.109949.

Global Kitesports Association. 2017. *Kitesurfing and Birds – A Review*. Hamburg: Global Kitesports Association. Accessed November 2020. www.global-kitesports.org/wp-content/uploads/2018/01/Final-Study-Birds-and-Kitesurfing_2017.pdf

Gomon, M., D. Bray, and R. Kuiter. 2008. *Fishes of Australia's Southern Coast*. Melbourne: New Holland Press.

Gratwick, A. 2015. *The Kiteboarding Manual*. London: Bloomsbury.

Gray, E., and M. A. Weston. 2021. "Pilot Perceptions of Options to Manage Drone-Wildlife Interactions; Associations with Wildlife Value Orientations and Connectedness to Nature." *Journal for Nature Conservation* 64: 126090. doi:10.1016/j.jnc.2021.126090.

Haddaway, N. R., P. Woodcock, B. Macura, and A. Collins. 2015. "Making Literature Reviews More Reliable through Application of Lessons from Systematic Reviews." *Conservation Biology : The Journal of the Society for Conservation Biology* 29 (6): 1596–1605. doi:10.1111/cobi.12541.

Hardiman, N., and S. Burgin. 2010. "Recreational Impacts on the Fauna of Australian Coastal Marine Ecosystems." *Journal of Environmental Management* 91 (11): 2096–2108. doi:10.1016/j.jenvman.2010.06.012.

Hewitt, C. L., M. L. Campbell, R. E. Thresher, R. B. Martin, S. Boyd, B. F. Cohen, D. R. Currie, et al. 2004. "Introduced and Cryptogenic Species in Port Phillip Bay, Victoria, Australia." *Marine Biology* 144: 183–202. doi:10.1007/s00227-003-1173-x.

Hübner, T., and D. Putzer. 1985. " Störungsökologische untersuchungen rastender kormorane an niederrheinischen kiesseen bei störungen durch kiestransport, segel-, surf- und angelsport ." *Seevögel* 6: 122–126.

Hume, R. A. 1976. "Reactions of Goldeneyes to Boating." *British Birds* 69: 178– 179.

Hüttemann, M. 2013. " Kitesurfen und vogelschutz. Eine Untersuchung der situation am kitespot und Naturschutzgebiet 'Grüner Brink' auf der Insel Fehmarn." Diploma thesis, Leibniz University.

Jansen, M. 2008. *Kleine- en Wilde zwanen op het Veluwemeer, een samenvatting van drie seizoenen tellen en observeren*. Rapport in eigen beheer.

Jansen, M. 2011. *Monitoring Kitesurfzone Wolderwijd. Eindrapport*. Elburg, the Netherlands: Provincie Flevoland and the Provincie Gelderland.

Keller, V., and H. Stark. 2012. *Überprüfung Der Thurgauer Kitesurfzonen Am Bodensee*. Sempach: Kanton Thurgau, Schweizerische Vogelwarte.

Kennedy, R. O., S. I. Lonhart, and J. J. Stachowicz. 2019. "Human-Induced Reductions in Fish Predator Boldness Decrease Their Predation Rates in Kelp Forests." Proceedings of the Royal Society B: Biological Sciences 286: 20182745. doi:10.1098/rspb.2018.2745.

Koepff, C., and K. Dietrich. 1986. "Störungen von küstenvögeln durch wasserfahrzeuge." *Vogelwarte* 33: 232–248.

Krijgsveld, K. L., R. Smits, and J. Van Der Winden. 2008. *Verstoringsgevoeligheid van vogels: update literatuurstudie naar de reacties van vogels op recreatie*. Culemborg, The Netherlands: Bureau Waardenburg, Vogelbescherming Zeist Nederland.

Krüger, T. 2016. "On the Effects of Kitesurfing on Waterbirds – A Review." *Inform. d. Naturschutz Niedersachs* 36 (1): 3–64.

Küsters, E., and H. Von Raden. 1986. "Zum einfl uss von tieffl ug, schiessbetrieb und anderen anthropogenen störungen auf vögel im wattenmeer bei list/sylt." *Vogel Luftverk* 6: 75–89.

Larson, C. L., S. E. Reed, A. M. Merenlender, and K. R. Crooks. 2016. "Effects of Recreation on Animals Revealed as Widespread through a Global Systematic Review." *PloS One* 11 (12): e0167259. doi:10.1371/journal.pone.0167259.

