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University of St Andrews

Sea Mammal Research Unit

Natural Environment Research Council

Scientific Advice on Matters Related to the Management of Seal Populations:

Interim Advice 2023

Natural Environment Research Council Special Committee on Seals

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Background

Under the Conservation of Seals Act 1970 and the Marine (Scotland) Act 2010, the Natural Environment Research Council (NERC) has a duty to provide scientific advice to government on matters related to the management of seal populations. NERC has appointed a Special Committee on Seals (SCOS) to formulate this advice so that it may discharge this statutory duty. Terms of Reference for SCOS and its current membership are given in Annex I.

Formal advice is given annually based on the latest scientific information provided to SCOS by the Sea Mammal Research Unit (SMRU). SMRU is an interdisciplinary research group at the University of St Andrews which receives National Capability funding from NERC to fulfil its statutory requirements. SMRU also provides government with scientific reviews of licence applications to shoot seals; information and advice in response to parliamentary questions and correspondence; and responds on behalf of NERC to questions raised by government departments about the management of marine mammals in general.

During the Covid-19 pandemic, the annual SCOS meeting timing moved from the traditional timing of late summer/early autumn (August/September) to the winter (December/January). However, due to this latter timing coinciding with the northwest Atlantic seal fieldwork season it was proving difficult to secure appropriate expertise relating to seal populations in this region. Therefore, a decision was made at the SCOS 2022 meeting to revert to the original timing. Due to the short interval between the full SCOS meeting in January 2023 and August 2023 it was recognised that there would be no new seal population estimates available. A decision was made to plan for an 'interim' meeting in August 2023 to ensure that any required advice on matters arising relating to the conservation and management of seals could be provided in a timely manner, avoiding a gap of 18 months in the provision of advice.

As a result, this report will not provide an update on the status of UK seal populations as has been provided in full SCOS reports. This report instead provides formal advice in the form of responses to specific questions raised in summer 2023 by the Marine Directorate (Scottish Government) (MDSG) and the Department of the Environment, Food and Rural Affairs (Defra). Natural Resources Wales (NRW) and the Northern Ireland Department of Agriculture, Environment were also approached for questions but had none at that time.

Advice 2023

1. Can SCOS advise on whether they would expect to see any impacts to seals from the current extreme sea water temperatures and if so, what these impacts might be (MDSG Q1).

Sea surface temperatures (SST) off the UK and Ireland were as much as 4-5°C above normal in June 2023 during a category 4 Marine Heat Wave (MHW). The coastal regions off the east coast of the UK, from Durham to Aberdeen saw the highest SST anomaly.

It is unlikely that the observed temperatures will have significant direct impacts on either grey or harbour seals in terms of their physiology or energetics. Any potential medium or longer term impacts are likely to be due to MHW effects on prey species.

There has been no detected increase in seal strandings/mortality in Scotland through to August 2023. However, evidence from MHW events in similar ecosystems suggest that there can be medium to long term effects that may not yet be apparent. Detection of long term effects will require targeted monitoring. However, considering the wide range of potential responses to MHW events, and the apparent absence of immediate impacts, SCOS highlighted the importance of increased vigilance to a range of effects and the potential need for responsive monitoring should some effects emerge. As part of the regular seal population monitoring programme several sections of the east coast (Helmsdale to Fife Ness, and Donna Nook to Scroby Sands) were surveyed in summer 2023, and east coast grey seal breeding sites will be surveyed in autumn 2023.

Negative impacts on many trophic levels, from invertebrates to marine birds and mammals, have been reported for MHWs in similar temperate marine ecosystems. These are briefly reviewed below. However, a recent review of MHW effects on demersal fish in temperate North Pacific and North Atlantic waters did not indicate that MHWs are major drivers of changes in demersal fish populations. Demersal species form the majority of grey and harbour seal prey in UK waters.

At present our ability to detect effects on seals in UK waters is limited to monitoring strandings records and detecting changes in population size for both species. Events such as the 2023 MHW highlight the potential utility of long term seal breeding site studies to detect changes in body condition and reproductive output and investment, as well as flagging up the need for finer scale regular assessments of fish stocks at appropriate temporal and geographical scales.

Large areas of the North Atlantic have experienced extreme high temperature anomalies, referred to as Marine Heat Waves (MHW), during the late spring and summer of 2023. Some of the most severe marine heat increases on Earth occurred in the seas surrounding the UK and Ireland. Sea surface temperatures (SST) off the UK and Ireland were as much as 4-5°C above normal (Figure 1a). The coastal regions off the east coast of the UK, from Durham to Aberdeen, and off the northwest coast of Ireland were particularly warm. Figure 1b shows sea surface temperatures on 18 June 2023, compared with the long-term (1981-2016) average.

The UK MHW coincided with a global trend of increased SST in 2023, with the highest-ever recorded global sea surface temperatures occurring in April and May 2023. In July 2023 NOAA estimated that

44% of the global ocean was experiencing MHW events compared to an expected 10-15% in a normal year. NOAA predictive modelling suggests that this will increase to approximately 50% in September (https://psl.noaa.gov/marine-heatwaves/#report accessed 30/07/2023) and that approximately 66% of the North Atlantic could be experiencing MHW conditions by October.

Recent modelling by Mercator Ocean International oceanographers suggests that the intensity of the MHW for most of the North Atlantic region has decreased, with temperature anomalies in the North Sea moving from extreme to moderate categories, with temperature anomalies of between 1°C and 2°C. (Mercator Ocean International, 2023).

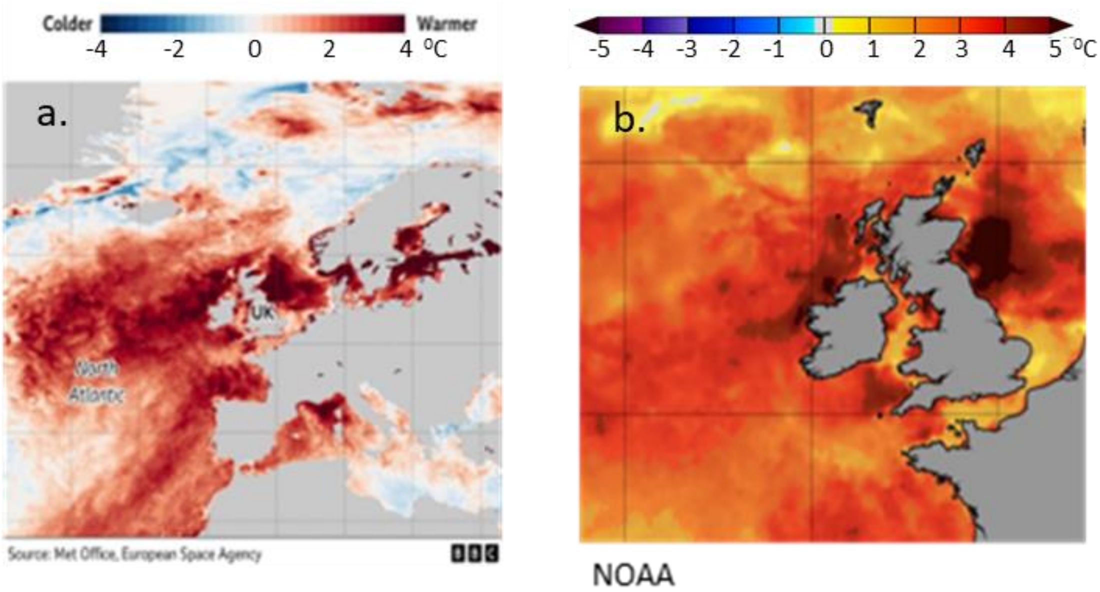

Figure 1. a) Map showing the widespread SST anomaly in the NE Atlantic and Baltic in June 2023. The map shows SST anomaly compared to the 1981 to 2016 June monthly average temperature (European Space Agency, 2023). b) SST anomaly estimates for 16th June 2023, showing an intense, wide area anomaly along the Scottish East and English NE coasts and the coast of western Ireland and Northern Ireland with temperatures up to 4^{0}C above the 1985 to 1993 average (New Scientist, 2023).

