Marine Ecosystems

Review of potential impacts on pinnipeds in Australia from offshore wind farms

Roger Kirkwood[1], Christine Erbe[2], Chong Wei[2], Sam Thalmann[3], David Slip[4], Ben Pitcher[5], Vanessa Morris[5], Shannen Smith[1] and Simon Goldsworthy[1]

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Cover Photo: Judgement Rocks, site of a large Australian fur seal colony in central Bass Strait – there is scant information on where seals from this island forage (Photo R. Kirkwood).

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EXECUTIVE SUMMARY

This report reviews the on-ground activities involved in offshore wind farm developments, the seal species in Australia and their overlap with declared offshore wind farm areas, and potential impacts of offshore wind farm developments in Australia on those seals. A final summary of the critical knowledge gaps is presented.

In August 2022, the Australian Government identified six priority areas within which offshore wind farms could be developed, three in the Bass Strait region (recognised here to be shelf waters between Victoria and Tasmania), two on the New South Wales (NSW) coast and one on the west coast of Western Australia. These areas overlap with the ranges of numerous species protected under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), including three otariid pinnipeds (eared seals): the Australian fur seal (*Arctocephalus pusillus doriferus*), the Long-nosed (New Zealand) fur seal (*Arctocephalus forsteri*) and the Australian sea lion (*Neophoca cinerea*).

To date, hundreds of offshore wind farms and thousands of turbines in total have been installed worldwide, mostly in Europe and Asia. Studies on impacts of wind farm developments on marine mammals mostly have been conducted in Europe, on the local Harbour porpoise (*Phocoena phocoena*), and two phocid (true) seals, Harbour seals (*Phoca vitulina*) and Grey seals (*Halichoerus grypus*). Phocid and otariid seals have different behaviours, foraging strategies and breeding strategies. Responses to a given stimulus will be individual and species-specific, and importantly, responses by a phocid seal will not be representative of those by an otariid seal.

Australian fur seals are abundant year-round in all declared offshore wind farm areas in the Bass Strait region, common on the areas on the NSW coast, and are unlikely to occur in the Bunbury area off Western Australia (Table ES.1). Long-nosed fur seals are likely to be common in all offshore wind farm areas. Australian sea lions likely occur frequently in the Bunbury area and are rare visitors to Bass Strait and Australia's east coast. There will be occasional transits through all the declared offshore wind farm areas by individuals of subantarctic and Antarctic breeding species, notably Southern elephant seals (*Mirounga leonina*), Leopard seals (*Hydrurga leptonyx*) and Subantarctic fur seals (*Arctocephalus tropicalis*).

Table ES.1. Approximate numbers of seals that could be present at a time in each declared offshore wind farm area.

	Hunter	Illawarra	Gippsland	Bass Strait	Southern Ocean	Bunbury
Australian fur seal	10-100	10-100	>1000	>1000	>1000	0
Long-nosed fur seal	10-100	10-100	100-1000	10-100	10-1000	10-100
Australian sea lion	0	0	0	0	0-10	1-10

Potential impacts to seals from offshore wind farm developments include habitat and ecosystem alterations, and responses to noise generated by geophysical surveys, vessel traffic, construction activities (including pile driving) and the operation of offshore turbines. These impacts may affect seal hearing, movement patterns and foraging ability, and could lead to population-level consequences.

The various sounds produced during offshore wind farm construction and operation activities are expected to be detected by seals (see sound descriptors used in this report in Table ES.2). The sound exposure level received by seals will be influenced by many factors, including the source sound level, techniques adopted to mitigate sound propagation (such as bubble curtains around pile-driving), distance from the source, animal depth in the water column, and duration of exposure. Seals are likely to detect sound levels produced by offshore wind farm activities when these exceed ambient levels. Non-anthropogenic ambient sounds come from rain, wind and wave action, geological events, and noises produced by marine species (such as cetaceans, fishes, and crustaceans).

Table ES.2. Sound descriptors used in this report.

Quantity	Abbrev.	Symbol	Unit	Description
Sound pressure	n/a	p	Pa	Sound pressure $p(t)$ at any location; varies with time t; measured with a microphone in air or a hydrophone in water.
Peak sound pressure	n/a	p_{pk}	Pa	The greater of the greatest magnitude during compression and the greatest magnitude during rarefaction.
Peak-to-peak sound pressure	n/a	p_{pk-pk}	Pa	The sum of the greatest magnitude during compression and the greatest magnitude during rarefaction.
Root-mean-square sound pressure	n/a	p_{rms}	Pa	The root of the time-average of the squared pressure: $p_{rms} = \sqrt{\frac{\int_{t_1}^{t_2} p^2(t)dt}{t_2-t_1}}$, where t_1 and t_2 are the start and end times, respectively.
Sound pressure level	SPL	L_p	n/a	The level of the root-mean-square sound pressure: $L_p = 20\log_{10}\left(\frac{p_{rms}}{p_0}\right)$ relative to a reference value p_0, which is 20 μPa in air and 1 μPa under water. Expressed in decibel, dB re p_0.
Peak sound pressure level	SPL$_{\text{pk}}$	$L_{p,pk}$	n/a	The level of the peak sound pressure: $L_{p,pk} = 20\log_{10}\left(\frac{p_{pk}}{p_0}\right)$ relative to a reference value p_0. Expressed in dB re 20 μPa in air and in dB re 1 μPa under water.
Sound exposure	n/a	E_p	Pa^{2}s	The integral of the squared sound pressure p over time t: $E_p = \int p^2(t)dt$.
Sound exposure level	SEL	$L_{E,p}$	n/a	The level of sound exposure. $L_{E,p} = 10\ \log_{10}\left(\frac{E_p}{E_0}\right)$ relative to a reference value $E_0\ =\ 1\ \mu\text{Pa}^2\text{s}$ under water and (20 μPa)^{2}s in air.
Source level	SL	L_S	n/a	Can be expressed as a sound pressure level or a sound exposure level. Is the level referenced to a nominal 1 m distance from the centre of the source, typically by back-propagating levels recorded farther away from the source.

The responses of individual seals to anthropogenic sounds will vary depending on the received sound levels, the individual's motivation for moving through an area (e.g., foraging, transiting, exploring) and its previous experiences with that sound or other novel sounds. Studies in the Northern Hemisphere have shown that immediate responses by phocid seals to offshore wind farm activities (particularly pile-driving) include increased vigilance, altered diving behaviour and movement away from the sound source. Seals may also receive temporary or permanent hearing loss from high levels of, or extended exposures to, sounds.

Key knowledge gaps relating to pinnipeds and offshore wind farm developments in Australia include the numbers of individuals that could be affected, the potential for physical changes to foraging environments and trophic structures, and the seal's hearing abilities. Also, their short and long-term responses to anthropogenic underwater sounds are poorly understood.

Keywords:

Arctocephalus pusillus doriferus, *Arctocephalus forsteri*, *Neophoca cinerea*, offshore wind farm impacts, underwater sound, underwater hearing, pile driving.

1. INTRODUCTION

The need to reduce reliance on expensive and diminishing fossil fuels for energy, and growing concerns over the impact of burning fossil fuels on current, rapid, climate change has stimulated the investment into renewable energy sources (Papież et al. 2018, Xu et al. 2019). Offshore wind farms were first developed in Europe in the 1990s and by the early 2000s represented one of the fastest-growing sectors for renewable energy supply (Perveen et al. 2014). By 2020, hundreds of offshore wind farms were operational in Europe and Asia (Möllerström et al. 2024). In Australia, no offshore wind farms had been constructed by 2025, though planning was underway in eastern, southern and western shelf areas.

Despite the environmental benefits, wind energy developments are associated with a range of potential impacts on the surrounding environment. Key concerns include effects on wildlife, landscape aesthetics, electromagnetic interference, habitat alteration, and noise emissions (Köller et al. 2006, Leung and Yang 2012, Dai et al. 2015, Galparsoro et al. 2022). Among these, noise is a prominent and complex issue that occurs across all stages of a wind farm's lifecycle, from site investigation and construction to operation and eventual decommissioning.

Environmental impacts of offshore wind farms can be site specific and potential impacts on species occurring in Australia, but not in Europe, are poorly understood. For example, constructions in Europe have considered impacts on numerous seabird species, but not on large dynamic-soaring seabirds such as albatross, small odontocetes (toothed whales) have been considered but not large baleen whales (e.g., humpback), and while phocid seals have been studied, little is known of impacts on otariid seals (fur seals and sea lions).

This review summarises knowledge and identifies knowledge gaps for potential impacts of offshore wind farm developments in Australia on the otariid seals.

1.1. Background

Under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), any proposed offshore wind farm development in Australia likely to have a significant impact on a matter of national environmental significance must first be referred to the Minister for the Environment for assessment. Environmental impact assessments must demonstrate steps taken to identify and minimise potential impacts to protected matters.

In August 2022, the Australian Government identified six priority areas for offshore wind farm consideration, three in the Bass Strait region (recognised in this report as being shelf waters between Victoria and Tasmania) two on the New South Wales (NSW) coast and one on the west coast of Western Australia. These areas overlap with the ranges of numerous species protected under the EPBC Act, including populations of three species of pinniped.

Pinnipeds (seals and walruses) are amphibious carnivores that forage at sea and rest on land. The three species with breeding populations around the southern coasts of mainland Australia are the Australian sea lion (*Neophoca cinerea*), the Australian fur seal (*Arctocephalus pusillus doriferus*) and the Long-nosed (aka New Zealand) fur seal (*Arctocephalus forsteri*). These seals are from the Family Otariidae, or eared seals (fur seals and sea lions), which differ substantially in their behaviour, biology and physiology from Phocid seals (true seals), which predominate in the Northern Hemisphere and the Antarctic. Information on the impact of offshore wind farms on seals comes largely from the Northern Hemisphere, where the offshore wind farm industry is most developed. In Australia, seals occupy all the declared offshore wind farm areas and are at risk of impacts from developments.

There is relatively good information on the abundance and distribution of the three seal species in Australia, but there are information gaps on the distribution of their activities at sea, as well as their potential vulnerabilities to offshore anthropogenic activities, including behavioural and physiological responses to underwater sounds. Potential impacts from offshore wind farm developments include altered movements, masking by underwater noise, stress, and ecosystem changes. Pile driving of monopile tower-bases for wind farms produces substantial underwater sound that can cause seals to move from an area, reduce their feeding activity, and cause them temporary or permanent hearing loss (Southall et al. 2007, Erbe et al. 2018, Kastelein et al. 2018a). More accurate information is needed on seal hearing and responses to anthropogenic sounds to understand potential impacts from offshore wind farms. Clarifying unknowns regarding the distributions at sea and hearing abilities of Australian seals will enable better-informed decision-making and risk mitigation for offshore renewable projects, and compliance of these projects with the EPBC Act.

1.2. History of offshore wind farms

While the harnessing of wind to produce electricity was first identified in the late 1800s, development of modern wind-powered turbines did not commence until the 1970s. Then, governments seeking alternatives to burning fossil fuels for electricity production provided funding to test alternative energy sources (Möllerström et al. 2024). Development of wind farms offshore commenced in the 1990s. Offshore investigations commenced partly because winds offshore are stronger and more consistent than on land, but also because there was more space offshore and less conflict with land uses and users. However, transmission and maintenance costs are higher offshore, and environmental impacts are more difficult to identify (Snyder and Kaiser 2009, Perveen et al. 2014).

