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Vulnerability of Grey Seal Pups (*Halichoerus grypus*) to Storm Disturbances in the Context of Climate Change: A British Isles Case Study

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Abstract: Marine mammals may be particularly vulnerable to climate change. While some climate-change-induced impacts on these species have been recognised, the potential consequences of storminess have been less well-defined, and understanding of its significance largely relies on anecdotal evidence. To quantify the relationship between storminess and its possible impacts on grey seal pups (*Halichoerus grypus*), data from marine wildlife rescue databases and hospitalisation records (2015–2024) within the British Isles were examined (n = 20,686). Daily mean windspeed was used as a proxy for storminess. Significant relationships were found between storminess and pups presenting with malnourishment, head trauma, flipper injury, other wounds, and infections. This study provides the first empirical evidence of the explicit impacts of storminess on seal pup health, with all the presenting conditions increasing and higher rates of call-outs and pup admissions to rescue centres following stormy weather also recorded. Given the predicted increase in storm severity, these findings will aid rescue and rehabilitation planning by helping to predict when rescuers can anticipate increased admissions and the potential injuries that pups may experience following storms. The potential significance to the long-term conservation of the species is also highlighted.

Keywords: climate change; storm casualties; seal pups; pupping phenology; injuries; welfare; conservation

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1. Introduction

The consequences of climate change are multifaceted and manifesting in ways that are detrimental to the health of marine ecosystems. Direct impacts of climate change within marine environments include rising sea surface temperature (SST) and sea surface height, and alterations in oceanic stratification [1]. These changes produce a cascade of effects for marine species, resulting in shifts in species abundance, distribution, predator–prey interactions, stranding frequency, and reproductive patterns, as well as increased exposure to algal blooms and disease [1]. Additional associated threats include increased seal disturbance caused by extreme weather events and increased coastal erosion and cliff falls [2].

The combined effects of long-term warming and extreme weather have emerged as a critical focus, particularly in recent Arctic research due to their profound influence on sea ice [3], and have been extensively investigated for various Arctic marine mammal species [4]. Regions other than the Arctic have also been assessed for climate change impacts, although the evidence often remains speculative, with anecdotal evidence and models used to infer effects [5,6]. However, it is now possible to gather empirical evidence of change which can validate and refine such predictions (e.g., [7,8]).

Recent changes in climate, including the impacts of the El Niño–Southern Oscillation (ENSO) and other episodic ocean anomalies, have produced well documented impacts on pinniped populations across the globe [5,9]. The reduction in oceanic upwellings drives changes in the body fat content, abundance, and distribution of seal prey, resulting in altered foraging behaviour and success [10,11]. In turn, observed declines in body condition have been documented in various seal species [5,12–14]. Climate change also impedes pinniped breeding dynamics, with associated shifts in reproductive cycles, shorter breeding seasons, and reduced reproductive outputs [5,15–19]. Cumulatively, these impacts affect survival and may ultimately manifest in declines in pinniped abundance [5,20].

One serious consequence of climate change is the escalating frequency and intensity of storm activity ('storminess') [21,22]. This is hypothesised to have serious implications for both the welfare and conservation of seal pups, although few cases in the published literature provide direct evidence. The early onset of strong autumnal storms in the Bering Sea has been tenuously linked to the alteration of departure-from-site phenology, direction of dispersal, and survival of Northern fur seal pups (*Callorhinus ursinus*) [23]. Similarly, severe storms, alongside the rapid acceleration of sea level rise, in subtropical US waters resulted in unforeseen changes in shoreline morphology with the nursing habitat for endangered Hawaiian monk seals (*Neomonachus schauinslandi*) being adversely affected by inundation [24]. This resulted in a considerable loss of pupping sites, increased pup drownings, and increased predation by Galapagos sharks (*Carcharhinus galapagensis*) [5].

Another species that may be at risk is the Atlantic grey seal (*Halichoerus grypus*), found along the UK's coastline, which hosts approximately 34% of the world's grey seal population [15,20,25,26]. These pinnipeds predominantly utilise beaches and rocky inlets as pupping sites, some of which flood during storms (Figure 1a,b) [27]. There is also evidence that some seal mothers exhibit considerable site fidelity to particular nursery sites [28–30], and this may be a complicating factor in restricting their ability to move to new sites when their original ones become unsuitable.

Since 2010, the northwestern coasts of Europe have experienced a series of powerful storms, with the number of major storms impacting the UK coastlines having tripled [31–34]. The roughening of the wave climate, as a result of increased windspeed from storms, has the potential to increase the severity of wave action on breeding sites, potentially increasing pup injuries and mortality [35–40]. This is supported by anecdotal evidence (Jarvis; Sayer; Howe; Bevington, pers comms/obs.).

Current responses by marine wildlife rescue organisations to injured or stranded pups involve admission to rescue centres or temporary holding facilities (Figure 1c). Such places are scarce across the British Isles. Projected increases in oceanic temperatures and sea levels will intensify storminess across the British Isles in coming decades [20,36,41]. A deeper understanding of the potential impacts of storminess on seal pups will better inform the rescue network and contribute to the protection and conservation of seal populations. Hence, this study aimed to quantify the broad hypothesis that storminess may be adversely impacting seal pup health and survival, and that this might be recognised by considering the frequency of casualties, the nature of these casualties, and the numbers of rescues. In addition, seal reproductive phenology (i.e., the timing of pupping) might be affected, and so this, too, was explored.