Such elevated temperatures are unprecedented in UK waters during spring and early summer, but are unlikely to have had a significant, direct impact on either grey or harbour seals in terms of their physiology or energetics. The large thermal gradient between the internal body core at ~37°C and the much colder seawater means that seals will be within their thermoneutral zone while swimming, even at water temperatures significantly higher than those observed during the MHW. Indeed, temperatures 3° - 5°C higher than the June peaks of the east coast MHW are routinely encountered during July to September (Figure 2) in the central and southern North Sea. Large numbers of both grey and harbour seals forage, haulout and breed in these regions and populations of both species have been increasing in the southern North Sea over the past 20 years, indicating that they are able to thrive in those water temperatures.

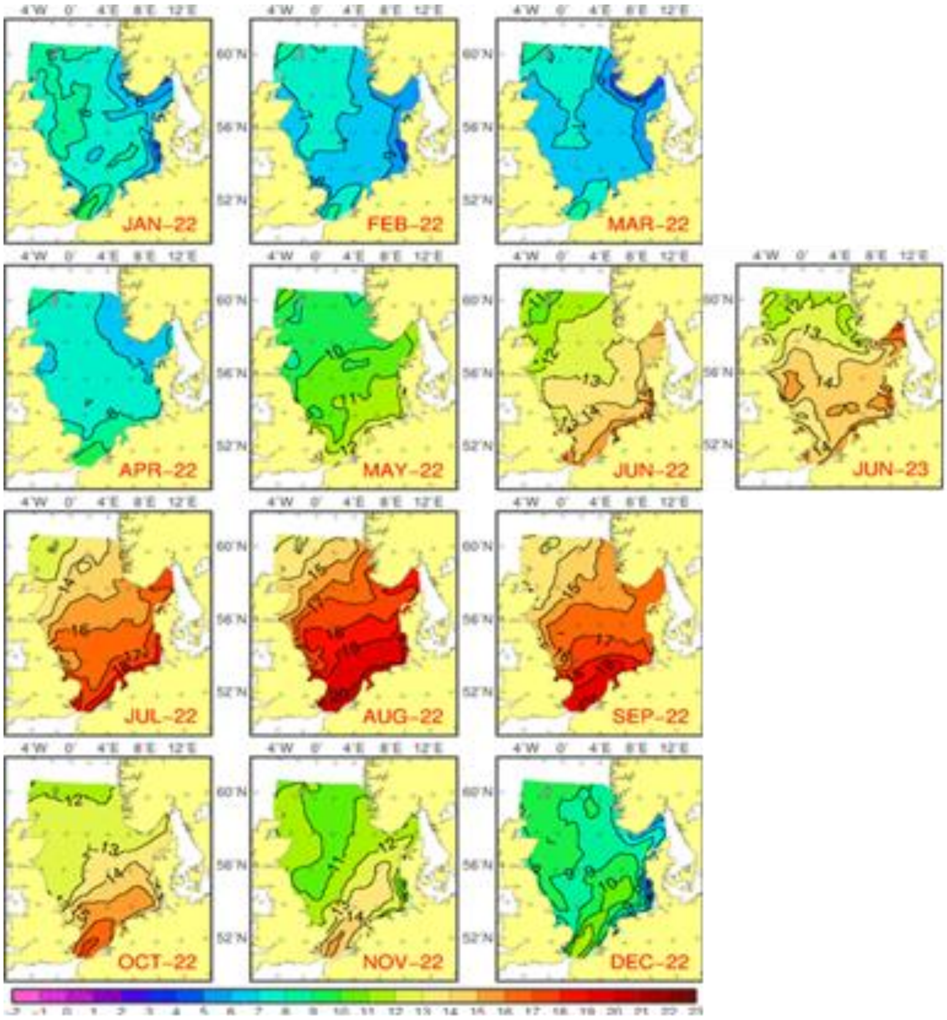

Figure 2. Monthly mean SST for 2022 and for June 2023 for the North Sea. June 2023 map shows a warm water mass along the coasts of SE Scotland and NE England, but the recorded temperatures are lower than the late summer temperatures of the whole of the central and southern North Sea. Modified from Bundesamt fur Seeschifffahrt und Hydrographie (BSH, 2023).

Warmer temperatures are more likely to impact animals in terms of thermoregulation when on land during breeding or haul out since opportunities to cool down are reduced. Even in cooler air temperatures of Autumn in the UK, grey seal females spend more time by pools on days with higher air temperatures and lower wind speed (Twiss *et al.*, 2000). Lactation appears to be a time of heightened cellular stress for grey seal females when additional thermal challenges may exacerbate other stressors (Armstrong *et al.,* 2023). If females cannot reduce metabolic costs during higher temperatures they may end lactation early, with potential impacts on pup survival (Shuert *et al.,* 2020).

As of early August 2023, there has been no reported increase in seal strandings/mortality in Scotland (SMASS pers comm.). Seal population monitoring data are being collected along the east coast in summer 2023, and east coast grey seal breeding sites will be surveyed in autumn 2023. Results will be examined for any signal that the MHW might have had an impact on numbers hauling out in the affected regions, or on pup production at east coast grey seal colonies. However, our ability to assign cause to any observed changes will be limited.

Short to medium term consequences for seals are most likely to result from changes in prey availability, as fish and their prey species are likely to be more sensitive to such temperature changes. For example, Robinson *et al*. (2023) concluded that the lack of clear effects on benthivorous coastal birds supports the hypothesis that top predator responses to the Pacific MHW were driven primarily by how the heatwave affected prey availability. Previous, albeit lower amplitude, MHW events have occurred in the North Sea over the past 25 years. Analyses of UK fisheries data did not detect in-year effects on catches but did show lagged effects occurring 5 years following the temperature events; catches of sole, lobster and sea bass increased but catches of red mullet decreased (Engelhard *et al.* 2021). Fredston *et al*. (2023) investigated the effects of 248 sea-bottom heatwaves on demersal marine fishes using data from long-term scientific surveys of continental shelf ecosystems in North America and Europe. Results showed that the effects of MHWs on fish biomass could not be distinguished from natural and sampling variability. That study addressed demersal fish populations which provide the great majority of the diets of both grey and harbour seals in UK waters.

So far, the effects of the 2023 MHW on fish in UK waters are unknown. As far as we are aware, existing fish population monitoring programmes are unlikely to provide information at appropriate temporal and spatial scales to estimate the likely impact of the MHW on prey availability to seals in the short term. Catch data for commercially exploited species are available from ICES and have been used to examine the impact of previous MHW events on certain fisheries (Engelhard *et al*. 2021). Fish abundance data from the International Bottom Trawl Survey (IBTS), carried out in August and September 2023 may provide information on impacts of the MHW on abundance of prey species in the area affected by the MHW, unfortunately, sandeels are not included in these surveys.

High temporal and spatial resolution oceanographic datasets such as sea surface (SST) and sea bottom (SBT) temperature time-series, and indices of plankton abundance e.g., those based on satellite imagery are available for the North Sea. The latter might serve as proxies for food availability for major seal prey such as sandeels. However, because these indices relate to lower trophic levels any effects will be lagged.