Laursen, K., T. Bregnballe, O. R. Therkildsen, T. E. Holm, and R. D. Nielsen. 2017. "Disturbance of Waterbirds by Water-Based Recreational Activities – A Review." *Dansk Ornitologisk Forenings Tidsskrift* 111: 96–112.

Laursen, Karsten, Berit C. Kaae, Jesper Bladt, Hans Skov-Petersen, Preben Clausen, Anton Stahl Olafsson, Hélène Draux, et al. 2021. "Countrywide Screening of Spatiotemporal Overlap between Coastal and Marine Recreation and Waterbirds in Denmark." *Journal of Outdoor Recreation and Tourism* 35: 100399. doi:10.1016/j.jort.2021.100399.

Lethlean, H., W. F. Van Dongen, K. Kostoglou, P. J. Guay, and M. A. Weston. 2017. "Joggers Cause Greater Avian Disturbance than Walkers." *Landscape and Urban Planning* 159: 42–47. doi:10.1016/j.landurbplan.2016.08.020.

Lewis, L. J., and T. Adcock. 2017. *An Assessment of the Effects of Kitesurfing and Other Activities on the Waterbirds using Dollymount Strand*. Dublin: Dublin City Council and BirdWatch Ireland. https://a.storyblok.com/f/47927/x/fe2cd3cf66/171110_dollymount-waterbird-study_final.pdf

Liley, D., and H. Fearnley. 2012. *Poole Harbour Disturbance Study*. Wareham, UK: Natural England and Footprint Ecology. https://www.footprint-ecology.co.uk/reports/Liley%20and%20Fearnley%20-%202012%20-%20Poole%20Harbour%20Disturbance%20Study.pdf

Liley, D., K. Cruickshanks, J. Waldon, J, and H. Fearnley. 2011. *Exe Disturbance Study*. Wareham, UK: Exe Estuary Management Partnership and Footprint Ecology. https://www.footprint-ecology.co.uk/reports/Liley%20et%20al.%20-%202011%20-%20Exe%20Disturbance%20Study.pdf

Linaker, R. 2012. Recreational Disturbance at the Teesmouth and Cleveland Coast European Marine Site. Bird Disturbance Fieldwork Winter 2011/2012. York: Natural England and University of York. https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=1b7fef3d58e7223bc8b9ecadc5c13400394c7d62.

Loss, S. R., T. Will, and P. P. Marra. 2015. "Direct Mortality of Birds from Anthropogenic Causes." *Annual Review of Ecology, Evolution, and Systematics* 46 (1): 99–120. doi:10.1146/annurev-ecolsys-112414-054133.

Lukas, Juliane, Pawel Romanczuk, Haider Klenz, Pascal Klamser, Lenin Arias Rodriguez, Jens Krause, David Bierbach, et al. 2021. "Acoustic and Visual Stimuli Combined Promote Stronger Responses to Aerial Predation in Fish." *Behavioral Ecology: Official Journal of the International Society for Behavioral Ecology* 32 (6): 1094–1102. doi:10.1093/beheco/arab043.

Madsen, J. 1998. "Experimental Refuges for Migratory Waterfowl in Danish Wetlands. I. Baseline Assessment of the Disturbance Effects of Recreational Activities." *Journal of Applied Ecology* 35 (3): 386–397. doi:10.1046/j.1365-2664.1998.00314.x.

Mayer, M., D. Natusch, and S. Frank. 2019. "Water Body Type and Group Size Affect the Flight Initiation Distance of European Waterbirds." *PloS One* 14 (7): e0219845. doi:10.1371/journal.pone.0219845.

McBlain, M., K. A. Jones, and G. Shannon. 2020. "Sleeping Eurasian Oystercatchers Adjust Their Vigilance in Response to the Behaviour of Neighbours, Human Disturbance and Environmental Conditions." *Journal of Zoology* 312 (2): 75–84. doi:10.1111/jzo.12812.

Møller, A. P. 2014. "Life History, Predation and Flight Initiation Distance in a Migratory Bird." *Journal of Evolutionary Biology* 27 (6): 1105–1113. doi:10.1111/jeb.12399.

Møller, A. P., and P. Tryjanowski. 2014. "Direction of Approach by Predators and Flight Initiation Distance of Urban and Rural Populations of Birds." *Behavioral Ecology* 25 (4): 960–966. doi:10.1093/beheco/aru073.