Figure 1. (**a**) Mother with her suckling whitecoat pup on Bardsey Island, Wales; (**b**) Grey seal mother with her whitecoat pup on a rocky shore on Bardsey Island, Wales; (**c**) Weaned grey seal pup admitted to Cornish Seal Sanctuary, Cornwall. Credit: (**a**,**b**): Mark P. Simmonds and (**c**): Keely Saville.

2. Materials and Methods

2.1. Data Collection and Processing

In the initial stages of this project, informal interviews were conducted with six relevant experts in seal rescue, rehabilitation, and pathology to help guide the research and identify potential datasets for investigation. Experts were identified from the research literature, online sources, and word of mouth. Representatives of the Seal Research Trust (SRT), Cornish Seal Sanctuary (CSS), British Divers Marine Life Rescue (BDMLR), the Royal Society for the Prevention of Cruelty to Animals (RSPCA), and Cornwall Marine Pathology Team were interviewed in person or online with, in some instances, follow-up questions by email. Where these experts are cited in the text, these quotes have been verified with them and permission was granted for their use. A total of 37 seal rehabilitation centres, organisations, and charities across the British Isles were subsequently contacted and, whilst twenty responses were received, only five were able to provide relevant data for this project. They provided 15,548 individual call-out records, 2644 admission records, and 2494 rescue records, all of which were considered in this investigation.

Grey seals are the most common seal species found around the British Isles [25], and harbour seals (*Phoca vitulina*) were only occasionally recorded in the data considered in this project. Initial data screening involved separating the two species and discarding harbour seal data due to their low representation in the dataset. To isolate species-specific and regional variations in pupping seasonality, the analysis was restricted to the primary pupping periods [42], with data from August to January considered. Based on previous studies, individuals were classified as ‘pups’ when they were up to 10 months old [40].

Records of ‘juvenile’ and ‘adult’ age classes, as well as any individual which was recorded to be older than 10 months, were subsequently discarded from the data. Animals of unknown age were also excluded. The remaining individuals, referred to as ‘whitecoats’, ‘weaned’, ‘pre-moult’, ‘mid-moult’, ‘post-moult’, or ‘moulter’ by rescue centres, are collectively referred to here as ‘pups’.

These data were then organised into 4 strands. First, details of pup admissions into Cornish and Irish rescue centres were provided by BDMLR and CSS, and Seal Rescue Ireland (SRI), respectively. The individual ‘reasons for rescue’ were pooled together into 6 non-mutually exclusive categories (Table 1; Figure 2). When records indicated multiple reasons for an individual pup’s admission to the facility, all reported reasons were included in the data analysis. Data on the number of rescued pups admitted into these facilities were subsequently extracted from the data sets, and this comprises the second strand of data. Pupping data makes up the third strand, wherein SRT provided monthly unique newborn pup counts (i.e., pups were only recorded on their first sighting) at sensitive seal sites across Cornwall.

Table 1. Classification of reasons for admission of seal pups to rescue centres where such data were available (i.e., in Cornwall, Ireland, and Suffolk).

Reason for Admission	Subcategories
Malnourishment	Starvation, underweight, lethargy, dehydration, unresponsive, hypoglycaemia, maternal separation.
Public Disturbance	Displaced by the public, public harassment, unadvised public lift, dog attack.
Head Trauma	Broken jaw, ocular ulcers, damaged teeth, mouth infection.
Flipper Injury	Broken limbs, nailbed swelling.
Other Wounds	Propeller wounds, bite wounds, entanglement, unspecified wounding (i.e., “wounds”) or wounds on body parts other than head or flippers.
Infection	Gastrointestinal, respiratory, hypothermia, nasal discharge, high body temperature, pyrexia, seal pox, lungworm.

The final strand explored pup stranding data. This was extracted from the BDMLR national call-out database, the Environmental Records Centre for Cornwall and the Isles of Scilly (ERCCIS) database, and SRI hospitalisation records. Data obtained from the same regions across datasets were cross-checked against dates and locations of rescue to avoid any duplication of data. The 58 locations recorded in the call-out database were consolidated into 15 regions based on their geographic proximity.

Meteorological data was sourced by the National Meteorological Library and Archive—Met Office UK. Windspeed is a key factor in predicting storminess impacts and was used as a reliable proxy [22,36,43]. Due to the unavailability of county-wide daily windspeed data (Ball, pers comm.), the average daily windspeed from the nearest operational meteorological weather stations to the coastlines where pup stranding data was obtained was used. To correspond with the pupping data, the daily average windspeed in Cornwall was averaged to produce monthly windspeed values. As part of quality control, certain daily mean windspeeds were recorded as blank in the database (Ball, pers comm.) and these were subsequently excluded from data analysis.