Preliminary reports from seabird colonies on the Scottish and English North Sea coasts (F. Daunt pers comm.) suggest that provisioning rates and breeding success were not depressed during the 2023 summer breeding season. This may indicate that prey availability was not severely impacted by the high-water temperatures in the short term.

Large scale seabird die-offs in response to MHWs have been recorded in the North Pacific (Jones *et al.*, 2023). Large scale mortality events occurred more frequently following MHWs, and the scale and intensity of mortality events were related to the previous year's averaged sea surface temperature anomaly. A common sequence of mortality events (at 1–6 and 10–16 months after heatwave onset) was observed in the California Current large marine ecosystem following 3 prolonged MHW events. Such mortality would not have been detected yet in the North Sea.

A mortality event affecting auks in autumn 2021 may have been linked to unusually warm, settled temperatures that might have altered prey availability (F. Daunt pers comm.). The 2023 heatwave was much more severe, so would likely have had a greater effect on fish and possibly on prey availability. The ongoing highly pathogenic H5N1 avian influenza (HPAI) epidemic is currently impacting auk populations in the North Sea and may mask possible enhanced mortality associated with the MHW event. However, preliminary results show that a significant proportion of dead stranded guillemots and razorbills collected from the east coast during late summer, did not die from HPIA (MDSG unpublished data). Postmortem analyses are planned, and results will be reported to SCOS 2024.

In the absence of useful data on the effects of the UK MHW it may be informative to examine effects of previous MHWs in similar ecosystems. The best known MHW event of recent years was the Blob, a multiyear temperature anomaly in the eastern North Pacific and Alaskan waters between 2014 and

2017 which had wide ranging effects throughout the ecosystem. The effects varied between regions and habitats and ranged from early responses detected in 2014 to delayed effects on several fish and seabird species. For example:

- Large increase in sea lion strandings along the US west coast (NOAA, 2021);
- Large scale, repeated extreme mortality events in seabirds (Jones *et al*., 2023);
- recruitment failures for several fishery species (Laurel & Rogers, 2020; McClatchie *et al*., 2016);
- Large (100's km) northward extension of fish species distributions;
- Reduced size and marine survival of salmon, and in 2014 the salmon returning to the Fraser River in British Columbia avoided U.S. waters because of high ocean temperatures (NOAA, 2019);
- The loss of kelp forests and the abalone and urchin fisheries that depend on kelp (Rogers-Bennett & Catton, 2019);
- Increased harmful algal blooms including *Pseudo-nitzschia* blooms and increased domoic acid that resulted in shellfish fishery closures (McCabe *et al.,* 2016);
- An Unusual Mortality Event (UME #61) involving large cetaceans in Alaska (Savage, 2017)
- Decreased survival and reproductive success in humpback whale (Megaptera novaeangliae) in southeastern Alaska (Gabriele *et al.,* 2022);
- Changes in humpback whale (Megaptera novaeangliae) foraging areas that increased overlap with the Dungeness crab (*Metacarcinus magister*) fishery (Santora *et al*., 2020) with consequent increases in entanglements;

Not all species were adversely affected, e.g., catch per unit effort of 18 common fish species and total fish assemblage biomass in eelgrass meadows in the northern California Current were significantly higher during heatwave years and some Rock fish species showed increased growth and increased biomass (Robinson *et al*., 2022; NOAA, 2019).

Repeated MHWs in New Zealand waters have been associated with major ecological impacts (Salinger *et al*., 2019;Thomsen *et al*., 2019) including:

- Die off of extensive bull kelp beds and consequent disruption of the associated ecosystem;
- Dramatic changes in fish distribution with warm water species occurring outside their normal ranges;
- Changes in timing of spawning in some exploited stocks (e.g., red snapper spawned 6 weeks earlier);
- Significantly increased mortality at marine salmon farms in Marlborough Sound.

Clearly the effects of large scale and/or repeated MHWs are predicted to be dramatic with large changes in marine ecosystems (e.g. Cheung *et al*., 2021). A recurring theme in ocean climate temperature modelling studies is the prediction that MHWs will increase in frequency, severity and longevity in the coming decades.

At present the ability to detect effects on seals in UK waters is limited to monitoring strandings records, and detecting changes in population size for both species, and pup production in regional grey seal populations. Events such as the 2023 MHW highlight the potential utility of long-term seal breeding site studies to detect changes in body condition and reproductive output and investment, as well as flagging up the need for finer scale regular assessments of fish stocks at appropriate temporal and geographical scales. Given the range of observed effects in other MHW scenarios, SCOS recognise the difficulty in identifying likely detectable effects, and the resource implications of establishing large numbers of monitoring programmes. Although to date there have been no clear indications of significant effects on seals in the North Sea, evidence from MHW events in similar ecosystems suggest that there can be medium to long term effects that may not yet be apparent. Detection of long term effects will require targeted monitoring. However, considering the wide range of potential responses to MHW events, and the apparent absence of immediate impacts, SCOS highlighted the importance of increased vigilance to a range of effects and the potential need for responsive monitoring should some effects emerge.

2. Are there any planned or ongoing studies into seal behaviour/ predation and the efficacy of Acoustic Deterrent Devices (ADDs) in rivers and at or in proximity to fish farms? (MD Q2)

The use of ADDs to protect marine aquaculture sites and salmon river fisheries from seal predation is a potential alternative to lethal control following changes to the Marine (Scotland) Act 2010 removing provisions for which licences can be granted to take or kill seals. However, there is a limited robust evidence base for the effectiveness of ADDs as a deterrent tool as well as their potential for impacts (e.g., disturbance) on cetaceans. There is therefore a need to fill these evidence gaps, to support decision making regarding their use at fish farm sites.

Aquaculture

A study by SMRU, Ace Aquatec and Scottish Sea Farms which runs from April 2023 to September 2024, plans to investigate the effectiveness of the Ace Aquatec RT1 at reducing seal predation across a sample of fish farms in Shetland.

Anwary *et al*. (2022) reported a study by Ace Aquatec which tested a camera system for automatic detection of seals around salmon farms. This study reported high confidence in the detection of still images but reduced confidence with moving images.

The ADD manufacturer Genuswave is reportedly planning research into the effectiveness of the Targeted Acoustic Startle Technology (TAST) device at fish farms on the west coast of Scotland.

The coincident cessation of both seal shooting and use of ADDs may provide an opportunity to assess the combined effectiveness of these two previously widely used active control measures. To date there have been no targeted studies to assess changes in seal predation rates or levels of seal activity at aquaculture sites coincident with the cessation of shooting and ADD use, but industry records of salmon mortality and seal sightings may provide a basis for such a comparison.

In rivers

SMRU are conducting a project to develop an automated 'detect and deter' system as a non-lethal measure to manage seal predation on salmon in Scottish rivers. This project, funded by the Scottish Government, tested a Genuswave TAST device in the river North Esk over winter 2022/23. All seals exposed to the TAST signal responded by rapidly moving down river and subsequently did not move upriver past the TAST location.

Trials of the TAST device have also been carried out in rivers in Washington State, USA, where pinniped predation on salmon is a problem. These studies have generally demonstrated an effect of the device in reducing seal presence and seal predation, but the device has not been 100% effective in deterring pinnipeds or preventing predation. However, there were significant differences in methodology and physical characteristics of study sites.

Studies on ADDs and seal predation in Aquaculture.

The use of ADDs to protect marine aquaculture sites and salmon river fisheries from seal predation is a potential alternative to lethal control which is no longer permitted under a licence to protect fisheries. However, there are a limited number of studies on the effectiveness of ADDs, particularly at aquaculture sites. This has made it difficult to licence ADDs due to concerns about the potential disturbance impacts to cetaceans. As a result, the use of ADDs at fish farm sites is not currently practiced by the industry.