Morrison, C. E., R. N. Johnson, C. E. Grueber, and C. J. Hogg. 2020. "Genetic Impacts of Conservation Management Actions in a Critically Endangered Parrot Species." *Conservation Genetics* 21 (5): 869–877. doi:10.1007/s10592-020-01292-4.

Ojanen, M. 1979. "Effect of a Cold Spell on Birds in Northern Finland in May 1968." *Ornis Fennica* 56: 148–155.

Orth, R. J., J. S. Lefcheck, and D. J. Wilcox. 2017. "Boat Propeller Scarring of Seagrass Beds in Lower Chesapeake Bay, USA: Patterns, Causes, Recovery, and Management." *Estuaries and Coasts* 40 (6): 1666–1676. doi:10.1007/s12237-017-0239-9.

Palmer, G. 2019. *Wildlife of the Otways and Shipwreck Coast*. Clayton: CSIRO Publishing.

Petch, N., G. S. Maguire, T. A. Schlacher, and M. A. Weston. 2018. "Motivations and Behavior of off-Road Drivers on Sandy Beaches." *Ocean & Coastal Management* 163: 82–91. doi:10.1016/j.ocecoaman.2018.05.021.

Phaka, F. M., M. P. Vanhove, L. H. Du Preez, and J. Hugé. 2022. "Reviewing Taxonomic Bias in a Megadiverse Country: Primary Biodiversity Data, Cultural Salience, and Scientific Interest of South African Animals." *Environmental Reviews* 30 (1): 39–49. J. doi:10.1139/er-2020-0092.

Pickthall, B. 2021. *Dinghy Sailing Start to Finish*. Leamington Spa: Fernhurst Books.

Powell, E. J., M. C. Tyrrell, A. Milliken, J. M. Tirpak, and M. D. Staudinger. 2019. "A Review of Coastal Management Approaches to Support the Integration of Ecological and Human Community Planning for Climate Change." *Journal of Coastal Conservation* 23 (1): 1–18. doi:10.1007/s11852-018-0632-y.

Rebolo-Ifrán, N., M. G. Grilli, and S. A. Lambertucci. 2019. "Drones as a Threat to Wildlife: YouTube Complements Science in Providing Evidence about Their Effect." *Environmental Conservation* 46 (3): 205–210. doi:10.1017/S0376892919000080.

Richardson, M. F., C. D. Sherman, R. S. Lee, N. J. Bott, and A. J. Hirst. 2016. "Multiple Dispersal Vectors Drive Range Expansion in an Invasive Marine Species." *Molecular Ecology* 25 (20): 5001–5014. doi:10.1111/mec.13817.

Ross, P. M. 2006. "Macrofaunal Loss and Microhabitat Destruction: The Impact of Trampling in a Temperate Mangrove Forest, NSW Australia." *Wetlands Ecology and Management* 14 (2): 167–184. doi:10.1007/s11273-005-7552-y.

Rothlisberger, J. D., W. L. Chadderton, J. McNulty, and D. M. Lodge. 2010. "Aquatic Invasive Species Transport via Trailered Boats: What is Being Moved, Who is Moving It, and What Can Be Done." *Fisheries* 35 (3): 121–132. doi:10.1577/1548-8446-35.3.121.

Rycyk, Athena M., Charles J. Deutsch, Margaret E. Barlas, Stacie K. Hardy, Katherine Frisch, Erin H. Leone, Douglas P. Nowacek, et al. 2018. "Manatee Behavioral Response to Boats." *Marine Mammal Science* 34 (4): 924–962. doi:10.1111/mms.12491.

Samia, Diogo S. M., Daniel T. Blumstein, Mario Díaz, Tomas Grim, Juan Diego Ibáñez-Álamo, Jukka Jokimäki, Kunter Tätte, et al. 2017. "Rural-Urban Differences in Escape Behavior of European Birds across a Latitudinal Gradient." *Frontiers in Ecology and Evolution* 5: 66. doi:10.3389/fevo.2017.00066.

Scarton, F. 2018. "Flight Initiation Distances in Relation to Pedestrian and Boat Disturbance in Five Species of Waders Breeding in a Mediterranean Lagoon." *Revue d'écologie* 73 (3): 375–384. doi:10.3406/revec.2018.1942.

Schafft, M., B. Wegner, N. Meyer, C. Wolter, and R. Arlinghaus. 2021. "Ecological Impacts of Water-Based Recreational Activities on Freshwater Ecosystems: A Global Meta-Analysis." *Proceedings. Biological Sciences B* 288 (1959): 20211623. doi:10.1098/rspb.2021.1623.