Figure 2. Examples of pup presenting conditions to rescue centres following periods of stormy weather: (**a**) Maternal separation in storm-induced swell; (**b**) Blunt force head trauma; (**c**) Severe mandibular fracture with secondary infection; (**d**) Deep laceration wounding to chest cavity. Credit: (**a**): Sue Sayer, Seal Research Trust and (**b**–**d**): British Divers Marine Life Rescue.

2.2. Statistical Analyses

All data were recorded and organised using Excel® version 2405 and statistically analysed using RStudio® version 4.1.1.

To examine if time or windspeed affected how many pups were born, a linear regression analysis was performed. Logistic regression analysis was used to assess if wind speed affected why pups were being admitted to rescue facilities, with location as a control factor. Given the increased chance of detecting false positives (i.e., Type I error) due to multiple comparisons here, we applied the Bonferroni correction to p-values. The Bonferroni correction is a common method to adjust the significance threshold of multiple tests by dividing the alpha (here 0.05) by the number of comparisons [44]. To examine if windspeed affected how many pups were rescued, a logistic regression analysis was performed for each location. A similar analysis was also performed on the stranding data.

3. Results

3.1. Pupping

Fitting a linear regression with year and month as predictor variables and the number of pups being born in Cornwall as the outcome variable showed a significant effect (F_{11} = 47.058, p = 1.451 × 10^{-6}) (Figure 3). We found that the number of pups increased by 4.967 each year (SE = 2.2118, p = 0.0388). The effect of month was also significant and pairwise post-hoc analysis (Tukey test) indicated that the number of pups born in September was significantly higher than August (estimate = 73.8, SE = 7.34, p < 0.0001) and October (estimate = 74.2, SE = 7.34, p < 0.0001). There was no significant difference between the number of pups born in August and October (estimate = 0.4, SE = 7.34, p = 0.9984). Neither adding an interaction term between year and month (F_2 = 1.5484, p = 0.2643) nor including monthly average windspeed as a predictor variable (F_1 = 3.3802, p = 0.09583) improve the fit of the model significantly. Birthing data for other regions was not available.

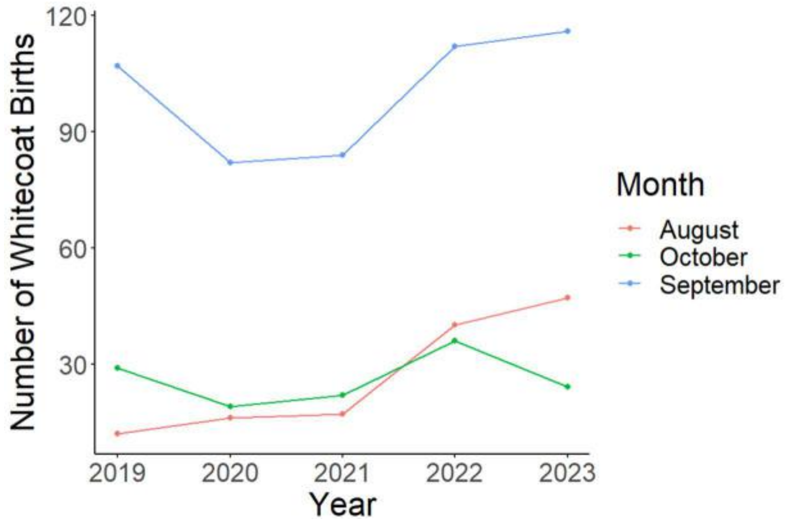

Figure 3. The number of unique whitecoat pups born during the pupping season over time in Cornwall.

3.2. Admission to Rescue Centres

Mixed effects logistic regression models with average windspeed as a fixed variable and location (Cornwall, Ireland, or Suffolk) as a random variable with a common slope and varying intercepts indicated significant associations between average windspeed and several presenting disorders between January 2015 and January 2024 (n = 1569). Pups were significantly more likely to be admitted to rescue centres with malnourishment, head trauma, flipper injury, other wounds, and/or infection as windspeed increased. To account for multiple comparisons, we applied the Bonferroni correction to the resulting p-values (Figure 4; Table 2).

Table 2. Results of mixed effects logistic regressions for each presenting condition of grey seal pups to rescue centres in Cornwall, Ireland, and Suffolk.

Reason for Admission	Estimate	p Value	% Increase per Unit of Windspeed (1 Knot)
Malnourishment	0.05367	1.14 × 10^{-8} *	5.5136
Public Disturbance	−0.009848	0.841	-
Head Trauma	0.03439	0.0482 *	3.4988
Flipper Injury	0.05778	0.000964 *	5.9482
Other Wounds	0.044621	6.05 × 10^{-6} *	4.5631
Infection	0.07317	4.10 × 10^{-9} *	7.5913

* Statistically significant.