In 1991, the first commercial offshore wind farm in the world, Vindeby Offshore Wind Farm, was commissioned in Denmark (Olsen and Dyre 1993). The progression toward offshore wind farms in Denmark was driven by Government policy to reduce reliance on oil imports. Vindeby was constructed as a proof-of-concept for offshore developments and comprised 11 turbines that produced a total of 5 MW of electricity. Construction was in ~6 m water-depth using concrete plinths to support the towers. After 26 years of operation, Vindeby was decommissioned and all its structures were removed in 2017 (Feddersen et al. 2023).

In the early 2000s, global interest for renewable energies to replace higher carbon-emitting energy sources resulted in a scaling-up of offshore wind farms, particularly in Europe (Bailey et al. 2014). During the 2010s, the United Kingdom and Germany were the leaders in offshore wind farm construction (Figure 1.1). Coastal waters around much of northern Europe were declared as zones for potential wind farm installations. In 2010, China commenced constructions of offshore wind farms and by 2021 were producing close to half the global energy production from offshore wind farms (McCoy et al. 2024). The USA commenced development of offshore wind projects in 2016 and its first offshore wind farm was commissioned in 2024 (McCoy et al. 2024).

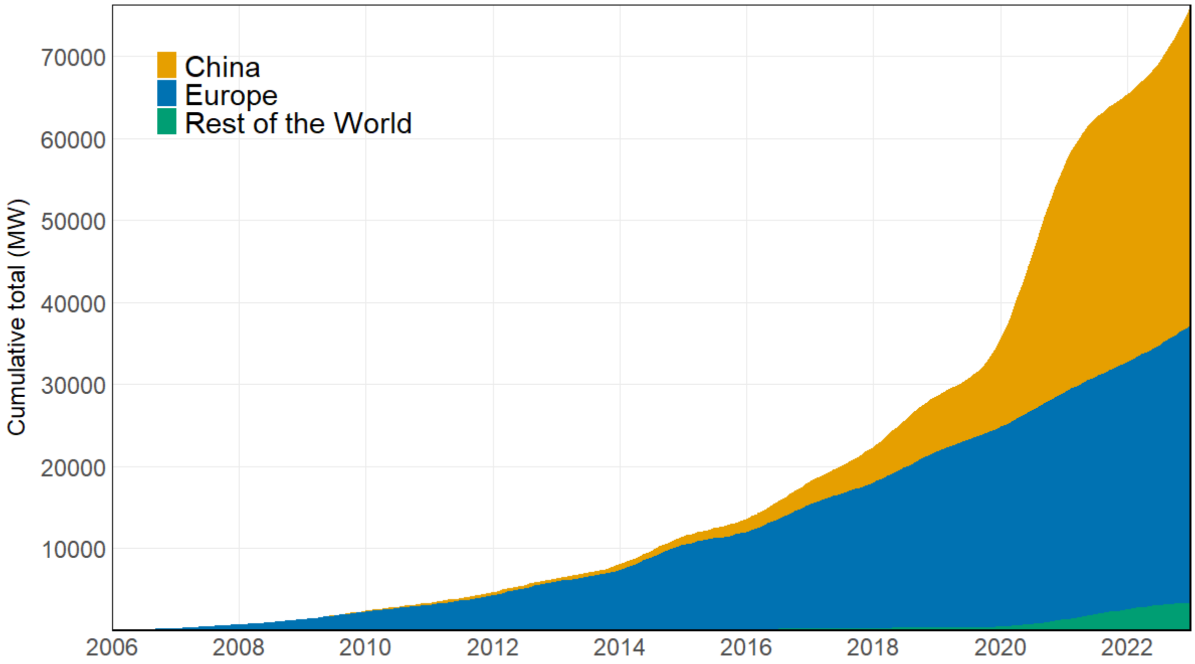

Figure 1.1. Global cumulative installed offshore wind energy (MW) from 2006 – 2023 from China (orange), Europe (blue) and the rest of the world (green). Data is based on published values in the Global Wind Energy Council (GWEC) 2024 Report.

The growth in offshore wind farm construction in Europe and Asia has made offshore wind zones the fourth largest declared use of ocean space, following shipping, fishing, and protection zones (see Figure 1.2, Figure 1.3). In 2024, the UK alone had 268,000 km^2 of marine area leased out for offshore wind farm developments: it had 45 operational wind farms and a total of ~2,800 turbines that produced a total of ~15.9 GW of electricity[1]. In 2024, the UK Crown Estate projected that 30 – 50 GW would be produced by UK offshore wind farms in the 2030s[2]. The UK trade association for offshore renewable energies, RenewableUK, estimated that in 2025, China had 129 operational offshore wind farms producing a total of ~41 GW of electricity[2].

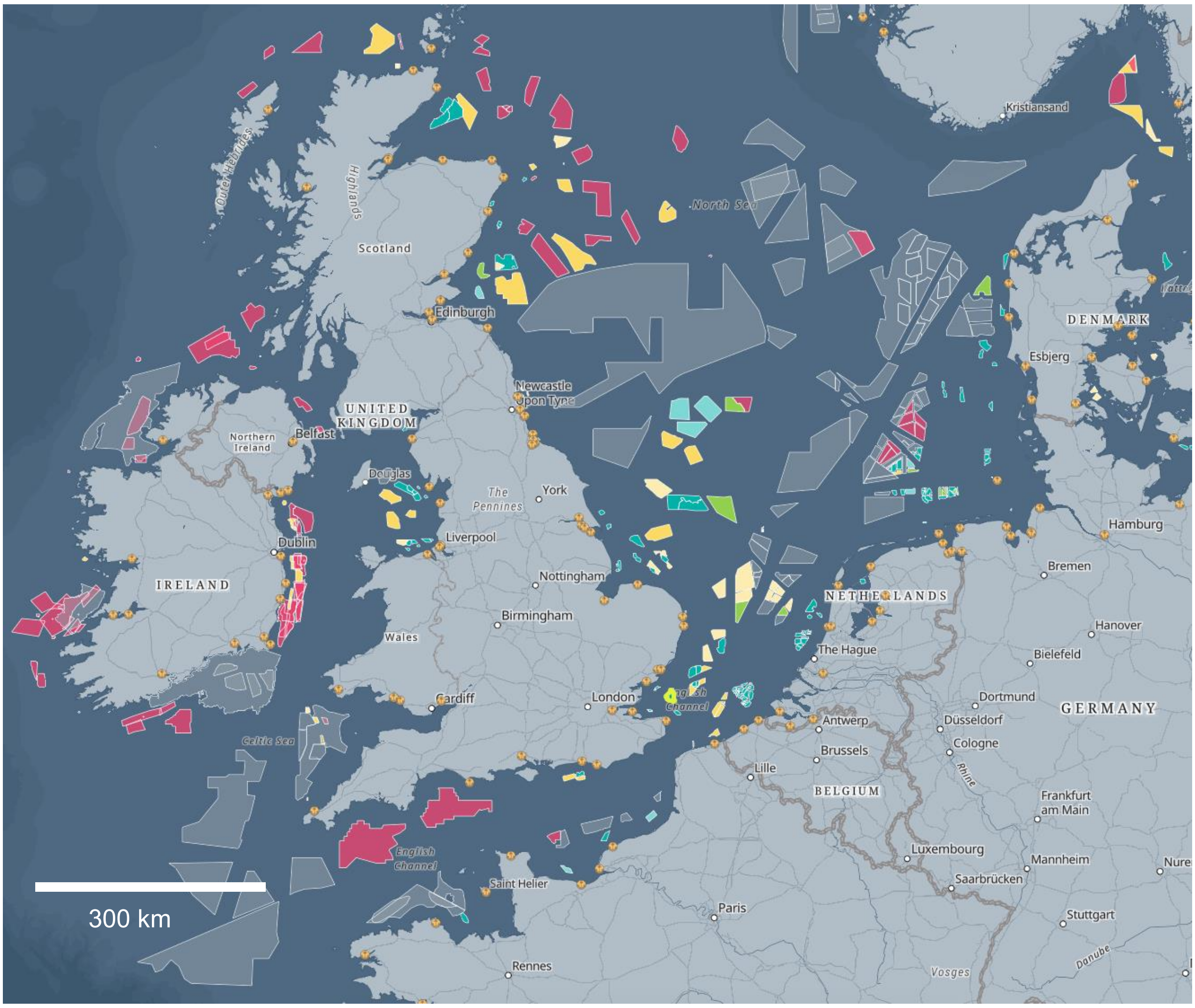

Figure 1.2. UK and North Sea offshore wind farm areas in 2025. Shape coding: grey = development zone, pink = planning, yellow = consent for construction sought/ supplied, green = pre-construction, blue = in construction and commissioned (figure from https://map.4coffshore.com/offshorewind/).

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[1] https://www.thecrownestate.co.uk/our-business/marine/offshore-wind-report-2024

[2] https://www.renewableuk.com/energypulse/reports/global-offshore-wind-pipeline-june-2025/