The coincident cessation of both seal shooting and use of ADDs may provide an opportunity to retrospectively assess the effectiveness of these two previously widely used active control measures. There have been anecdotal reports from the industry of increases in predation at fish farms since the use of ADDs has been stopped but these have not been verified. To date there have been no targeted studies to assess changes in seal predation rates or levels of seal activity at aquaculture sites coincident with the cessation of ADD use. However, the industry has continued to record salmon mortality and there may have been some monitoring of seal sightings over the transition period that could provide a basis for such a comparison.

SCOS are aware of a collaborative study underway by SMRU, the ADD manufacturer Ace Aquatec and the aquaculture company Scottish Sea Farms. This project started in April 2023 and will run until September 2024. The project will investigate the efficacy of a specific ADD (the Ace Aquatec RT1) in reducing seal predation across a sample of Scottish Sea Farms salmon farms in Shetland. This project also aims to build on the results of a previous collaborative study and add to the dataset on cetacean responses to ADDs.

This study is proposing to instal RT1s at around 18 trial sites across Shetland. The use of these devices will be strictly controlled, being switched on/off according to a pre-defined randomised routine. Acoustic recorders will be deployed at farm sites to verify the status of the deterrent. The numbers of fish killed by seals will be recorded during these on/off periods, and data will be analysed to examine the impact of the RT1. Acoustic data from these sites may also provide insights into distribution of low- and mid- frequency cetaceans such as killer whales and dolphin species in relation to the RT1 operation. Additionally, a previous trial in Orkney will be extended in duration to increase sample size, allowing a better understanding of the responses of harbour porpoises to the low-frequency signal. This study is funded by the Sustainable Aquaculture Innovation Centre with matched funding from Industry partners.

Anwary *et al*. (2022) recently described a 'market analysis and validation of the Ace Aquatec seal detection system for protecting salmon from predation at fish farms'. This system is described as using a "360 degree PTZ camera which covers a circular area of up to 125664 m^2" for detecting seals. This camera also operated in 'night mode' to enable detection in darkness. An "artificial intelligence based detection algorithm" is reported to detect seals in the live camera view. Validation of the seal detection was carried out using images of seals printed and displayed around the camera. The study reported levels of 'confidence' in detection of seals in still images in relation to distance and indicated high levels of confidence (80-99%) above 2m out to 200m but it is unclear how this confidence metric was derived or measured. Reported confidence in detection in moving images was lower (40-80%). This study did not include any tests of effectiveness of any deterrent element of the system.

The ADD manufacturer Genuswave are reportedly planning research into the effectiveness of their TAST device at fish farms in the west of Scotland, but no details are currently available on the scope or extent of this work.

Seal predation, ADDs and rivers - UK

SCOS are aware of an ongoing research project being conducted by SMRU developing a 'detect and deter' system to act as a barrier to passage of seals, for use in rivers as a practical alternative to lethal removal of seals to reduce seal predation on salmon. This project is part of the Marine Mammal Scientific Support Programme funded by the Scottish Government, Marine Directorate. As part of this work, a targeted acoustic startle response technology (TAST; Genuswave) device was tested in the River North Esk between December and February 2022/23. During this study a total of 15 trials were conducted whereby if a seal was observed transiting upstream within a specified 'trigger' zone, the observer activated the TAST device, emitting short 0.2 second pulses at a peak frequency of 1 kHz for a period of <20 seconds. A total of 16 harbour seals entered the trigger zone and all exposed seals immediately stopped their transit and most then rapidly moved away downstream. However, there were 4 exceptions (treatments 7, 10, 11, 12) where the seal did not initially return far downriver, remaining approximately 60m-100m downriver of the acoustic deterrents for a short time before then moving downriver of the study area.

Good quality photo-ID data allowed confident identification of individuals in ten treatments. These images identified three different harbour seals, with seven treatments conducted on one persistent individual over two non-consecutive days. Lower quality photo-ID data were available for two further treatments and no photos were available for the remaining three treatments. All known seals were exposed to a TAST treatment during the first two tides, and repeated attempts by seals lead to a total of 13 treatments over the first four tides (with only two further treatments conducted in the remaining 30 tides).

After the initial repeated attempts by seals to pass the deterrents, seals were either absent (resulting in a drop in the occurrence of seals of approximately 50% compared with winter 2021-2022) or stopped moving upriver into the trigger zone during daytime observation periods (with seals observed to retreat downriver shortly before reaching the trigger zone). These results suggest seals quickly learnt not to approach the trigger zone, as a result the deterrents were not triggered for most of the remainder of the study. The deterrent effect lasted for at least the duration of the study, but it is not possible to say how much longer this change in behaviour may last due to the study ending in February.

The response of these seals to the deterrent may or may not be typical of seals in general, and it is not possible to say if the deterrent was redeployed in a different location with different seals whether they would respond in the same way. In particular, the North Esk is a relatively small river and the responses of seals in larger rivers maybe different. It is also uncertain whether grey seals would respond in the same way as harbour seals. However, despite the relatively small sample size, the clear responsiveness of seals in all the exposure treatments and the apparent change in behaviour across the time period of the trial, the study concluded that further development and testing of acoustic deterrents within a detect and deter framework was warranted.

This study will be reported in full by SMRU as part of the deliverables of the Marine Mammal Scientific Support Programme funded by the Scottish Government, and a manuscript note is being prepared for publication. This project is also working on the development of automated detection of seals in rivers using multibeam sonar. This is to allow the triggering of deterrents only in the presence of seals to increase their effectiveness and reduce potential impacts on non-target species.

Seal predation, ADDs and rivers – USA.

In the summer of 2020, TAST was deployed at the Ballard Locks in Seattle, Washington, to deter harbour seals and Steller sea lions preying on salmon near the fish ladder (Williams, Ashe, Bogaard, *et al*., 2021). During the study, when the TAST was operating, harbour seal presence in the overall survey area declined by 25% compared to when it was off, and sea lion presence declined by 21%. Statistical analysis indicated a 49.3% reduction in predation rate when TAST was operating. Furthermore, TAST redistributed harbour seals away from the fish ladder and increased overall fish passage through the ladder, although some seals remained within 10 m of the device (Williams, Ashe, Bogaard, *et al.,* 2021).

A Master's thesis by McKeegan (2002), Western Washington University in Washington State, US, describes controlled exposure field trials of the TAST device at Whatcom Creek in Bellingham WA in 2020, a location where harbour seals were known for preying on fall runs of hatchery chum (*Oncorhynchus keta*) and Chinook (*O. tshawytscha*). Observations were conducted between 2019-2021 to assess the short- and long-term effectiveness of TAST on mitigating harbour seal predation.

Analyses showed that TAST significantly decreased the duration that individuals remained at the creek, with individual seals spending 34.5% less time in the creek when the TAST was on. Visual observations of foraging events indicated that TAST had variable effects on the foraging success of individuals, but the number of foraging successes in 2021 was 35% lower when TAST was transmitting than when it was off. Generalized Linear Models showed no lasting effect of exposure to TAST on the presence or foraging success of seals the following year.

There were differences in both the methodologies and physical site characteristics between the ADD trials in Scotland and the USA. In Scotland, narrow rivers were deliberately chosen to test the effectiveness of ADDs to act as an acoustic barrier, to prevent movement of seals upriver. Trials in Scotland involved manual triggering where ADD signals were only used when seals were observed attempting to move past the ADD to reach foraging sites upriver. In the USA trials, seal activity levels during on-off playback sessions were used to estimate the deterrence effect in locations where seals were actively preying on salmonids.

The intensity of the stimuli driving seal activity was likely to have been different. In the USA trials seals were actively preying on salmonids moving through the study site, the runs of salmon were much larger, and predation opportunities would have been much more frequent than in Scottish rivers. In Scottish trials the seals were likely moving upriver in a speculative search for salmonids and may have been less motivated to pass the ADD.