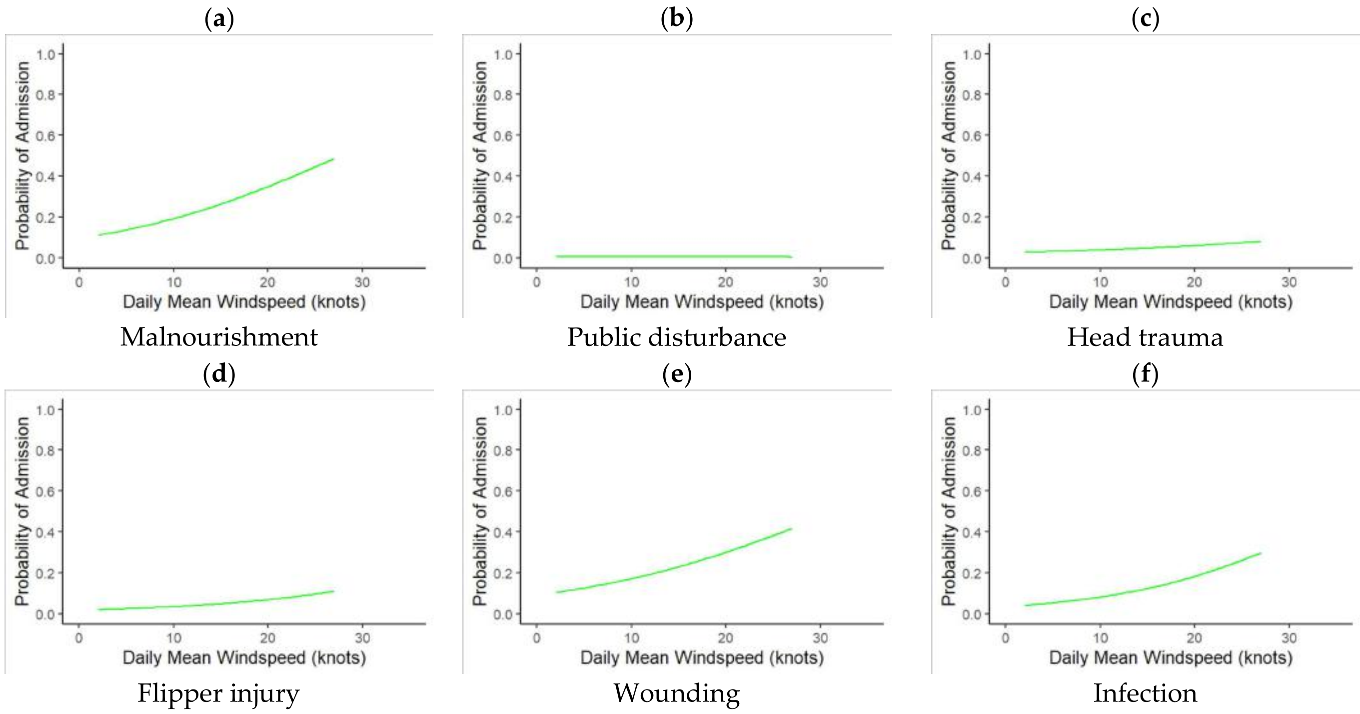

Figure 4. The relationship between storminess and the likelihood of pups presenting with (**a**) malnourishment; (**b**) public disturbance; (**c**) head trauma; (**d**) flipper injury; (**e**) wounding; or (**f**) infection, to rescue centres in Cornwall, Ireland, and Suffolk.

3.3. Rescue

To analyse the effect of windspeed on the number of rescues made for grey seal pups (n = 1511), we first fitted a mixed effects logistic regression model with a fixed effect of windspeed and a random effect of location with a common slope and different intercepts. We found that this model gave an estimate for the effect of windspeed on the number of rescues of 0.048687 (SEM = 0.006004), and this was significantly different from zero (Δdeviance = 65.259, df = 1, $p = 6.569 \times 10^{-16}$).

After fitting logistic regressions for each individual location, we found the windspeed had a significant effect on the chance of rescuing a pup in Cornwall, Ireland, Norfolk, Northumberland, and Suffolk (Figure 5; Table 3).

Table 3. Results of logistic regression models for grey seal pups needing to be rescued across the British Isles between January 2015 and January 2024 at different locations.

Location	Estimate	df	p Value	% Increase per Unit of Windspeed (1 Knot)
Cornwall	0.045904	2341	1.1×10^{-6} *	4.6974
Devon	0.05405	1114	0.265	-
Ireland	0.08352	1074	2.06×10^{-9} *	8.7107
Middlesbrough	0.05627	400	0.109	-
Newcastle	0.02735	1156	0.472	-
Norfolk	0.07678	942	0.00288 *	7.9804
Northumberland	0.07596	585	0.00149 *	7.8919
Scotland	−0.007995	1218	0.719	-
Suffolk	0.15730	1139	1.22×10^{-5} *	17.0347
Wales	−0.07928	1314	0.0911	-
Yorkshire	−0.01603	1327	0.51	-

* Statistically significant.