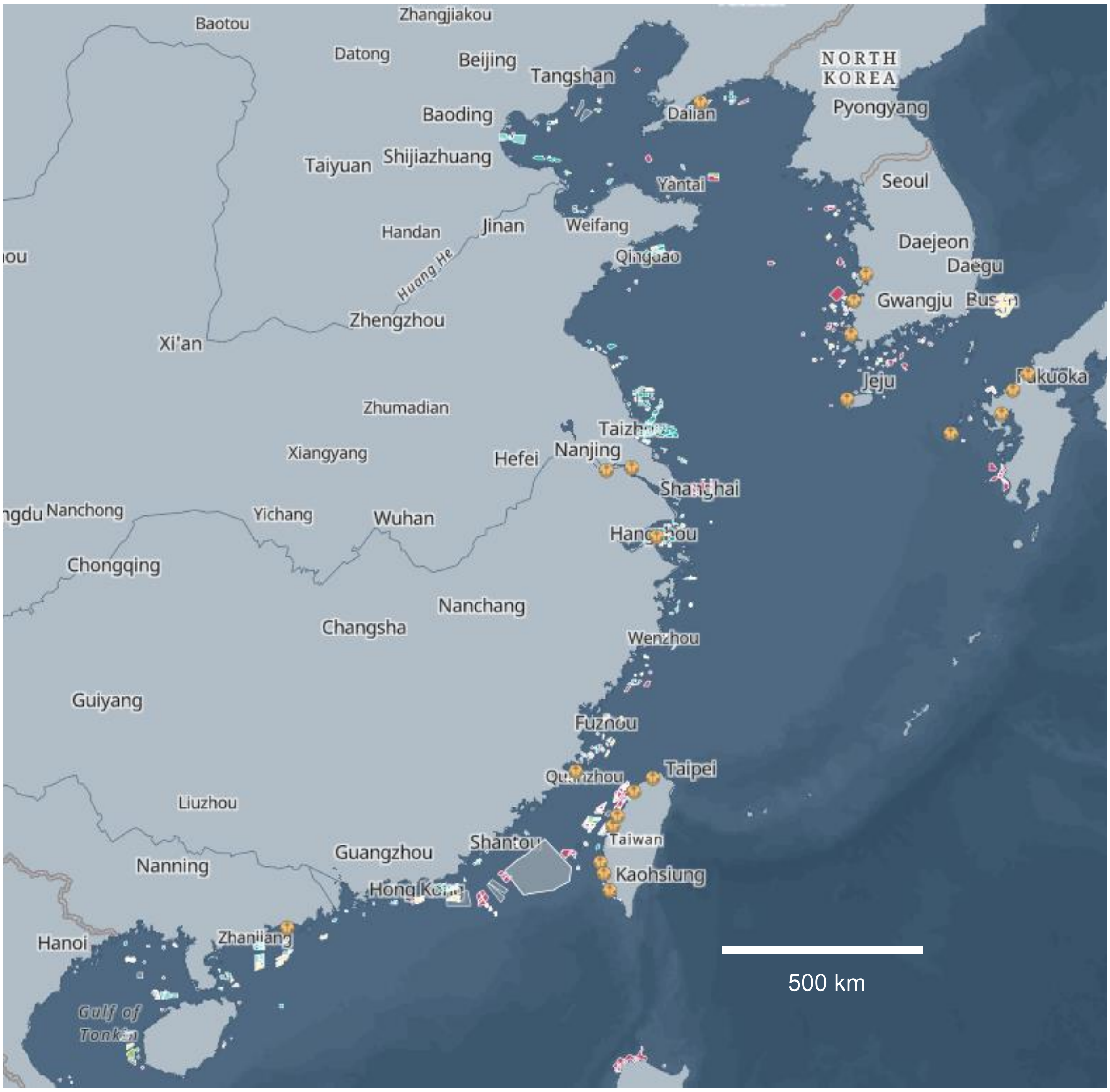

Figure 1.3. Chinese, Taiwanese and Korean offshore wind farm areas in 2025. Shape coding: grey = development zone, pink = early planning, yellow = consent for construction sought/ supplied, green = pre-construction, blue = in construction and commissioned (figure from https://map.4coffshore.com/offshorewind/).

Offshore wind farms are a major contributor to renewable energy initiatives, reducing carbon emissions from burning fossil fuels that have contributed to rapid global climate change. The size and capacity of turbines has steadily increased resulting in increases in energy production efficiencies. In the 1980s, individual land-based wind-powered turbines were producing 0.03 MW of electricity. In 1991, Vindeby Offshore Wind Farm had 0.5 MW turbines with hub-heights of 35 m and blade lengths of 17 m. By 2009, average turbine sizes had 3 MW outputs, and in 2022, the largest turbines produced 7.2 MW (Möllerström et al. 2024). In 2025, a 26 MW turbine with a hub-height of 185 m and blade lengths of 155 m was constructed in China, by

Dong Electric Corporation[3]. The Global Wind Energy Council projects that offshore wind will grow from 83 GW of global capacity in 2024 to >400 GW in the 2030s[4].

Currently, most offshore wind turbines are fixed-bottom structures supported by monopile towers driven into soft sediments, in water depths up to 60 m (e.g., Díaz and Guedes Soares 2020). Recent development of floating wind farm technology has enabled installation of wind farms in water depths up to 1,000 m, further offshore and where winds can be stronger (Collu and Borg 2016). Floating wind farms typically have turbine towers positioned on sub-surface floats that are anchored to the seafloor by cables (Jahani et al. 2022, Danovaro et al. 2024).

1.3. Underwater noise

Underwater noise production from offshore wind farms is the most frequently cited source of potential impact on seals (Teilmann et al. 2004, 2006, Tougaard et al. 2006, 2009, Kastelein et al. 2013a, 2013b, Thompson et al. 2013, Kirkwood et al. 2015, Russell et al. 2016, Aarts et al. 2018, Brasseur et al. 2018, Kastelein et al. 2018a, 2020, Thompson et al. 2020, Tougaard et al. 2020). Noise can change seal behavioral patterns, damage their hearing, and potentially have population-level consequences (Southall et al. 2007). All pinnipeds are sensitive to sound in air and under water, so are likely to be susceptible to loud noises in both media. An important focus of this review is to highlight the current understanding and gaps in knowledge of the hearing capability and vulnerability to anthropogenic noise of otariid seals in Australia.

1.4. Objectives

This report aims to provide a review of the pinnipeds in Australia and the potential impacts on them from offshore wind farms. To achieve this, the following objectives were adopted:

1. To describe steps in the construction of offshore wind farms (including pre-construction, construction and post-construction).
2. To present on the status of wind farm development in Australia, including descriptions of the declared offshore wind farm areas.
3. To describe the seal species that occupy the mainland Australian coastline, their distribution and abundance, at-sea movements, threats, and overlap with the declared offshore wind farm areas.
4. To describe potential impacts on the seals from offshore wind farm developments.
5. To assess gaps in knowledge of seal biology that could influence their exposure to, and potential impacts from, offshore wind farm developments.

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[3] https://www.dongfang.com.cn/

[4] https://www.gwec.net/

2. OFFSHORE WIND FARM LIFECYCLE

The lifecycle of an offshore wind farm involves four major phases: pre-construction, construction, operation (post-construction), and decommissioning. Pre-construction involves surveys of the site to map water-depths, benthic structure and sediment depth, and deployment of equipment to monitor wind and oceanographic characteristics. Because of such operations, localised shipping activity is also altered. The main impact on seals during pre-construction could come from geophysical surveys of the sub-seafloor structure, which can emit high-intensity sounds through the water column.

Activities during construction of an offshore wind farm include alterations to the benthos to provide a suitable surface, often the deposition of crushed rock to form a scour-proof pad around foundation bases (so currents do not erode sediment around the base causing instability), installation of tower foundations (e.g., pile driving of monopiles), attachment of towers, attachment of turbine-hubs and blades, and installation of benthic cables (Jiang 2021). During construction, there are alterations to shipping, including increased large-vessel activities and exclusion of non-construction vessels, such as fishing vessels. The most profound impacts on seals during construction will likely come from the production of high-intensity sounds such as during pile driving of tower bases (Diederichs et al. 2008).

During post-construction, main impact sources come from maintenance shipping activities, ecosystem changes caused by the presence of the towers (such as colonisation of scour pads and underwater structures and altered fishing activities), sounds from blade motion and tower vibration, and electromagnetic currents around the cabling (DEA 2013, Dai et al. 2015). Decommissioning of wind farms will require altered shipping regimes and production of underwater sound, which could influence seal activities in the area (Diederichs et al. 2008).

2.1. Pre-construction phase

2.1.1. Surveys

Prior to installation of wind farms, the seafloor needs to be surveyed to determine sediment depth, and presence of rocky outcrops or other structures that could limit the location of turbine towers and cable-laying. A range of methods employed to examine and test substrate may cause physical disturbance to marine fauna. Such methods include multibeam echosounders that emit high-frequency (>100 kHz) sound pulses to map the seafloor, side-scan sonar operating between 100 – 500 kHz to produce detailed images of the seafloor, sub-bottom profilers that emit medium frequency (2 – 20 kHz) ‘chirps’ that penetrate the seafloor to profile sediment layers, and cone-penetration testing, vibrocores and drop-cores to determine substrate composition and strength (Wu et al. 2021, Smith 2024). Sound from these surveys, particularly from the sub-bottom profilers, which emit high-energy, broadband, impulsive noise, will be detected by seals in the vicinity and may alter their behaviours or cause injury (Crocker et al. 2019, Hanke et al. 2021, Erbe et al. 2025b).

A variety of recording devices and structures may be installed at a wind farm prior to construction, to monitor *in-situ* ocean and wind conditions, ambient noise levels, and to survey the marine life including marine mammal occurrence. Some of these devices, and the shipping involved to install and maintain them, may emit noise or light that influence the behaviour of passing seals.

2.1.2. Shipping

Vessel noise has the potential to impact marine environments during offshore wind farm developments (McLean et al. 2024). Shipping activity within a declared offshore wind farm area may increase with an abundance of survey, construction, and maintenance vessels, or decrease, through the exclusion of vessels that otherwise would pass through the area. Ships produce underwater noise due to propeller cavitation, engine noise transferred through the hull, and interactions with waves (McKenna et al. 2012). Sounds are also introduced into the ocean from dynamic positioning equipment, depth sounders, sonar, and other scanning equipment that may be deployed from vessels (Peña 2018, Ruppel et al. 2022). Root-mean-square sound pressure levels produced by ships themselves are usually in the range 150 – 200 dB re 1 µPa at 1 m covering a frequency range of 10 Hz to >1 kHz (Erbe et al. 2019). Shipping noise will be detected by otariid seals and has the potential to alter their behaviour through either direct impact, or by masking their ability to hear other sounds (Southall et al. 2000).

Further potential impacts from shipping include direct collision risk, although otariids have a low collision risk compared with cetaceans (Schoeman et al. 2020), and pollution, from normal engine running, bilge pumping or accidental spills and vessel collisions (Talley 2003, Walker et al. 2019).

2.2. Construction phase

2.2.1. Benthic changes

During the construction phase of offshore wind farms, existing local vessel traffic is typically excluded from a declared area and only vessels associated with construction activity are permitted. The exclusion of fishing vessels from an offshore wind farm area may allow benthic habitats to adjust (e.g., following exclusion of benthic trawlers) and prey availability for otariids to change, especially if exclusions extend into the operation phase (Harris et al. 2025).

Benthic manipulation, such as dredging, may be required to ensure the seafloor is suitable for wind farm construction. The addition of crushed rock may be required to form a scour-proof pad around monopiles, with sonar scanning of the pads to ensure evenness of stone-coverage. In some coastal regions, search and removal of other anthropogenic structures has been required prior to wind farm constructions, for example, repositioning of communications cables, removal of ship-wrecks or of unexploded ordinances (von Benda-Beckmann et al. 2015, Backstrom et al. 2024). Impacts on seals from benthic manipulations could come from the production of underwater sound, short-term increases in water turbidity, and longer-term, localised, habitat changes.

Increased shipping activity during the construction phase of an offshore wind farm includes vessels that transport building materials from port to site, a jack-up barge, and supporting tugs and transit vessels. A jack-up barge is a large vessel with four tower structures that are lowered to the sea floor to jack-up the vessel hull clear of the sea surface. This allows the vessel's deck to become a stable surface from which to position the tower bases, and attach towers, nacelle (the house for the turbine machinery and electrics) and the blades (Thomsen 2014, uit het Broek et al. 2019).

2.2.2. Tower base installation

Currently, most offshore wind farms have one of two bases: either monopiles that are pile-driven into sediments, or floating bases that are anchored to the seafloor, often by shorter pile-driven poles (Thomsen et al. 2015) (Figure 2.1). Other means of tower support include tri-piles (3 x monopiles), tripods, jackets (which are steel lattice-frames that have three footings anchored to the seafloor), and gravity bases (large concrete structures sitting on the seafloor) (Dolores Esteban et al. 2015, Jalbi and Bhattacharya 2020). Although monopile towers have been the most common, they require shallow bathymetries, usually <30 m but can be in water with depths up to 60 m, and soft substrates, usually with thicknesses <20 m but may require up to 40 m of sediment depth, depending on the tower height (Dolores Esteban et al. 2015, Sánchez et al. 2019). Floating platform structures have become more common in recent years because they can be installed in deeper water and do not require such deep sediment for anchoring (Danovaro et al. 2024).