3. Can SCOS advise on any new and emerging methods or technical solutions that could be used to monitor seal populations with respect to abundance? Are there methods used by other countries that have proven to be particularly successful, efficient and cost-effective? (Defra Q1)

Seal populations are typically monitored on land where seals haul out and breed, rather than at sea. Such monitoring involves decisions on methods through the whole process in terms of the survey platform, camera system, image processing, counting method, and estimation method. SMRU's current monitoring programme is conducted through manned aerial surveys of haulout and breeding colonies; images are taken and later counted by researchers. The survey programme typically covers >95% of UK seals; counts for the remainder of UK seals are compiled from available data from ground surveys conducted by other organisations (e.g. National Trust, NGOs). The counts are then used, in combination with other information (e.g. demographic parameters, telemetry data), to model the abundance of seals, and trends therein.

Here, emerging techniques are reviewed and evaluated in terms of their current, and likely future, potential to replace or augment the current monitoring programme. The most promising emerging methods are associated with the survey platform and counting methods. The number and spatial extent of seal haulouts and breeding colonies in the UK means drones are not an appropriate platform for the majority of the SMRU survey programme. However, drone surveys can be the most appropriate platform for some accessible study areas of a limited spatial extent, especially when additional information is required (e.g. animal condition). The relatively low temporal and spatial resolution of opportunistic observations, including satellite imagery, means it is not a viable option to replace or augment SMRU surveys.

While counting is still typically conducted by researchers, Citizen Science and Artificial Intelligence (AI) are also being used in other projects, with mixed success. In particular, AI is a promising future avenue but there are no fully operational systems in use that involve classification of seals (e.g., species, age) in images from manned aerial surveys.

SCOS conclude that the current SMRU aerial survey programme is the most appropriate solution for monitoring seal populations in the UK. If and when future drone capabilities and legislation allow, SMRU should consider augmenting or replacing parts of the manned aerial surveys if funding is available. Longer-term, AI-counting techniques would be advantageous but the development and implementation of effective AI-counting techniques, would require significant additional resource. Nevertheless, SMRU should continue to build a training set of annotated images to facilitate such development, and to allow retrospective application of AI techniques to historic images. SCOS highlight that adoption of new techniques would need to be predicated on an ability to account for changes in methods to ensure continuity of time-series and to maximise comparability across the UK and Europe.

Monitoring seal population abundance can be via surveys on land or at sea. For the most part, to monitor spatial and temporal trends, and overall abundance, efforts are focused on land rather than at sea (see below). Monitoring abundance on land involves decisions on methods through the whole process in terms of the survey platform, camera system, image processing, counting method, and estimation methods. To facilitate interpretation of the potential for emerging techniques, we summarise the current SMRU population monitoring programme, providing context of techniques used elsewhere. We then discuss the key emerging techniques - survey platform (satellite and drone) and counting methods (Citizen Science and Artificial Intelligence) - and their potential utility for SMRU surveys. It should be noted that the adoption of new techniques would need to be predicated on availability of funding and technical ability to account for changes in methods, to ensure continuity of time-series and to maximise comparability across the UK and Europe.

Monitoring at sea

At sea surveys are not typically used for seal population monitoring. This is because seals range over huge areas (e.g. >250 km offshore) and spend a varying proportion of their time under water. Furthermore, even when on the surface, reliable identification to species is often difficult, especially from aerial surveys, and there will be marked temporal variation in the spatial distribution at sea as they move to and from haulout sites. Methods such as eDNA are unlikely to be useful in the context of monitoring the distribution and abundance of seals; they can provide complementary information alongside traditional survey methods, such as detection of animals in areas where they are previously unreported or poorly detected by other survey methods. However, little is currently known about how environmental factors affect the spatial and temporal persistence of eDNA in aquatic systems (Suarez-Bregua *et al.,* 2022). For example, the highly dynamic marine environment may contribute to the transport and dispersion of eDNA therefore making it difficult to interpret presence and absence in sampled areas. Furthermore, for the most part, seals are present throughout the sea surrounding the UK (Carter *et al.,* 2022).

In terms of providing information on relative abundance, eDNA of marine mammals in the sea will likely be biased towards where they defecate; the likelihood of a seal defecating will depend on time since it last fed and digestion (which can be delayed at sea). Combined with the patchy distribution of seals, and the dynamic nature of the marine environment, samples of eDNA cannot be used to quantify numbers of seals in an area. Such density estimates at sea are required for management purposes. Currently, such estimates are based on the relationship between seal locations (from animal-borne tracking data) and the environment (habitat associations) along with haulout counts, to predict density at sea (Carter et al. 2022). These techniques are also used elsewhere in Europe to estimate seal abundance at sea (e.g. Aarts *et al.* 2016; Huon *et al.* 2021). Incorporating the substantial variation in habitat association between individual seals for such a large dataset is difficult but should be a priority to increase the robustness of at sea density estimates.

SMRU population monitoring programme

SMRU conduct aerial surveys of grey seal breeding colonies (September to December; Russell *et al.* 2019; Russell *et al.,* 2022a) and of seal haulouts in August (Thompson *et al.* 2019). SMRU focus their survey efforts on Scotland and eastern England, which hosts the majority of seals in the UK (> 95% of both species; Russell and Morris 2020; SCOS 2022). Some additional counts and estimates from other areas of the UK are provided by individual organisations. SMRU have recently extended their grey seal breeding surveys to include the east coast of England. Historically, these have been ground counted by other organisations, but their increased size made this increasingly difficult (Russell *et al*. 2022b).

Grey seal breeding surveys

For grey seal pup surveys, a vertical camera system (two 40MP medium format digital cameras that combined give a swath width of 340m with a resolution of around 2.5cm/pixel) has been used since 2012. The survey platform is a twin-engine fixed-wing aircraft. Key colonies, representing over 90% of UK pup production, are surveyed every two to three years. The duration of the pupping season at any one colony is longer than the duration of stay of individual pups. As such, the count of pups from an individual survey represents an unknown proportion of the pups that will be born in a given year. Thus, each colony is surveyed multiple times (usually five) in a given breeding season. Photographs are then enhanced, and batch processed (to maximise ability to distinguish whitecoat and moulted pups). The images overlap, so they are stitched together to avoid double counting of pups. After trialling various methods, the stitching software currently in use is Microsoft Image Composite Editor (ICE). The non-georeferenced stitched images are then imported into Manifold GIS software where each pup is manually marked and classified as either a whitecoat or a moulted pup. The total counts of whitecoat and moulted pups for each colony are then input into a "pup production model". Within this model (Russell *et al.,* 2019), the counts are combined with information of the observation process (probability of detecting a pup, and of correctly classifying it) and life history traits (age at which pups complete moult, age at which they leave the colony) to derive a birth curve and estimate pup production.

Trends in pup production are then considered on both a SAC and SMU level (Russell *et al,.* 2022a). A time series of pup production estimates and available estimates of population size (from the scaled August counts; see below) are input into a Bayesian age-structured model (Thomas *et al.,* 2019) which includes up-to-date prior information of grey seal population demography (e.g. fecundity; Russell *et al*., 2022c). The output of this model is used to examine trends in population size, and to assess the degree to which density dependence is acting on first year survival. Outside the UK, grey seals are typically surveyed during the moult and/or during the breeding season. For the most part, fixed-wing aerial surveys are used with some use of drone surveys for specific colonies/haulouts. The UK and Canada hold the majority of the global population of grey seals. In Canada, grey seal population monitoring is focussed on pup production in a similar way to the SMRU monitoring programme. However, in Canada a single survey to count all pups is completed and the birth distribution is estimated by staging surveys (as a proxy for age) of a subset of pups throughout the breeding season at the larger colonies (DFO 2022). That is not possible in the UK due to the number and distribution of key colonies; the variation in timing of breeding in the UK means such ground staging would be required on a colony level. In many other areas, with smaller numbers of grey seals, maximum (peak) pup counts (a single survey) are used to examine trends. However, in the UK there is substantial variation across colonies and years, in the scalar between maximum pup count and estimated pup production. An absolute estimate of pup production is required for the population model.