Schikore, T., K. Schröder, G. Siedenschnur, M. Zimmermann, S. Maehder, and O. Albrecht. 2013. *Auswirkungen Des Kite- Und Windsurfens Auf Rastvögel An Der Wurster Küste Im Nationalpark Niedersächsisches Wattenmeer An Den Standorten Dorum-Neufeld Und Wremen*. Osterholz-Scharmbeck, Germany: Nationalparkverwaltung Niedersächsisches Wattenmeer and BIOS. https://loveitlikealocal.de/wp-content/uploads/2016/02/bericht_kitesurf_wursten-end-bios.pdf

Schneider, T. J., G. S. Maguire, D. A. Whisson, and M. A. Weston. 2020. "Regulations Fail to Constrain Dog Space Use in Threatened Species Beach Habitats." *Journal of Environmental Planning and Management* 63 (6): 1022–1036. doi:10.1080/09640568.2019.1628012.

Schoeman, R. P., C. Patterson-Abrolat, and S. Plön. 2020. "A Global Review of Vessel Collisions with Marine Animals." *Frontiers in Marine Science* 7: 292. doi:10.3389/fmars.2020.00292.

Smith, E. R. C., H. Bennion, C. D. Sayer, D. C. Aldridge, and M. Owen. 2020. "Recreational Angling as a Pathway for Invasive Non-Native Species Spread: Awareness of Biosecurity and the Risk of Long Distance Movement into Great Britain." *Biological Invasions* 22 (3): 1135–1159. doi:10.1007/s10530-019-02169-5.

Smith, R. 2004. *The effect of Kite Surfing on Wader Roosts at West Kirby, Dee Estuary*. UK: Dee Estuary Conservation Group. Accessed November 2020. www.deeestuary.co.uk/decgks.htm

Steven, R., C. Pickering, and J. G. Castley. 2011. "A Review of the Impacts of Nature Based Recreation on Birds." *Journal of Environmental Management* 92 (10): 2287–2294. doi:10.1016/j.jenvman.2011.05.005.

Thomsen, M. S., P. Adam, and B. R. Silliman. 2009. "Anthropogenic Threats to Australasian Coastal Saltmarshes." In *Human Impacts on Salt Marshes. A Global Perspective*, edited by Silliman B. R., E. D. Grosholz, and M. D. Bertness, 361–390. Berkeley: University of California Press.

Tripovich, J. S., S. Hall-Aspland, I. Charrier, and J. P. Y. Arnould. 2012. "The Behavioural Response of Australian Fur Seals to Motor Boat Noise." *PloS One* 7 (5): e37228. doi:10.1371/journal.pone.0037228.

Van Rijn, S. H. M., K. L. Krijgsveld, and R. C. W. Strucker. 2006. *Gedrag Van Vogels Tijdens Een Kitesurfevenement in De Grevelingen*. Culemborg: Rijkswaterstaat Zeeland, Bureau Waardenburg.

Verdaat, H. J. P. 2006. "Gebiedsgebruik, Gedrag En Verstoring Van Roodkeelduikers (Gavia Stellata)." In *De Voordelta. Afstudeerproject Ter Ondersteuning Van De Nulmeting in Het Kader Van Het Monitoring En Evaluatie Programma, Project Mainport Rotterdam PMR – MEP MV2*. Culemborg: Hogeschool Van Hall, Larenstein, Bureau Waardenburg.

West, R. 2012. "Impacts of Recreational Boating Activities on the Seagrass *Posidonia* in SE Australia." *Wetlands Australia* 26 (2): 3–13. doi:10.31646/wa.295.

Weston, M. A. 2019. "Human Disturbance." In *The Population Ecology and Conservation of Charadrius Plovers*, edited by M. A. Colwell and S. M. Haig, 277–308. Boca Raton, FL: CRC Press.

Weston, M. A., C. O'Brien, K. N. Kostoglou, M. R. E, and Symonds, M. R. 2020. "Escape Responses of Terrestrial and Aquatic Birds to Drones: Towards a Code of Practice to Minimize Disturbance." *Journal of Applied Ecology* 57 (4): 777–785. doi:10.1111/1365-2664.13575.

Weston, M. A., E. M. McLeod, D. T. Blumstein, and P. J. Guay. 2012. "A Review of Flight-Initiation Distances and Their Application to Managing Disturbance to Australian Birds." *Emu - Austral Ornithology* 112 (4): 269–286. doi:10.1071/MU12026.