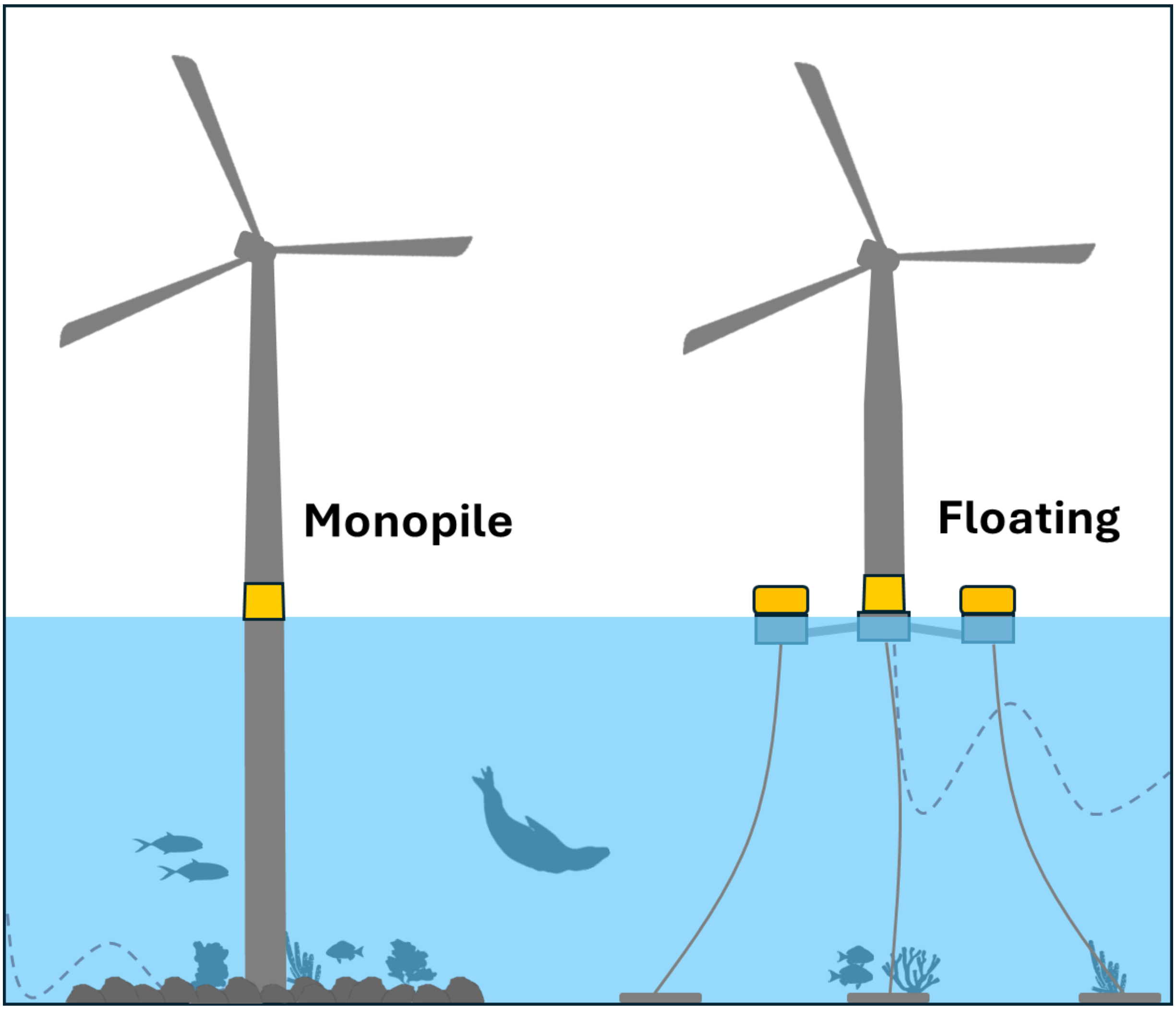

Figure 2.1. Schematic examples monopile and floating foundations for offshore wind turbines.

2.2.3. Pile-driven tower foundations & moorings

The greatest impact on seals during wind farm construction is likely to be caused by pile driving of tower bases into the seafloor (Madsen et al. 2006). Pile driving could be for monopiles, tri-piles, tripods, jacket foundations, or the moorings of floating turbines. The noise from pile driving originates in air when a hammer mechanism hits the pile: sounds pass through the sea surface into the water at steep inclination angles. The impact also creates a 'deformation' (flexing) of the structure that travels down the pile, reflects up off the base of the pile (at the seabed), and continues to travel up and down the pile. This dynamic deformation creates a sound wave in the water and the seafloor (Wilkes et al. 2016). Sound that enters the seafloor can also radiate back into the water.

The following provides a description of activities during installation of monopiles for an offshore wind farm. Relatively calm conditions are required for the transport of the monopiles to the wind farm site and for the operation of the jack-up barge. Monopiles may be carried by the jack-up barge or by a separate vessel. When an opportune weather window is recognised, a vessel with several monopiles will leave port for the wind farm area. The jack-up barge is fixed in position using GPS and thruster activity, and its towers are lowered to the seafloor. Once the hull is jacked-up clear of any wave action and the deck is level, a monopile is positioned into a cradle and slowly lowered to the seafloor. A hammer-section containing a weight within a casing is positioned over the monopile. Following checking of alignment, a single or short series of relatively ‘soft’ blow/s may be applied followed by rechecking of angles. The power of the hammer can be varied by increasing or decreasing hydraulic pressure on the falling weight.

Over the period of pile driving, the energy and frequency of hammer blows usually increase, interspersed with ‘quiet’ periods when angles and depths are measured to ensure correct penetration is being achieved and the monopile remains upright (de Jong et al. 2013) (Figure 2.2). When delivered, blows come at a frequency of approximately one every 1 – 2 s. As greater substrate penetration depths are achieved, hammer blows are delivered consistently over periods of >10 min.

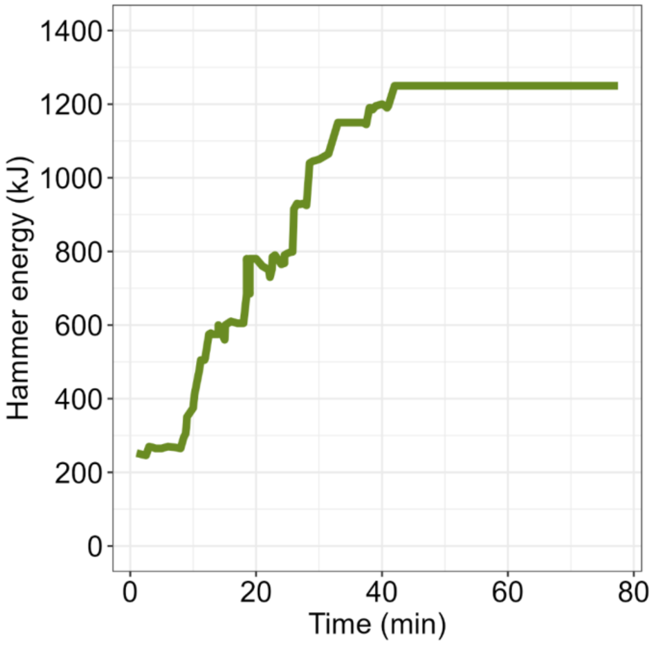

Figure 2.2. Increase in kJ of energy per hammer blow over time during pile driving of an offshore wind farm monopile (figure adapted from de Jong et al. 2013).

Depending on the depth into the substrate required and sediment composition, it may take 1 – 3 h to complete the driving-in of a single monopile (Bailey et al. 2014). Once at the required depth, the hammer section is removed, a cap placed on the monopile, and the barge is jacked down and moved to the next installation position. Towers may be installed 0.5 – 2.0 km apart (typically 5 – 9 times the rotor diameter), depending on the layout of the wind farm, wake effects and seafloor constraints (Liu et al. 2024). Following installation of all monopiles onboard, the vessel returns to port to collect more monopiles. The duration of pile-driving activities required for the installation of a wind farm will vary depending on weather conditions, breakdowns, distance from port, depth of pile-driving, number of monopiles required, and other logistical considerations. As an example, it took 78 days to install 44 monopiles for a wind farm in the Netherlands in 2014 (Figure 2.3).

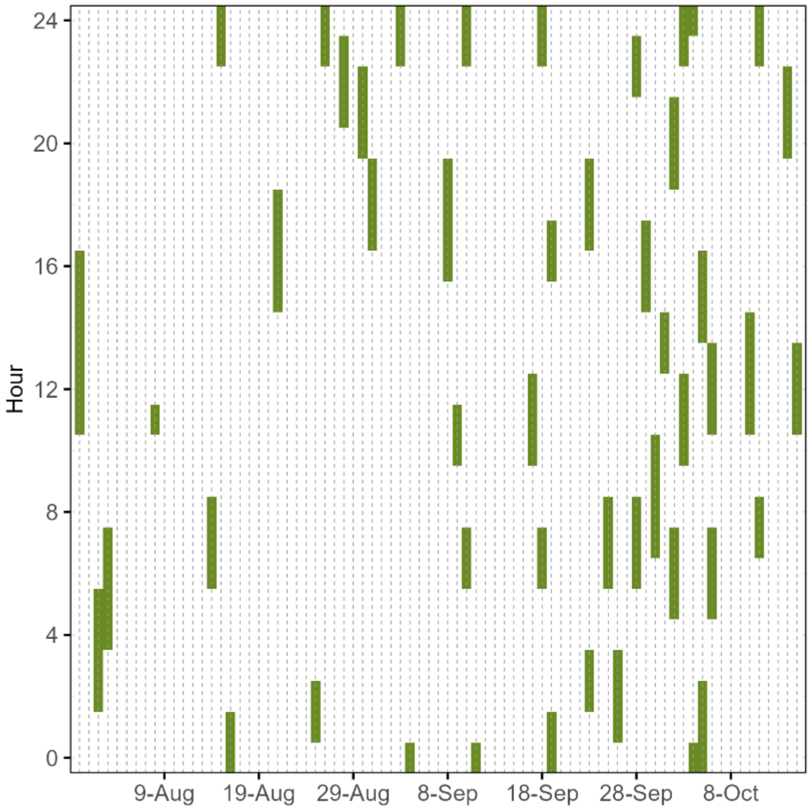

Figure 2.3. Date and time-of-day of pile-driving of 44 monopiles for Luchterduinen Offshore Wind Farm, in the Netherlands in 2014 (figure adapted from Kirkwood et al. 2015).

The underwater sounds produced during pile-driving of an offshore wind farm monopile vary depending on variables, such as monopile material, monopile diameter, hammer power level, duration of piling, water depth, sediment structure, and seafloor slope (Robinson et al. 2012). Underwater noise from impact pile-driving consists of brief, broadband pulses that last 50 – 100 ms, at the source (Remmers and Bellmann 2016). A typical monopile driving event can involve thousands of hammer strikes at strike rates of 30 – 60 per minute (Erbe 2009) (Figure 2.4).