It should be noted that SMRU are currently in the process of updating their camera system. A key feature of the new system will likely be geo-referenced images which will facilitate stitching.

August survey

The August surveys are the main monitoring method for harbour seals; they occur during the harbour seal moult when a high and relatively consistent proportion are hauled out. For grey seals, the pup production estimates provide the main time series, but the August counts provide critical data on the abundance and distribution of grey seals during the main foraging season.

The surveys conducted in August use a mixture of methods. Surveys on the west and north coasts of Scotland are conducted using a helicopter with a gyro-stabilised gimbal containing a thermal imaging video camera (required to detect well-camouflaged seals on rocks and seaweed), a HD colour video camera, a laser range finder, and a digital still camera with a 300mm lens (used to identify species). The haulout sites on the east coast of England and Scotland are predominantly sandy beaches where seals are relatively easy to spot, and thus most of those are surveyed using a single engine fixed-wing aircraft and oblique photography (70-300mm zoom lens). A twin-engine fixed-wing aircraft is used to survey the offshore islands in Scotland (e.g. Flannan Isles, North Rona, Sule Skerry) not covered by the helicopter surveys.

Following the surveys, the most appropriate set of images (with a resolution of 0.5-1.5cm/pixel) of a given group of seals are chosen and counted using DotDotGoose (American Museum of Natural History), a purpose-built tool for manually counting objects in images. For both species, the raw counts are used to assess trends in abundance within Special Areas of Conservation (SAC) and by Seal Monitoring Unit (SMU; Russell *et al.,* 2022a). SMRU telemetry data have been used to estimate the proportion of the population of each species hauled out during the survey window. The surveys are conducted during the harbour seal moult when 72% (95% CI 54 - 88%; Lonergan *et al.* 2013) of the population are estimated to be hauled out. In contrast only 25% (95% CI 21 - 29%; Russell and Carter 2021) of grey seals are estimated to be hauled out and thus available to count.

The counts are scaled, using the proportion hauled out, to estimate population size (SCOS 2022). Targeted deployment of telemetry devices together with application of cutting-edge analytical techniques will lead to improvements in the estimates of scalars and the uncertainty therein, ultimately increasing the robustness of abundance and trends estimates.

Through funding from Scottish Government, work is ongoing to build on the work focussed on the Moray Firth (Caillat *et al.,* 2019), to develop an age-structured population model for harbour seals that could be applied to other areas.

A limited number of harbour seal pup surveys are also conducted in The Wash. Outside of the UK, the majority of harbour seal surveys are conducted using fixed-wing aircraft (but see platform below) and also focus on the moult, with additional surveys during the breeding season in some areas.

Platforms

The survey platform used for seal surveys varies from counters on the ground (counting directly or with hand-held camera), boat, fixed-wing aircraft, helicopter, drones, and satellite. Counting on foot has been shown to be inaccurate for large colonies (Russell *et al.,* 2022b, and thus likely also for large haulouts). Drones have been used to survey seal haulout sites and colonies both in the UK and abroad. For example, drone surveys of the Farne Islands, Northeast England SMU, during the grey seal breeding season, have been commissioned by National Trust. Drones are ideal for collecting data on individual colonies and haulouts both for census purposes but also to collect more detailed data (e.g. estimation of animal condition, tracking individuals through time). However, given the number, geographical spread and isolation of surveyed haulouts, conducting the current August survey programme by drone would not be feasible. The grey seal breeding surveys in Scotland cover over 60 colonies, most of which are on islands, five times each. To survey all colonies once by fixed-wing aircraft, usually requires four flights, whereas by drone it would require a large number of boat and/or helicopter trips spread over many days. That would not be viable.

The greatest potential for regular drone surveys in the future lies with the large grey seal breeding colonies on the east coast of England (Farne Islands, Donna Nook, Blakeney, and Horsey; see Russell *et al.,* 2022b). Current SMRU fixed-wing surveys can efficiently photograph all four colonies in a single 5 hour flight. Nevertheless, over the last five years, SMRU have been exploring the potential for using drones at these sites. However, there are still considerable obstacles. First, four to five surveys are needed across the season and, particularly for the Farne Islands, access (by boat) is weather dependent. Indeed, this is a major reason for the current National Trust drone surveys finishing at the end of November, well before the end of the breeding season. Second, the other east England colonies are expansive, which presents challenges in terms of drone operating distance. For example, at Blakeney, visual line of sight (VLOS) operations would require drone operators to walk through (and operate from) high density areas of the colony. Although Horsey is a large colony (> 8 km long), it is relatively narrow (generally less than 200 m of beach and dunes), and thus may be suitable for drone surveys. Natural England UAV unit are exploring the potential to do trials at this colony. Third, is the cost and requirement for consistency across space and time to confidently determine trends. Drone surveys would be associated with different observation parameters (e.g. detection probability, likelihood of correctly classifying a pup) compared to fixed-wing surveys. Different drone survey specifications used at different survey sites could introduce even more variation, which would need to be assessed to ensure comparability of pup production estimates across surveys. The production of reliably good drone images for pup counting from the Farne Islands took considerable development time and investment from National Trust, and there is uncertainty on whether that survey programme will continue. Currently, given the obstacles described above, there is not the scope in resource at SMRU to develop a drone survey programme at the east England colonies, though SMRU will continue to work closely with organisations (e.g. National Trust, Natural England) that are trialling or conducting drone surveys. In collaboration with the National Trust, SMRU are, when possible, currently using concurrent drone and fixed-wing flights from the Farne Islands to refine the observation parameters for the fixed-wing surveys in the pup production model. However, until there is the potential for a sustainable, consistent, appropriate drone survey programme in place, manned aerial surveys of the east coast of England are fundamental for monitoring grey seal populations in England and the UK as a whole.

Opportunistic observations, from satellite or fixed-wing aircraft, have been used to monitor some marine mammal populations (reviewed in Khan *et al.,* 2023). Very High Resolution (VHR) satellite imagery (i.e. ≤50cm/pixel) is becoming increasingly available with around ten commercial companies selling archival images. The highest resolution images are 30cm/pixel but nearer 50cm/pixel for full colour (multispectral) images. Google Earth is a free software allowing access to both archival VHR satellite imagery and images from fixed-wing aircraft. The latter type of images are at a higher resolution (15 - 25cm/pixel) than those from satellite but are available at a lower temporal frequency than satellite (up to twice a year). Satellite imagery (60cm/pixel) has been used to count Weddell seals on ice (LaRue 2011). Similarly, Google Earth images from fixed-wing aircraft were used to count the number of grey seals on a sandy haulout sites in the USA (Moxley *et al.,* 2017). Given the image resolution, the utility of opportunistic images is restricted to featureless habitats (e.g. sandy beaches) and haulouts of single species, and in the case of satellite imagery, to allow individual seals to be distinguished, it is further restricted to species that do not haul out in close proximity. In the UK, seals breed and haul out on a multitude of habitats, and there is a need to be able to identify species (or classes for grey seal pups). For these reasons, the resolution of images from opportunistic observations precludes their general use in the SMRU seal population monitoring programme. However, images found on Google Earth and other online mapping platforms have occasionally proved useful for confirming the presence of seals at sites that were not previously known to be regular haulout or breeding sites.