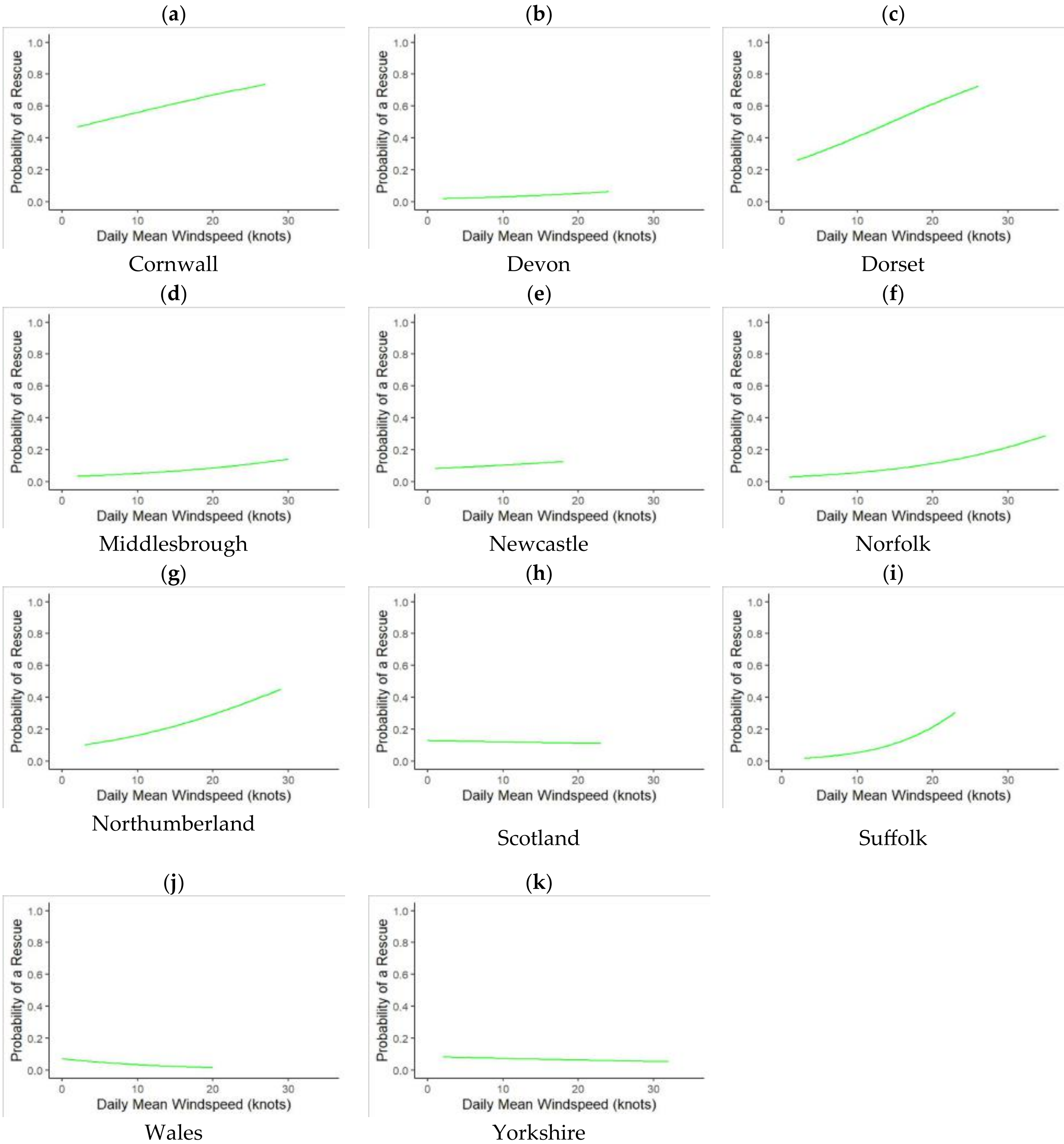

Figure 5. The relationship between storminess and the likelihood of a pup needing to be rescued in (**a**) Cornwall; (**b**) Devon; (**c**) Ireland; (**d**) Middlesbrough; (**e**) Newcastle; (**f**) Norfolk; (**g**) Northumberland; (**h**) Scotland; (**i**) Suffolk; (**j**) Wales; or (**k**) Yorkshire.

3.4. Call-Out

Like the previous analysis, to investigate the effect of windspeed on the number of call-outs made for grey seal pups (n = 10,215), we fitted a mixed effects logistic regression model with a fixed effect of windspeed and a random effect of location with a common slope and different intercepts. This model gave an estimate for the effect of windspeed on the number of call-outs of 0.0429 (SEM = 0.0042), and this was significantly different from zero (Δdeviance = 103.71, df = 1, $p < 2.2 \times 10^{-16}$).

After performing analyses for each location, we found the windspeed had a significant effect on the chance of getting a call-out in Cornwall, Ireland, Middlesbrough, Newcastle, Norfolk, and Northumberland (Figure 6, Table 4).