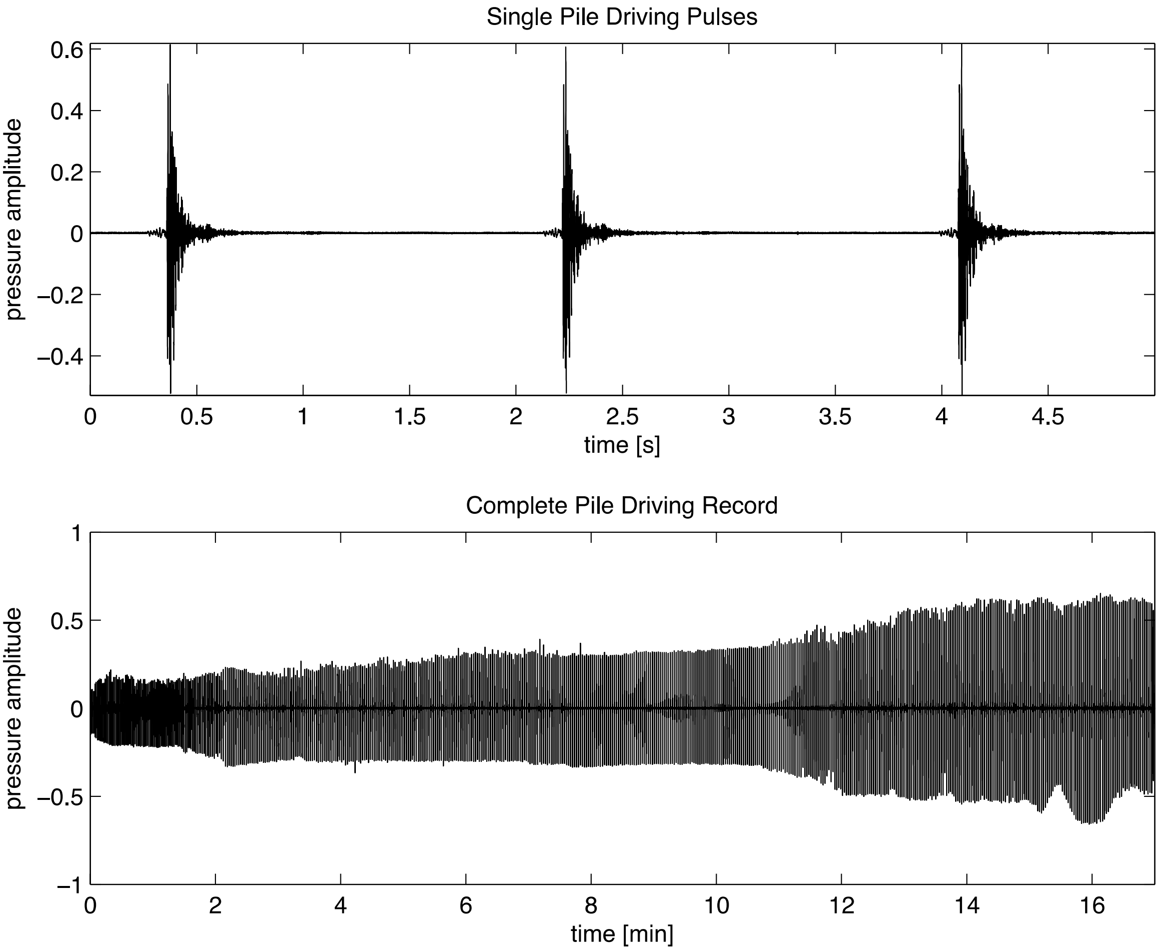

Figure 2.4. Time series of uncalibrated pressure recorded underwater 3 m from percussive pile-driving of a 0.8 m diameter steel pile to 25 m depth in the sediment, in which the hammer dropped every 1.8s (top panel) over a 17 min period (bottom panel), during which the hammer pressure was increased (figure from Erbe 2009, reproduced under CC BY 4.0).

Sound exposure levels at the source depend on pile size, shape, material, seafloor composition, and type of hammer: typically they range from 170 to 200 dB re 1 µPa^{2}m^{2}s (Erbe et al. 2025b). Five pile-driving operations with 4 – 4.7 m diametre piles at offshore wind farms in the United Kingdom had unweighted peak-to-peak source levels that varied between 243 and 257 dB re 1 µPa at 1 m (Nedwell et al. 2007). Moving away from the source, sound levels decrease in intensity as the sound spreads out, is partially absorbed by the water and the substrate, and scattered at the sea floor and surface (Figure 2.5). Sound propagation loss is a function of frequency, with energy at higher frequency typically lost over shorter ranges (Robinson et al. 2012) (Figure 2.6.). Thompson et al. (2013) modelled peak-to-peak sound levels at 10 km and 50 km from pile-driving of monopiles for a UK wind farm to be approximately 170 and 140 dB re 1 µPa, respectively. Sound exposure levels predicted at distances of 10 km and 50 km from pile-driving of towers at a wind farm in the Netherlands were estimated to be up to 140 and 120 dB re 1 µPa^{2}s, respectively (de Jong and Ainslie 2012, de Jong et al. 2013).

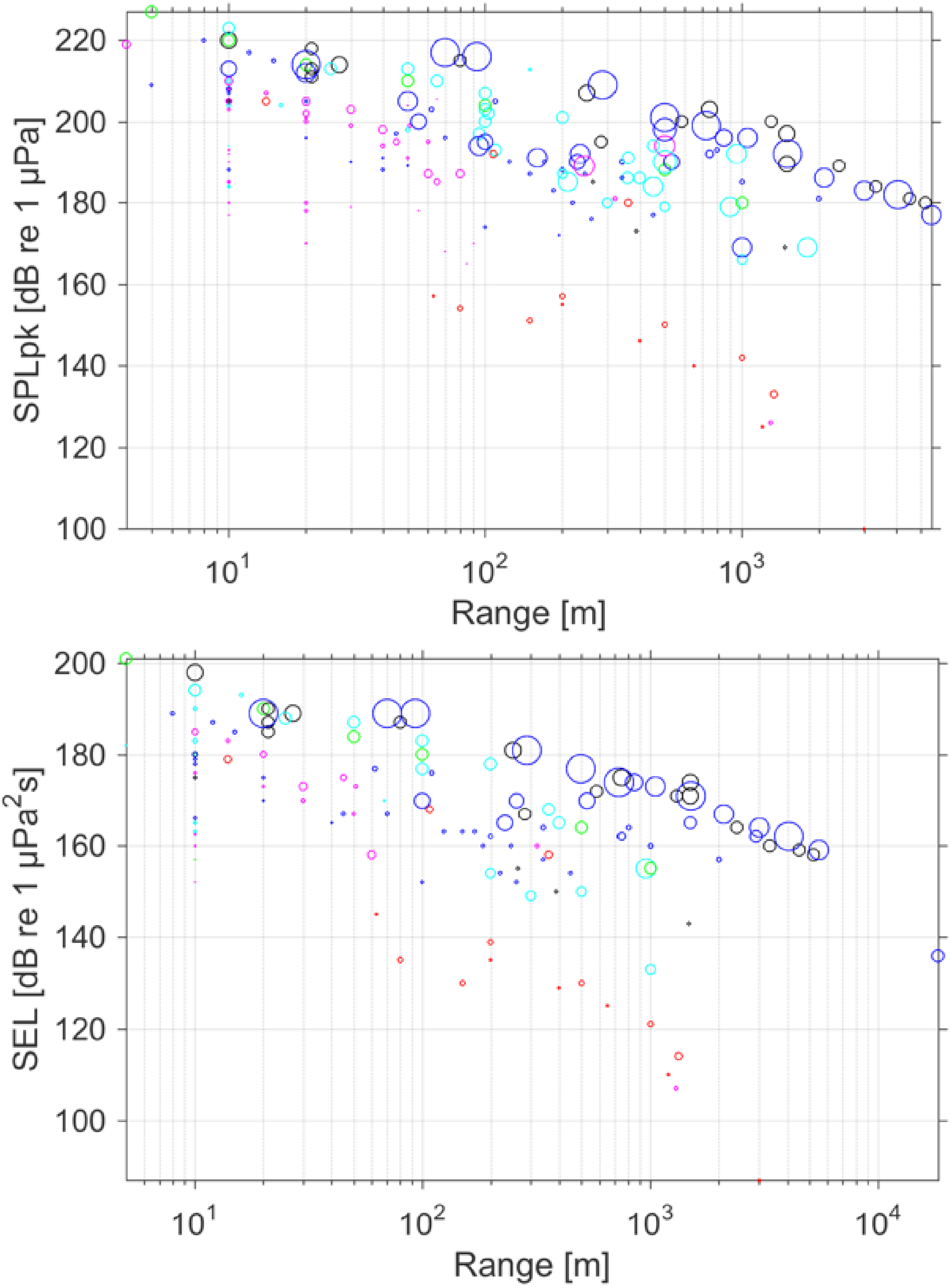

Figure 2.5. Peak sound pressure levels (SPLs, top) and average sound exposure levels (SELs, bottom) from percussive pile-driving recorded at distances from the source ranging between ~10 m and 10,000 m. Increasing circle size represents increasing monopile diameter, colour indicates water depth: red ≤ 1 m, pink 1 – 5 m, light-blue 5 – 10 m, dark-blue 10 – 30 m, black >30m; green – depth not listed (figure from Erbe et al. 2025b, reproduced under CC BY 4.0).

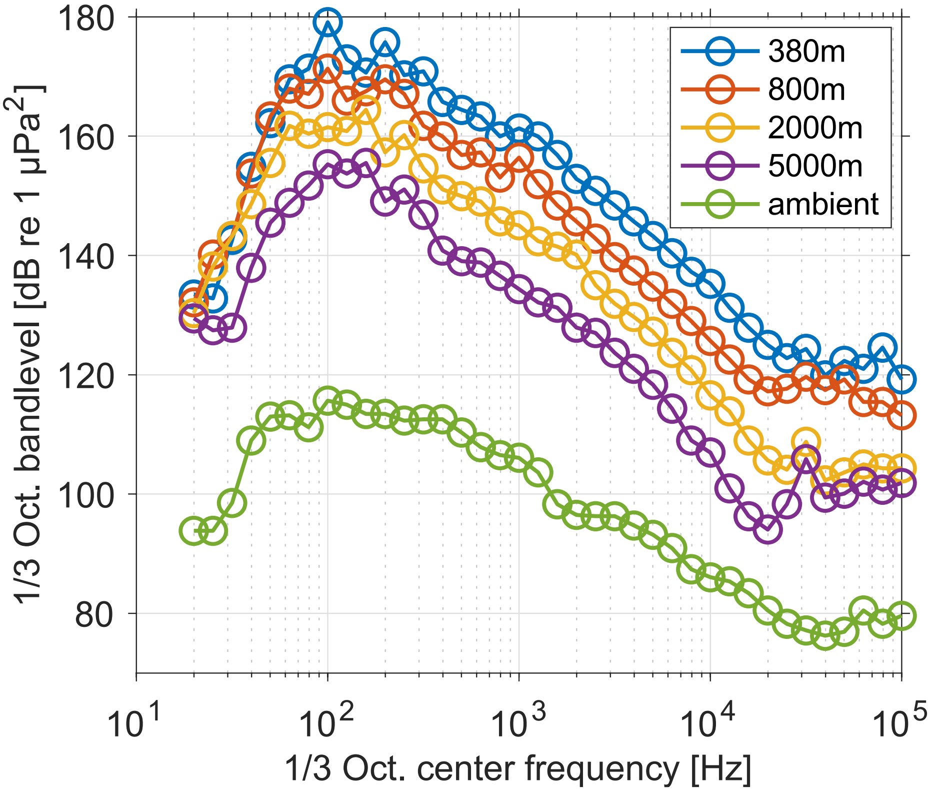

Figure 2.6. One-third octave band spectra from pile-driving a 5.2 m diameter monopile (hammer energy 1 MJ, water depth 15 – 20 m, seafloor consisting of sand and gravel over chalk) recorded at ranges from the source between 360 m and 5000 m. Ambient noise levels were a 'snapshot' recorded prior to pile-driving and included noise from vessel activity (figure from Erbe et al. 2025b, adapted from data in Robinson et al. 2012, reproduced under CC BY 4.0).