There are likely to be future improvements to the resolution of available imagery from satellite (current military satellites are speculated to achieve a resolution of <10 cm/pixel) though the eventual technological limit is likely to be significantly below the resolution required to detect seals on many habitats, and to distinguish species or age classes. If future advances in satellite imagery were to produce a similar resolution as the current Google Earth fixed-wing images, in theory, they could be used to count seals at a limited number of haulout sites (sites that are featureless and predominantly single species).

Archived satellite images can be purchased but the limited temporal and spatial coverage of such opportunistic observation means that "tasking" satellites to provide imagery would be necessary for long-term monitoring. Unfortunately, even with advancements in image resolution, there would still be considerable obstacles to the use of satellite images: (1) limited temporal and spatial coverage; (2) impact of cloud; (3) non-vertical images, (4) cost. Within the survey programme, surveys need to be conducted at specific times (within two hours either side of low tide in August, and for grey seal breeding, four to five approximately equally spaced daylight surveys across the season). The overlap with the August survey window would be restricted to a limited number of days which would vary along sections of coast within SMUs. Indeed, a single group of haulout sites may not necessarily be covered within a single satellite pass. Related to this is the impact of cloud and the associated shadows on the quality of the image, which would further reduce the number of survey days, and would likely prohibit their use for grey seal pup surveys. The height of SMRU surveys almost completely removes the impact of cloud, and survey schedules can be adjusted at short notice to ensure suitable survey conditions. For satellite imagery, there is also a consideration that, depending on the size of the area, some parts are likely to be non-vertical which can be detrimental to image quality. Finally, the cost of tasking satellites to provide imagery is prohibitively expensive currently. Tasking a single snapshot of sandbanks within The Wash, without guarantee of completely cloud-free coverage, would currently cost over £10,000. Given the above, it seems very unlikely that satellite imagery could usefully augment or replace parts of the aerial survey programme in the future.

Counting

Counts of seals in Europe are predominantly conducted by researchers either in real-time or from photographs. However, in some areas, seals are counted either through Citizen Science (e.g., Zooniverse) or using Artificial Intelligence (AI) techniques. Given that the August surveys involve selecting the most appropriate photographs, species identification, and most use a combination of thermal video and high-resolution photographs, there are added complications associated with assisted counting techniques. Thus, here we focus on grey seal breeding surveys which is the most time-consuming counting task.

Citizen Science techniques are most useful for counting high resolution images with no requirement for identification to species or class. Even in these circumstances, compared to experienced counters, non-experienced counters detect fewer individuals, requiring a high number of repeat counts (Wood *et al.,* 2021). Indeed, a preliminary investigation within SMRU comparing classifications on the ground (assumed truth) with those from concurrent aerial survey images indicated that the ability of counters to distinguish whitecoat and moulted pups varied markedly, and the most common classification (mode) of pups did not necessarily align with that of the most experienced and accurate counter. Gaining the required number of counts to ensure high detection rate is slow (Wood *et al.,* 2021) and the observation parameters (probability of detection) in the model already accounts for missing pups. Thus, currently Citizen Science techniques, although likely valuable for public engagement, are unlikely to result in a more efficient or robust counting method.

The use of Artificial Intelligence (AI), most typically Convolutional Neural networks (CNNs), to support population monitoring is a promising and rapidly developing avenue (Hollings *et al.,* 2018; Corcoran *et al.,* 2021). Here, we focus on the potential for such techniques for seal surveys. The use of CNNs (YOLO v3) for detecting and classing grey seal pups from SMRU surveys has been trialled through a Masters project based at Computer Science, University of St Andrews (Terzic unpub data). This showed considerable potential, but development halted due to a lack of resources. Building bespoke CNNs (e.g. in Python) or adapting CNNs (e.g. YOLO) requires considerable expertise in AI, but there are now various GUI-based software available to facilitate the process; key examples being AIDE, Picterra, and VIAME. AIDE, Annotation Interface for Data-driven Ecology (Kellenberger *et al*., 2018), is an open-source web-based system that supports annotation, machine learning and a human feedback loop. However, it does not currently appear to support georeferenced images and thus its application for seal surveys is likely limited. In contrast, Picterra has been used for detecting harbour seals from drone images (Infantes 2022); the body size of seals was measured automatically, and this was used to classify pups from other ages. However, its utility to distinguish whitecoat versus moulted grey seal pups (which can be of a similar size) on varied habitat from comparatively low-resolution images from aerial survey is unknown. Furthermore, it is a web-based system with the cost being charged per gigabyte uploaded; the use of such a system would be prohibitively slow and expensive for a large-scale survey programme such as that conducted by SMRU.

VIAME (Video and Image Analytics for Marine Environments) is an open-source software developed by Kitware in collaboration with NOAA (National Oceanic and Atmospheric Administration). This involvement of NOAA in its development means that, particularly in the US, VIAME has been the main AI software considered for seal population monitoring. For example, VIAME was used, with limited success, to detect and classify Antarctic fur seals (pups versus non pups) from drone images (Hinke 2022). NOAA have also conducted a preliminary study using VIAME to detect grey seal pups from fixed-wing surveys, but that work is on hold (Josephson and Murray, pers. Comm) and currently images are still counted manually. A recent development in use of VIAME has been through a project led by Marine Mammal Laboratory, NOAA, focussed on the detection and classification (age and sex) of Stellar sea lions (Sweeney *et al*., Unpublished report). Kitware were formally involved in this project providing support and changes to VIAME to facilitate the automation of aerial image processing and analyses. These sea lion surveys are similar to the grey seal breeding surveys conducted by SMRU; NOAA use a fixed wing aircraft with three vertical cameras providing overlapping images. That project has led to increased functionality within VIAME that will likely be applicable to other species. Indeed, it is possible to input unstitched images into VIAME with two potential methods available to mitigate against double counting. Such functionality would negate the need to stitch images, substantially reducing pre-processing time. However, it should be noted that the performance of these two methods has not yet been evaluated. That project has made great strides in the use of AI for seal population monitoring. However, the researchers note that the substantial funding was required to allow a collaboration with Kitware, and an immense investment of researcher time was required for the project. Significant challenges remain before an operational system is available for Steller sea lion surveys. Developing such a system for streamlining or automating counting of UK seal survey imagery would require substantial additional staff time, funding, IT resources (e.g. high performance computing facilities) and programming expertise.

AI techniques are rapidly developing, and clearly, they will eventually become a key component to support seal population monitoring especially for systems which allow information from thermal and colour images to be integrated. However, to our knowledge, currently no seal population monitoring programmes have integrated AI systems to facilitate counting of seals from fixed-wing aerial survey images. Development of such systems (bespoke or use of GUI-based) for SMRU aerial surveys, especially given the variation in terrain and the requirement to classify pups, would clearly only be possible through dedicated funding to provide the required time resource for both AI experts and seal researchers to develop and implement such techniques. Nevertheless, SMRU should continue to build a training set of annotated images. Such a dataset will facilitate future development of effective techniques by SMRU and/or collaborators. Furthermore, it provides the possibility of retrospective application of AI to historic imagery, which could ultimately increase the accuracy and consistency of historic counts.

4. Can SCOS advise on how seal conservation could be considered in the development of future Fisheries Management Plans? (Defra Q2)

Fisheries Management Plans are a Government commitment whereby plans for spatial and stock specific fisheries are produced to ensure that they are sustainable and consider wider fisheries management issues covering environmental, social and economic concerns. Multispecies ecosystem models would be the most appropriate approach to quantitatively consider seal populations in the development of fisheries management plans in an Ecosystem Approach to Fisheries Management. Currently, such models do not consider impacts of differing scenarios (e.g. fisheries management, oil and gas decommissioning) on seal populations.