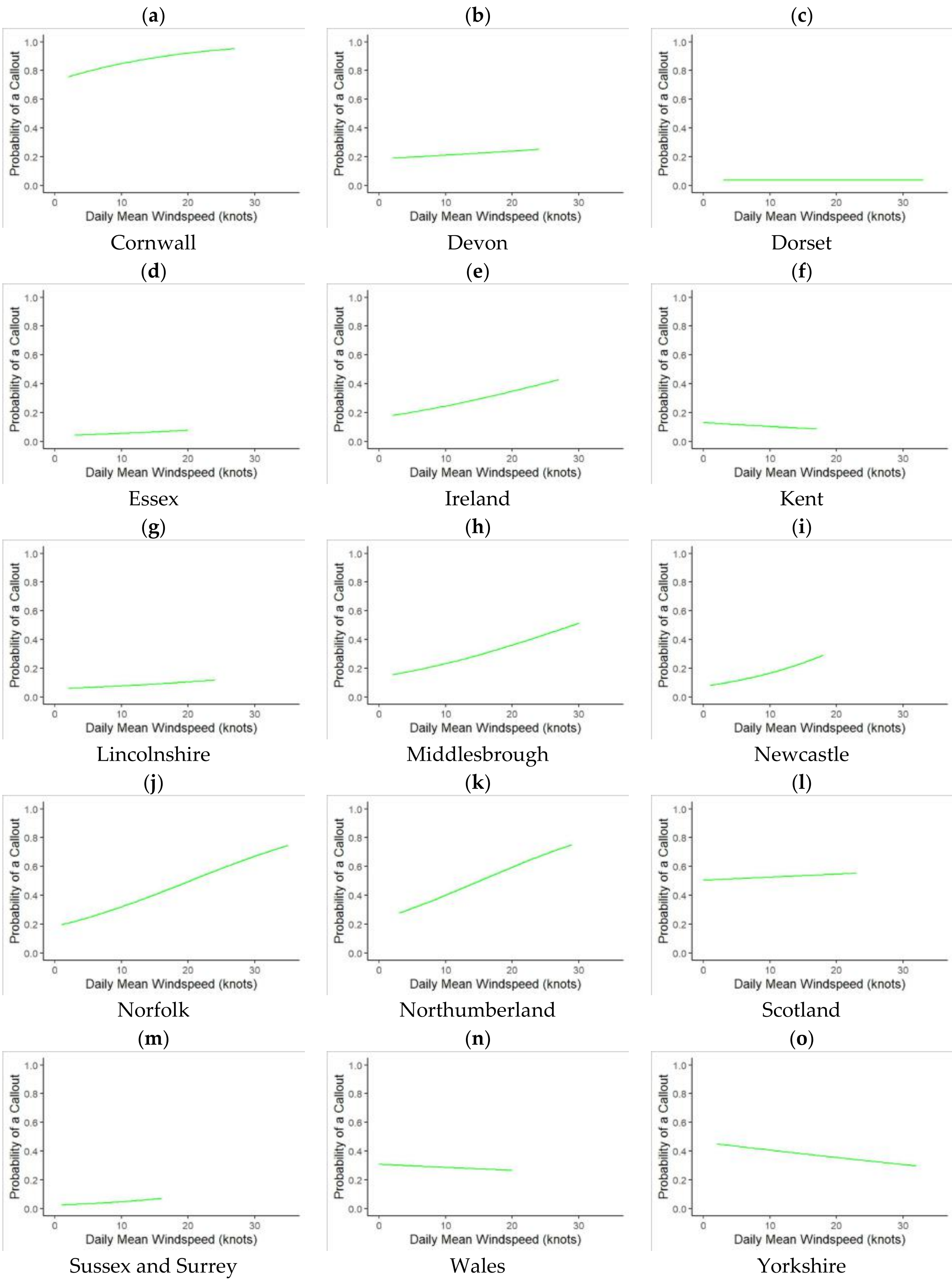

Figure 6. The relationship between storminess and the likelihood of a pup stranded in (**a**) Cornwall; (**b**) Devon; (**c**) Dorset; (**d**) Essex; (**e**) Ireland; (**f**) Kent; (**g**) Lincolnshire; (**h**) Middlesbrough; (**i**) Newcastle; (**j**) Norfolk; (**k**) Northumberland; (**l**) Scotland; (**m**) Sussex and Surrey; (**n**) Wales; or (**o**) Yorkshire.

Table 4. Results of logistic regression models for call-outs made for grey seal pups in locations across the British Isles between January 2015 and January 2024 at different locations.

Location	Estimate	df	*p* Value	% Increase per Unit of Windspeed (1 Knot)
Cornwall	0.07363	4122	1.37×10^{-12} *	7.6408
Devon	0.01622	1156	0.428	-
Dorset	−0.001522	765	0.961	-
Essex	0.03603	948	0.385	-
Ireland	0.4911	1822	1.82×10^{-5} *	5.0336
Kent	−0.02683	975	0.455	-
Lincolnshire	0.03286	958	0.307	-
Middlesbrough	0.06226	429	0.000974 *	6.4228
Newcastle	0.08986	1177	0.00419 *	9.4021
Norfolk	0.07325	1356	6.82×10^{-9} *	7.6
Northumberland	0.07908	1326	1.16×10^{-8} *	8.2291
Scotland	0.008445	1416	0.523	-
Sussex and Surrey	0.07151	948	0.236	-
Wales	−0.01004	1244	0.627	-
Yorkshire	−0.02199	1313	0.0917	-

* Statistically significant.