Application of sound mitigation techniques during pile-driving such as bubble curtains reduce sound exposure levels and thus the ranges over which the sound propagates before disappearing in ambient noise and potential bioacoustic impact ranges (Würsig et al. 2000, Peng et al. 2023). There has been significant effort to mitigate construction noise by adding sound absorption materials and changing installation methods, e.g., using cushioning caps (Deng et al. 2016), or bubble curtains (Bellmann 2014, Dähne et al. 2017). Several reviews of noise from pile installation and mitigation methods show that different environments require different solutions (Koschinski and Lüdemann 2020).

The sound levels received by a seal in the water vary with distance from the source, level in the water column, the hammer-blow intensity, water depth, sediment type, and levels of masking by ambient (e.g., shipping) noise. Distance is a key factor influencing the level of exposure to underwater sound received by marine mammals. Encouraging them to move away from a location prior to commencement of pile-driving may reduce their exposure to louder and potentially more harmful sound levels (Juretzek et al. 2021). Acoustic deterrent devices have been deployed in the vicinity of pile-driving to encourage marine mammals to move away prior to commencement of pile-driving (Koschinski and Lüdemann 2020, Thompson et al. 2020). A 'soft-start' to pile-driving, whereby low levels of energy are applied to the hammer until the monopile is well-seated in the sediment, is intended to provide a warning to marine mammals prior to the production of louder noise (Graham et al. 2023). While these methods shifted Harbour porpoises (*Phocoena phocoena*) from an area, their efficacy at moving otariid seals from the vicinity of pile-driving is unknown.

2.2.4. Floating structures

Floating offshore wind farm technologies increase development opportunity in deeper waters where offshore winds may be more consistent and there is less conflict with coastal marine users (Danovaro et al. 2024). Floating turbine structures may be installed in water depths nearing 1000 m (Musial et al. 2016).

The basic configuration for a floating offshore wind farm is a turbine tower attached to a submerged or semi submerged floating platform which is anchored to the seafloor by mooring lines (Maxwell et al. 2022, Edwards et al. 2024). Numerous anchor structures and power cable connector designs have been trialed for different water depths and seafloor conditions (Maxwell et al. 2022). The installation of moorings for a floating turbine may require drilling or hammering of multiple anchors, although as they would be smaller than a monopile, less energy would be required so noise levels would be lower.

The first operational floating wind farm was installed in the Scottish North Sea as part of the Hywind Scotland project in 2017 (Jacobsen and Godvik 2021). The deepest floating structures are currently installed at the Hywind Tampen project in Norway which became fully operational in 2023 (Lotfizadeh et al. 2024). Eleven turbines anchored at 260 to 300 m depth were installed ~140 km offshore to power adjacent oil and gas infrastructure.

In Australia, given the shallow seafloor of the Gippsland region, where the first Australian offshore wind farms are likely to be installed, and the relative infancy of floating wind farm technology (Asgarpour 2016, Devoy McAuliffe et al. 2024), it is unlikely that the first series of offshore wind farms will be floating platforms. The technology may be adopted by projects in NSW and Western Australia, however, as water depths within these wind farm areas exceed 100 m.

Construction, maintenance and decommission activities for floating wind farms differ from those required for fixed-foundation turbines. More of the assembly for floating structures can be completed on land, meaning there is a reduced requirement for vessel presence on site during installation. A major logistical and environmental benefit of floating structures is that installation of moorings is simpler and produces less noise than is required for monopile installation. However, anchor installations present unique logistical and environmental challenges, in part due to the water depth at which the operations are needed. Some anchors need to be drilled into rocky substrates and others need to be driven into the sediment (Cerfontaine et al. 2023).

Floating wind farm structures, including floatation tanks and cables, may represent collision and entanglement hazards for large cetaceans (Bailey et al. 2014) but are less likely to be a hazard for seals because their smaller size and greater agility allow them to avoid obstacles more effectively (Danovaro et al. 2024, Harris et al. 2025). The floating turbine structures may act as artificial reefs in a similar fashion to fixed turbine towers, and invertebrate recruitment and fish aggregations could attract seals (Harris et al. 2025).

2.2.5. Cable-laying

All wind farm turbines are connected by underwater cables to central transmission points within the wind farm area, which then connect with cables that carry the electricity to shore (Pérez-Rúa and Cutululis 2019, Cazzaro and Pisinger 2022). Cable-laying requires route selection surveys, pre-laying clearance of obstacles, trench digging, laying of cable, and burial at a sufficient depth (typically 1 – 2 m) to avoid damage, e.g., from ship's anchors (Srinil 2016).

2.3. Operation phase

2.3.1. Noise production

During the life of an offshore wind farm, shipping activity will be ongoing for routine maintenance. The frequency of maintenance activities will vary depending on proximity to port, environmental conditions, and usable life of components (Dalgic et al. 2015). Ship-based activities may be shared with aerial-based and robotic monitoring methods (Khalid et al. 2022).

Operating wind farms generate noise through many mechanisms (Madsen et al. 2006, Tougaard et al. 2020) including the rotor blades (aerodynamic noise, propeller blade rate modulations), the gearbox or generator in the nacelle (mechanical noise), the tower (vibration), and the foundation (vibration). Noise generated in air will travel through the air, and at incidence angles <13 degrees from the vertical, will pass through the air-water interface and continue under water (Figure 2.7). It will also travel down the tower, radiate into the water and propagate horizontally. Additionally, the vibrating tower will generate a noise field underwater that extends and travels through the entire water column. Vibrations on or in the seafloor will travel along or through the seafloor and radiate back into the water as noise (Nedwell and Howell 2004, Nedwell et al. 2007, Kikuchi 2010). The intensity of sound levels received by a seal in the water will vary depending on its distance from structures, the size and composition of the structures, wind-speed, and amount of masking from ambient noise levels.

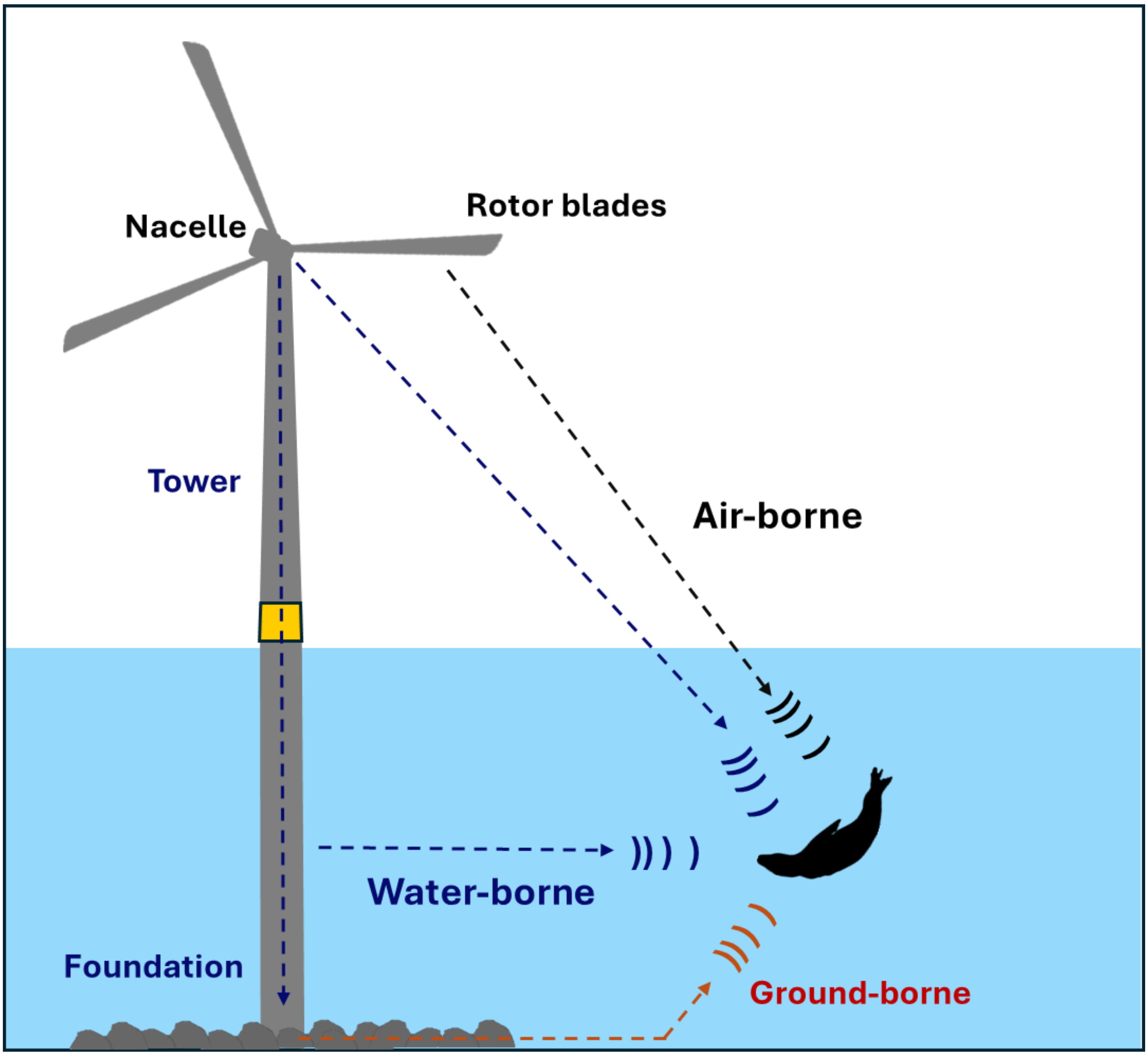

Figure 2.7. Schematic illustration of air-borne, water-borne, and ground-borne noise transmission paths from an offshore wind turbine to the surrounding environment.