A current project, led by SMRU, aims to incorporate both grey and harbour seals into a North Sea ecosystem model and test the impact of different management and climate change scenarios on fish density and distribution, and ultimately on seal populations and fishers. However, such models would not consider the impact of seal depredation or bycatch. A simple risk assessment process could be used to identify areas where further development is required for specific fisheries to address these questions. This would involve a consideration of the potential for interactions between the fishery and seals in three main areas:

Dietary overlap – is there overlap between the species that seals regularly feed on and those targeted by the fishery? This step should also consider the potential for indirect prey interactions– i.e. do seals eat the predators or the prey of the target species and size classes?

Spatial overlap – is there overlap between at sea foraging activity of seals and the spatial extent of the fishery?

Potential for direct interactions – is the fishing gear type known to be associated with seal bycatch or seal depredation?

The Joint Fisheries Statement published in November 2022 sets out the UK Administrations' commitments to sustainable fishing, arising from a legal requirement set out in section 2 of the Fisheries Act 2020, which identifies the need for an ecosystems approach to fisheries management (EAF). EAF recognises that fisheries rely on the ecosystems within which they operate and that their functioning may be compromised by human induced pressures, including fishing activity. The development of Fisheries Management Plans (FMPs) is a key part of this commitment and will provide a mechanism whereby the eight fisheries objectives set out in the Act will be applied. The JFS states that: "*The fisheries policy authorities will jointly publish individual FMPs for those stocks that are of social and economic importance, at risk of significant over-exploitation and have an ecosystem significance…… FMPs will focus on the sustainable management of stocks. However, the scope of a FMP may be extended to consider wider fisheries management issues covering environmental, social and economic concerns*."

To understand the functioning of marine ecosystems and therefore how removals of one species are likely to affect the dynamics of other species is an incredibly complex and challenging task. It requires the development and application of multispecies ecosystem models, which in turn require information on prey abundance and distribution, spatial and temporal patterns of predation, spatial and temporal distribution of fishing effort and an understanding of multispecies functional responses. See Püts *et al.,* (2023) for an example of a use of an ecosystem model (southern North

Sea) to explore future scenarios of fishing activity and offshore wind development on ecosystem health, including model outcomes specific to birds and cetaceans. Carlucci *et al.*, (2023) provides an example of the use of an ecosystem model to model both direct (bycatch mortality) and indirect (lowering availability of prey) impacts of a trawl fishery on various cetacean species in the Gulf of Taranto in the northern Ionian Sea. Determining the ecosystem-level impacts of fisheries on seal populations will require an integrated ecosystem modelling approach with inputs on the drivers of distribution for key components of the ecosystem.

Several data gaps in this context for UK seals were identified in SCOS 2019. As central-placed foragers, seals are particularly difficult to integrate into ecosystem models because land-based processes are not captured in such models. SMRU are involved in a number of projects to address these gaps and to better understand the impact of the changing ecosystem and potential management scenarios on both seals and fisheries, namely EcoSTAR, SEAwise and ACTNOW. Indeed, multispecies functional response models have been developed for both seal species (Ransijn *et al.,* in prep) as well as porpoise (Ransijn *et al.,* 2021) to allow predictions of how consumption of a given fish species will vary with its availability and the availability of other fish species. Such models are key to predicting seal diet and consumption under different management scenarios. Through the INSITE II EcoSTAR project led by SMRU, both harbour and grey seals are being incorporated into a North Sea ecosystem model developed by Cefas (Ecopath with Ecosim model). That model will be used to predict, under multiple climate change scenarios, the impact of fisheries management and offshore oil and gas infrastructure decommissioning options on fish density and distributions, and ultimately on both seal populations and fisheries. Further work would be required to robustly incorporate the direct impacts of bycatch and depredation on seals and fisheries, respectively.

In the current absence of appropriate multispecies ecosystems models to apply the EAF approach to seal conservation there are a number of ways that FMPs could consider seal interactions as a first step. There are two main aspects to consider in the context of the objectives of maintaining ecosystem functioning and reducing pressures on ecosystem components: 1) the risk of a fishery influencing seal populations through a reduction in prey availability, 2) the risk of direct interactions between seals and fishing gear leading to mortality and injury to seals and damage to fishing gear and catches. Notably, it is also in the interests of any fishery to attempt to minimise both risks.

Here, we outline the basic risk assessment steps that could be applied in a generic process to any FMP. Such a process could involve the following steps for any given FMP:

Assess the degree of overlap in seal diet with the target species and size: as detailed in SCOS (2019) and SCOS (2021), the results of previous major studies of seal diet in the UK are described in detail in a series of reports to Scottish Government (Hammond & Wilson, 2016; Wilson *et al.,* 2016; Wilson & Hammond, 2016 a, b). The results of the most recent study (2010/11) are summarised in Wilson and Hammond (2019). SCOS note however, that these data are now more than 10 years old and may not provide an accurate description of seal diets in areas where fish stocks and seal populations have changed. A study on seal diet (both species) is currently underway in the southeast of England and will provide updated information on seal diet. This step should also consider the potential for indirect prey interactions too – i.e. do seals eat the predators or the prey of the target species and size classes?

Assess the degree of spatial overlap between the fishery and seals: this would involve both a consideration of seal distribution and abundance at haulouts within foraging range of where the fishery operates (SCOS reports) as well as a consideration of at sea behaviour/density/distribution from telemetry data and published at-sea density maps (Carter *et al.,* 2020) and comparison with mapped historical and predicted future fishing effort. Understanding seasonal variation in activity will also be important where fishery operations are seasonal as well as informing management options such as area or seasonal restrictions. However, seasonal variation in seal distribution is not particularly well understood except at the level of breeding season vs nonbreeding season.

Assess the potential for direct interactions between the fishery and seals: this includes consideration of both bycatch and depredation. The fisheries that are most associated with seal bycatch are in the southwest of the UK where the gillnet/trammel/tangle net fishery is concentrated. A small amount of bycatch has been recorded in trawl fisheries around Orkney and Shetland and in the Hebrides and northwest Scotland. As highlighted in SCOS (2022 questions 11 – 15) bycatch monitoring effort is concentrated in areas where large mesh tangle nets and trammel nets are used, which accounted for 90% of the estimated bycatch despite being concentrated in a region with relatively low seal density. Areas that are under-sampled and where there is either a large amount of fishing effort, or a high density of seals, could benefit from further observational data. Sampling is not strictly apportioned according to effort or to gear type, and it is possible that there may be additional sources of bycatch mortality that remain unknown, e.g., bycatch from non-UK vessels are not monitored as part of the UK Bycatch Monitoring Programme. This limits the extent to which general predictions can be made for specific fisheries.

A current SMRU PhD project will use both seal and fishing boat tracking data to explore the degree to which seals associate with mobile gear fishing boats. Furthermore, University of College Cork, in collaboration with SMRU, are using similar methods to explore the association between seals and static gear around the UK and Ireland.

SCOS (2021) highlighted that despite increasing anecdotal reports of seal depredation, there is a lack of robust, quantitative evidence to inform an assessment for the potential for seal depredation in specific fisheries. The exception to this is the inshore handline mackerel fishery in northeast Scotland and in Cornwall where specific problems have been highlighted and mitigation trials have been undertaken (Whyte *et al.,* 2022). Focused evidence gathering would be required to further consider the risk of seal depredation for most individual FMPs.

These risk assessment steps will allow managers to identify where potential interactions may pose a risk to fisheries or seal conservation and will highlight where further knowledge is required to develop appropriate fisheries management measures.

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