4. Discussion

4.1. Pupping

Pupping data indicated that September had a significantly higher whitecoat pup count in Cornwall, which is a month earlier than previous survey findings, and this supports the idea that pups may be being born earlier in the year than previously [45–49]. However, these results do not suggest that storminess is a reliable predictor of key parameters describing the timing of the pupping season. Hence, the data do not appear to support the hypothesis that storminess drives phenological advancements in pupping timing [46–49]. Previous studies have predominantly identified SST as the most influential proximate factor affecting pinniped reproductive phenology [47,50].

However, one previous study has noted that the pupping period of Australian fur seals (*Arctocephalus pusillus*) synchronises with winter zonal winds in the Bass Strait region [51], and a shift in peak birthing dates has also been described in harbour seals in the North Sea [49–51]. Peak pupping for grey seals in Cornwall was in October up until 2016 [45,52], but since then, has been in September, as shown in these data (Figure 3), as well as in the Report to Natural England 2020 [53]. The observed increase in births in August and reduced number of births in October, shown in Figure 3, support a change in the timing of pupping and suggest that continued monitoring is needed. This new situation also coincides with peak tourism time, creating increased overlap in interactions between humans and seals.

A trend of older females breeding earlier in the breeding season has been observed in pinnipeds [47]. Research has shown that mothers who give birth early in the season tend to nurse their pups longer, resulting in a higher likelihood of successful weaning [47,54,55]. It is plausible that older seal mothers are beginning to pup earlier as a response to mitigate the risk of pup loss or displacement during the latter part of the pupping season, which is characterised by a higher frequency of storms [39]. This shift in reproductive timing could have significant implications for population resilience in the context of climate change and, indeed, storms [5,47]. Therefore, maternal age should be considered in future analyses.

Female grey seals typically begin pupping at six years old and continue to reproduce annually for life, contingent upon sufficient body condition to sustain gestation [56,57]. One photo-identified grey seal along the Cornish coastline has reportedly given birth annually since 2003, with the exception of 2018. This interruption was suspected to be related to the extreme storm events, Brian and Ophelia, which occurred during the 2017 pupping season (Jarvis and Sayer, pers obs.). She lost her 2017 pup most likely as a result of the storms. One possibility was that her hormones were then out of sync for mating, resulting in a lack of oocyte fertilisation. Another possibility is that she had not regained condition at the time of implantation, so the 2018 fertilised oocyte did not implant.

4.2. Admission to Rescue Centres

Our results demonstrate that the likelihood of each presenting condition increases with windspeed, providing support for the notion that within the British Isles, the primary causes of mortality in seal pups are starvation, infection, and trauma [39], with storminess acting as a significant contributing factor. These findings further indicate an increased incidence of wounding during stormy weather.

Additionally, from our discussions with rescue centres, it became apparent that some were already overwhelmed at certain times of year by the numbers of pups needing treatment and that this may mean that some pups had to be euthanised.

4.2.1. Malnourishment

Storm surges have previously been correlated to high incidences of mother–pup separation [58–61], which prevents pups from feeding. This finding aligns with the observed relationship between increasing windspeed and malnourishment. This can lead to stranding due to malnutrition and starvation unless pups are rescued. Similarly, disturbances during nursing, such as those caused by storms, can disrupt necessary suckling periods, leading to insufficient body weight at weaning [62–64]. This can result in inadequate blubber insulation and a high surface-to-volume ratio, which increases metabolic demands [65].

One result of storminess is increased turbidity, and this may make it more difficult for the seals to locate prey using their senses of sight and 'wake-sensing' [66].

4.2.2. Public Disturbance

There is no apparent relationship between storminess and admissions related to human disturbance (Figure 4b). However, there has been a surge in public interest in marine wildlife and coastal land, sea, and air access in recent years that has increased pinniped disturbance, although the physiological consequences have not been defined [5,67,68]. Human disturbance may also be under-reported as it may not always be witnessed, and it may also be less prevalent in bad weather.

4.2.3. Head Trauma

The increased prevalence of head trauma in seal pups may be attributed to being thrown against underwater, offshore, or cliff rocks during storms [69]. Additionally, in the absence of their mothers, pups have been observed attempting to suckle on other seals or rocks (Sayer and Saville, pers obvs.). This latter behaviour could contribute to head trauma and subsequent dental damage [53].

4.2.4. Flipper Injury

Our findings, which show that flipper injuries increase with windspeed, support a previous study suggesting that the majority of flipper injuries and fractures are sustained during extreme weather [70]. Moreover, these datasets revealed numerous seal rescues occurred inland, possibly indicating that pups are seeking refuge from storm-inundated areas or being washed inland [36]. The increased incidence of flipper injuries during stormy weather may be attributed at least in part to prolonged movements across haul-outs on uneven land surface whilst searching for their mother, leading to injury and friction abrasions. Seals might also be forced to haul out on more marginal sites which offer more chance of harm, such as sharp rocky shores or public beaches.

4.2.5. Wounding

The influence of sea conditions later in the pupping season aligns with the potential for resource limitation (e.g., food and habitat resources) and intraspecific competition [47]. There is also an increased likelihood of seals overcrowding on haul-outs during high tides and stormy weather [68], which may help to explain the higher prevalence of bites and the significant relationship between storms and wounds observed in these results.