Air-borne noise from wind turbines is mainly of two types: aerodynamic and mechanical. Aerodynamic noise is the dominant source of air-borne sound in modern wind turbines, especially those with large rotors. It results from the interaction between the rotating blades and the surrounding air, including phenomena such as turbulent boundary layers, blade tip vortices, and trailing edge separation (Dai et al. 2015). Aerodynamic noise increases with blade length, rotational speed, and wind speed. It is broadband in spectral energy and difficult to mitigate. However, advanced blade designs—such as serrated edges and optimised airfoil shapes—can help reduce noise emissions while maintaining energy efficiency.

Mechanical noise is generated by internal turbine components, such as gears, generators, and hydraulic systems located within the nacelle (Lowson 1996). It tends to produce tonal noise and is often more prominent in older turbines or those lacking sufficient acoustic insulation. While mechanical noise does not scale with turbine size, it can still significantly impact the soundscape if not properly managed. Effective mitigation typically involves isolating or dampening vibration sources and applying sound-absorbing materials during turbine manufacturing and installation (Wagner et al. 1996).

Airflow over the entire turbine structure and wave-induced motion in offshore environments may also generate additional vibration and noise that radiates through the air. These vibrations can contribute to structural noise transmission through the tower and foundation (Betke et al. 2004, Nedwell and Howell 2004).

Underwater noise is generated along several pathways. These are superposition of noise generated in air, which passes into the water at low incidence angles; noise from vibration of the tower, and ground-borne structural noise that radiates into the water (Figure 2.8). The noise is continuous, its spectrum is broadband, overlain with tonal components (tens of hertz to 1 kHz) (Madsen et al. 2006, Diederichs et al. 2008, Tougaard et al. 2020, also see review in Erbe et al. 2025b).

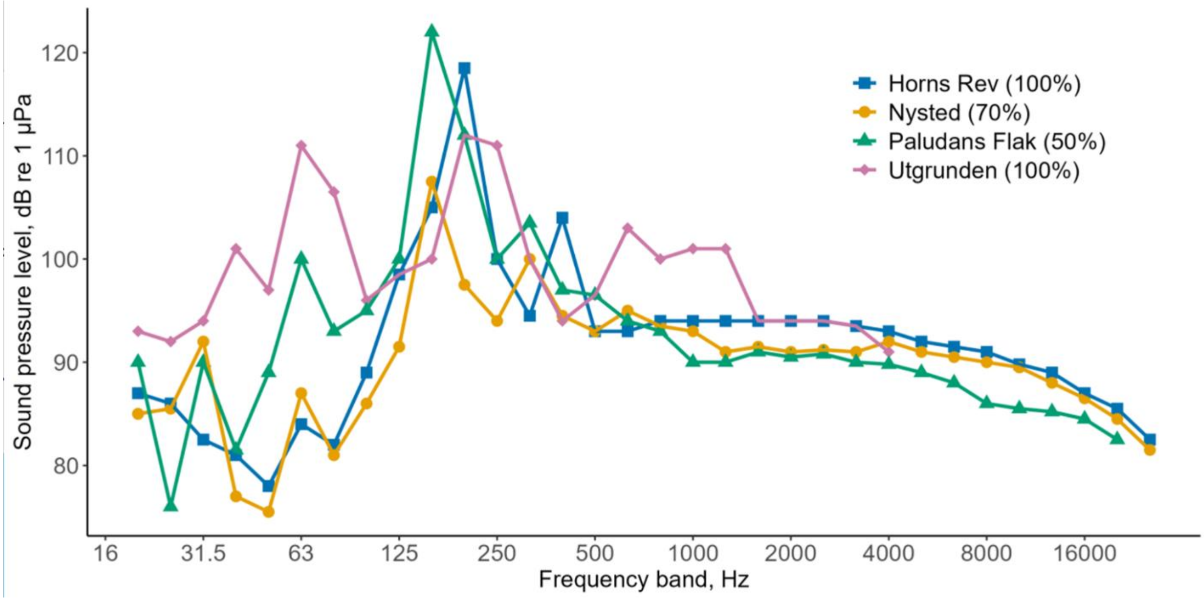

Figure 2.8. One-third octave band levels of underwater noise from operating offshore wind turbines at 100 m range. Percentages refer to operating powers (figure adapted from Diederichs et al. 2008, reproduced under CC BY 4.0).

Ambient noise in offshore wind farm areas is due to wind and often ships (Wenz 1962). Nedwell et al. (2007) reported low received levels from offshore wind turbines that exceeded ambient noise by only a few decibels. In other studies, the levels of tonal components at ~180 Hz have exceeded ambient noise by 20 to 30 dB (Lindell 2003, Betke and Schultz-von Glahn 2004, Betke et al. 2004). Based on a single-turbine source level of 156 dB re 1 μPa at 1 m, Tougaard et al. (2020) estimated that a wind farm with 81 turbines would have a source level of 175 dB re 1 μPa at 1 m. This was a simplified, idealised calculation, showing the theoretical difference between one and 81 identical sources. Such a combined source level does not occur at a single location within the wind farm, because the turbines are spatially distributed. However, at greater distances (several kilometres), the sound field may be detected as single point source with a higher exposure level than an individual turbine would produce.

Underwater noise levels depend on the type of wind turbine foundation. In the case of jacket foundation, received levels were 137, 128, and 122 dB re 1 µPa at 40 m, 60 m and 150 m range. In the case of monopile foundation, received levels were 135 and 133 dB re 1 µPa at 40 m and 150 m, and the offshore transformer station generated 139 and 120 dB re 1 µPa at 60 m and 150 m (Thomsen et al. 2015). Floating turbines are expected to generate less noise under water than fixed structures because of their more flexible coupling to the water and seafloor. A 6 MW and a 9.5 MW floating turbine at 15 m/s wind speed had source levels of 145 and 149 dB re 1 µPa at 1 m, respectively (Risch et al. 2023). Mooring chains of floating turbines, however, might create additional noise, typically transient, of snapping, banging, rattling, or creaking character (Burns et al. 2022). Median, broadband source levels from floating turbines (including mooring noise) were 163 – 167 dB re 1 µPa at 1 m (Burns et al. 2022).

Underwater noise levels also depend on turbine power. Received levels were 109 – 127 dB re 1 µPa at 14 – 20 m range from turbines of 450 kW to 2 MW in power (Tougaard et al. 2009). In a combination of power and foundation differences, a 5 MW turbine on a gravity-based (concrete) foundation was quieter underwater than a 3 MW turbine on a monopile (Norro et al. 2015, Tougaard et al. 2020) (Figure 2.9).

Finally, underwater noise levels produced by an offshore wind farm will vary with wind speed. Turbines operate between their ‘cut-in’ wind speeds, below which energy production is insufficient, and ‘cut-out’ wind speed, above which powering the blades is unsafe. Within the operational range, noise level and frequency of maximum noise power increase with wind speed (Tougaard et al. 2020). For example, under water at 50 m distance from a turbine monopile within the Sheringham Shoal Offshore Wind Farm, United Kingdom, the mean-square sound-pressure spectral-density-level varied by over 20 dB (Pangerc et al. 2016). Sound pressure levels increased with wind speed from 115 to 118 dB re 1 µPa at 50 m in wind speeds <4 m/s up to an average 126 dB re 1 µPa at 50 m in wind speeds of about 10 m/s, and then generally decrease with further wind speed increases (Pangerc et al. 2016).

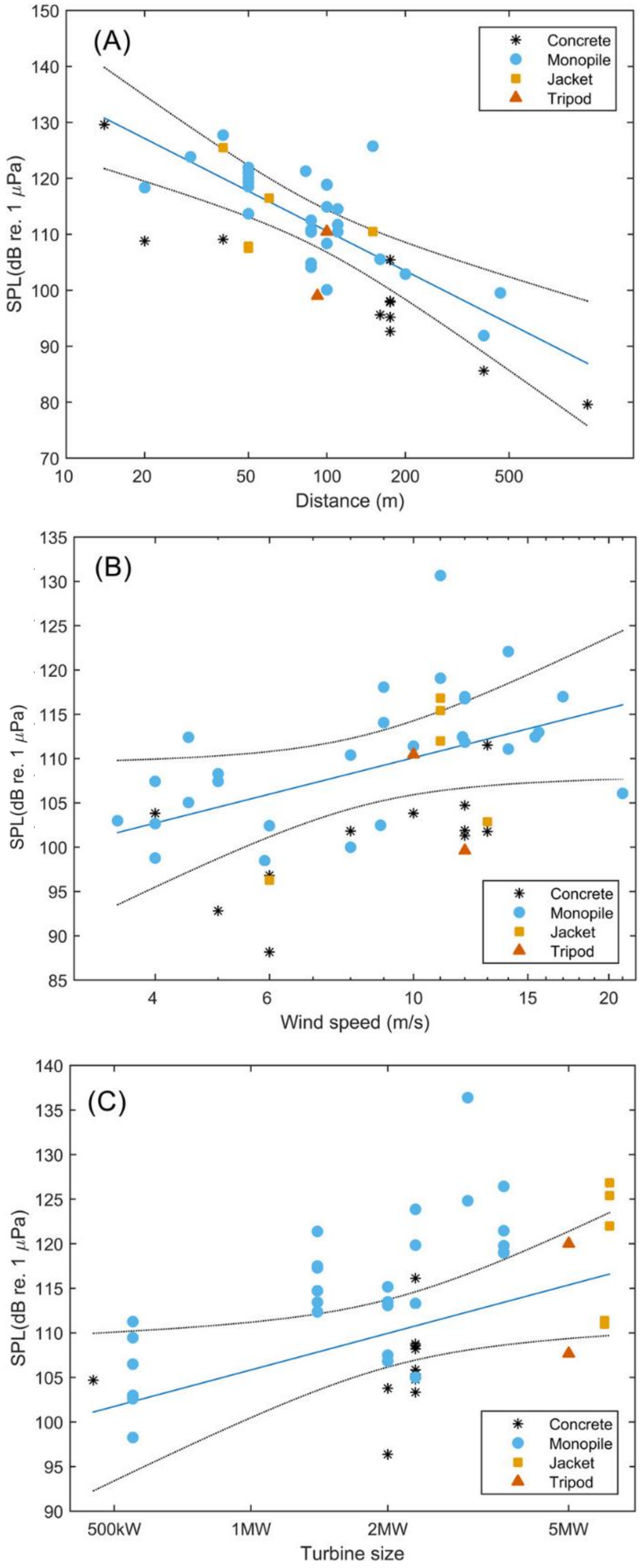

Figure 2.9. Trends of sound pressure level (SPL) measurements from operating wind turbines based on published data normalised to A) 10 m/s wind speed and 1 MW turbine size; B) 100 m distance and 1 MW turbine size; C) 100 m distance and 10 m/s wind speed. Blue lines show fitted linear relationships and grey lines show standard errors (figure from Tougaard et al. 2020, reproduced under CC BY 4.0).