High windspeeds contribute to a rougher wave condition, often resulting in substantial coastal erosion [21,71]. The morphology and structural landscape of a pupping site can influence a pup's vulnerability to storm effects [36]. It can therefore be anticipated that physical injuries, such as wounds, will be more common along rocky shorelines during storms, as pups may be dashed against the rocks or get hit by stones falling from cliffs (Achilleos and Sayer, pers comms/obs.).

4.2.6. Infection

Poor nutrition may increase a pup's susceptibility to infection through decreased energy resources and exhaustion resulting in a weaker immune response [72]. This might result from altered food sources for weaned pups, as well as separation from their mothers during the nursing period for maternally dependent ones [60,72]. The observed significant positive relationship between windspeed and pups presenting with infection supports this hypothesis. For example, there has also been a marked increase in the prevalence of lungworm in pinnipeds examined in Cornwall in recent years (Barnett, pers comm.). While numerous factors may contribute to this trend, storminess could be a potential contributory factor perhaps by creating additional stress, thereby depressing the seals' immune systems, causing more serious infections (Barnett, pers comm.). Further research is necessary to quantify the impacts of storms on disease transmission in these populations.

4.3. Rescue and Call-Out

Anecdotally, a strong correlation exists between stormy weather and seal strandings (Jarvis; Thompson, pers comms.). The significant relationship found in our results between windspeed and number of rescues confirms this relationship. This is supported by the observed increase in serious injuries during stormy weather, indicating that as storminess increases, seals with more severe injuries are more likely to require rescuing.

The observed variation in call-outs between locations (Figure 6) might be partially explained by an increase in the number of pups along the coast (Howe, pers comm.). Future studies should incorporate abundance estimates to better understand the significance of trends. Additionally, standardising data collection methods across rescue centres would improve data consistency and comparability, enabling more robust analyses of injury patterns. Establishing universal protocols for recording injury type, severity, and environmental conditions at the time of rescue would help create a more comprehensive dataset, ultimately enhancing our ability to assess the impact of extreme weather events on seal populations. Refining storm impact modelling by integrating standardised rescue data with environmental variables could further improve predictions of weather-related injury risk.

4.4. Caveats

While windspeed is regarded as a reliable proxy for storminess [22,36,44], several authors have argued that a combination of strong winds and other climatic variables, such as low atmospheric pressure, is necessary to propagate storm surges [33,71]. The approach used here is limited to exploring a single variable (i.e., windspeed), and, in future research, incorporating multiple variables or developing a "storminess index" may provide a more accurate representation of stormy weather. From the perspective of the seal pup on the shore, the conditions that it is faced with will be a combination of factors including tidal height, wave and wind direction, and local topographical features.

In 2023, a particularly stormy year [73], a greater proportion of pups were observed swimming, exploring, and interacting with their mothers in the water [27]. This led to an alternative hypothesis suggesting that this exposure could potentially make them more resilient to poor wave conditions during storms and better able to survive. Generally speaking, though, younger pups are likely to be more vulnerable to being swept away.

Numerous studies have demonstrated that variations in the frequency of casualties can be attributed to differences in reporting effort [74,75]. Increased public awareness of seal rescue facilities is likely a contributing factor to improvements in data collection and reporting efforts, as indicated by a rise in public reports (Howe, pers comm.). However, this contradicts a recent report which recorded the lowest number of dead marine mammal strandings in August—a month associated with high tourist footfall [76]. This therefore suggests that the increased number of pup casualties was unlikely to be an artefact of increased awareness and reporting.

5. Conclusions

This project provides the first statistically supported evidence that storms are adversely impacting grey seal pups.

While data quality and recording limitations may have affected the ability to predict the influence of storminess on call-outs and pupping phenology, the results strongly suggest that grey seal pups are likely to experience increased welfare issues and reduced survival as a result of the anticipated larger magnitude storm events in British Isles waters in the coming decades. The site fidelity of mothers may be a significant factor contributing to the vulnerability of pups to severe weather changes.

Seals are exposed to the cumulative impacts of multiple stressors, some of which are increasing and being exacerbated by climate change. Our findings, given the predicted increase in seal pup casualties, reinforce the urgent need for an expansion of seal rehabilitation facilities in strategic locations with adequate long-term resourcing. This will complement the existing rescue network and alleviate the current and increasing strain on facilities, and will help improve the welfare of grey seals in the light of climate change.

Noting the importance of UK waters for this species, and the threat that increased storminess poses, conservation actions should be taken that will build resilience in the population—for example, ensuring that nursery sites are not affected by other negative impacts such as disturbance and plastic pollution. The research presented in this paper will hopefully serve as a catalyst for further investigation using a wider range of climatic variables to define storminess and encourage continued reporting efforts by rescue facilities. Continued research is essential to gain a comprehensive understanding of the vulnerability of grey seal pups in the British Isles, and seals more generally, to storm disturbances. In the long term, this may have significant conservation implications, particularly if storm-induced population losses exceed populations' capacity to maintain themselves.

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