2.3.2. Electromagnetic fields

Electrical cabling connecting wind farm towers to each other and to shore may develop electromagnetic fields that could be detected by marine species (Hutchison et al. 2020). It is unclear to what extent marine species with the ability to detect electromagnetic fields may be attracted to or deterred from electromagnetic fields (Hermans et al. 2025, Labourgade 2025). Stronger fields are produced if electricity in the cables is transmitted as AC rather than as DC current (Perveen et al. 2014). AC current may be retained for shorter distance transmissions but loses power with distance. Thus, over longer distances, it can be more efficient to convert to a DC current (Zhan et al. 2010). This requires positioning a power-conversion plant offshore, usually on monopiles within the wind farm (Perveen et al. 2014).

2.4. Decommissioning

Offshore wind farms are anticipated to have running-lives of 20 – 30 years, after which increasing maintenance costs associated with fatigue of components are likely to end their utility (Márquez-Domínguez and Sørensen 2012). Decommissioning protocols for offshore structures ideally require consideration during the construction phase (Chandler et al. 2017). The removal procedures, which may take weeks to months depending on the size and number of structures, vessel availability, weather and transport considerations, can affect marine species. For example, decommissioning will involve underwater noise and local damage to habitats, including the removal of structures that have been colonised by marine species (Sommer et al. 2019).

3. OFFSHORE WIND FARMS IN AUSTRALIA

In 2019, investigations commenced for an offshore wind farm to be located off the Gippsland coast of western Victoria. The developers applied for a lease, and conducted geotechnical surveys, environmental assessments and public consultations. These activities stimulated the drafting of new legislations to enable the strategic development of offshore wind farms in Australian waters. In 2021, the Australian Government passed the *Offshore Electricity Infrastructure Act 2021*[5], and in 2022, the *Offshore Electricity Infrastructure Regulations*[6] were released. These legislative steps provided a regulatory framework for the progression of lease applications for the development of offshore wind farms. Also in 2022, the Federal Minister for Climate Change and Energy announced six priority areas for offshore wind farm consideration (Figure 3.1). The areas were identified based on their proximity to coastal regions with high electricity demands, a suitable port, and existing electricity transmission networks (such as existing fossil-fuel power stations), strength and consistency of wind, and industry interest. In 2025, although there had been investment in offshore wind farm development, no offshore wind farm had been installed in Australian waters.

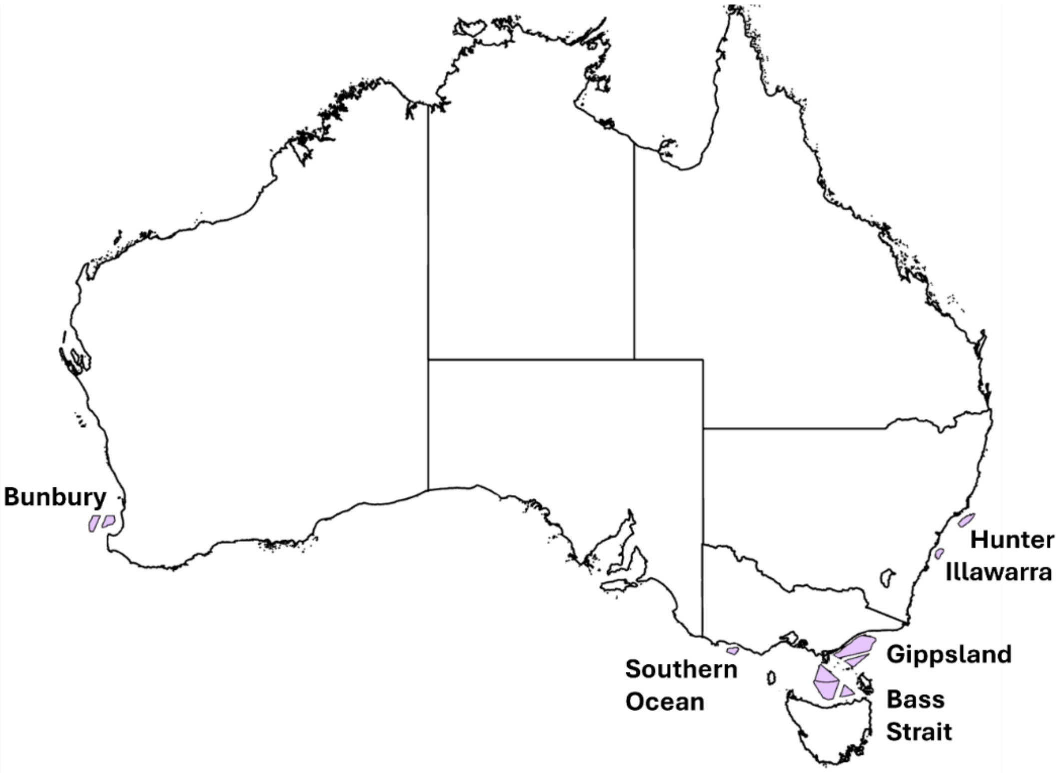

Figure 3.1. The six declared offshore wind farm areas along the Australian coastline, first identified in 2022.

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[5] https://www.legislation.gov.au/C2021A00120/latest/text
[6] https://www.legislation.gov.au/F2022L01422/latest/text

A first round of six offshore wind farm feasibility licenses, all within the declared Gippsland Offshore Wind Farm Areas, was released in May 2024[7]. In July 2024, a further six licenses were granted for projects in the Gippsland Offshore Wind Farm Areas. In February-March 2025, single lease licenses were provided for projects in the Hunter area in NSW and the Southern Ocean area in western Victoria.

The current state of knowledge regarding potential impacts of offshore wind farm development on seals in Australia relies on research elsewhere. McLean et al. (2024) outline best-practice standards for offshore wind farm development in Australia, including regionally specific information for each of the six offshore wind farm priority areas relating to species of interest, bathymetry and other guidance. A guidance document for offshore wind farm development by the Department for Climate Change, Energy, the Environment and Water (DCCEEW) outlines 14 potential impact pathways associated with the operation of offshore wind farms in Australia, plus cumulative effects (DCCEEW 2023), as listed below. Those recognised in the report that potentially impact seals are marked with an asterisk.

1. * Underwater noise
2. Collision with turbine-blades
3. Electromagnetic fields
4. * Seabed disturbance
5. Disturbance of cultural heritage
6. * Effects on hydrodynamic processes
7. * Barrier effects
8. * Light emissions
9. * Vessel interactions
10. Invasive species
11. * Socioeconomic – displacement of existing users (e.g., fishing vessels)
12. Socioeconomic – seascape and visual amenity
13. * Multiple pathways – including marine park values
14. * Cumulative impacts

3.1. Bass Strait region declared areas

Southern Australia has been identified as significant for the development of offshore wind farms primarily due to strong and persistent offshore winds. The Bass Strait, in particular, has some of the highest scores in national cost-benefit analysis for offshore renewable energy development (Salvador et al. 2022), and has a shallow, low-gradient, sand dominated seafloor

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[7] https://www.dcceew.gov.au/about/news/first-round-offshore-feasibility-licenses-granted

which facilitates pile-driving for offshore wind turbine installation (McLean et al. 2024). Both the geology and oceanography of this region is relatively well studied, likely in part due to the region's history of offshore oil and gas infrastructure development. There are two offshore wind development zones within Victorian jurisdiction and one under Tasmanian jurisdiction.

3.1.1. Gippsland

The Gippsland region in the north-eastern Bass Strait was the first of the six offshore wind priority areas to be nominated. Three separate areas have been declared in the Gippsland Offshore Wind Farm Area, with a total area of ~15,000 km^2. In 2025, 12 feasibility licenses had been granted for wind farm proposals in the Gippsland areas (Figure 3.2).

In 2025, the most advanced project in the Gippsland area, and in Australia, was Star of the South, located 10 km offshore in the north-west of Gippsland Offshore Wind Farm Area-1 (Figure 3.2). This wind farm was forecast to generate 2.2 GW of power and was projected to commence operation in the early 2030s. The project currently cites the intent to install turbines with monopile foundations and to use bubble curtains to reduce installation noise during the construction phase[8].

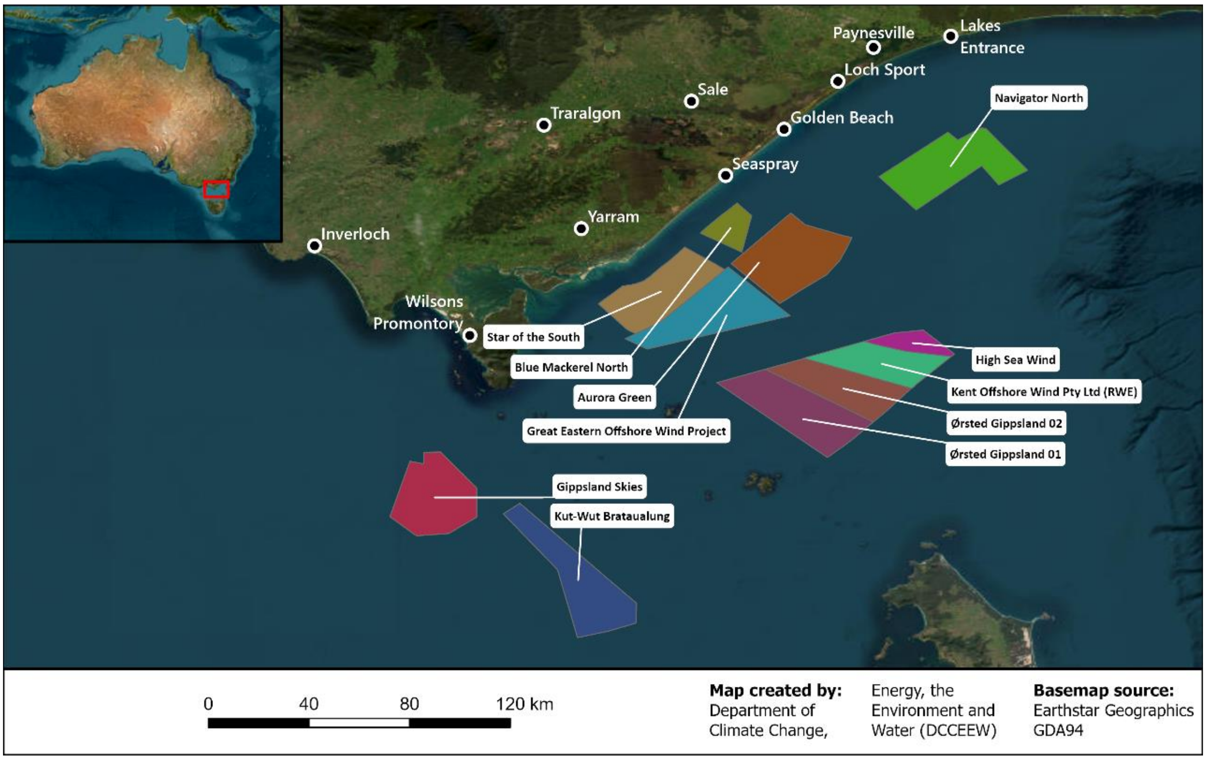

Figure 3.2. Distribution of feasibility licenses for offshore wind farm proposals in the Gippsland Offshore Wind Farm Areas, as of 2025 (from DCCEEW website, 27/8/2025).

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[8] https://www.starofthesouth.com.au/offshore-wind

3.1.2. Southern Ocean

The Southern Ocean Offshore Wind Farm Area is situated off the south-western coast of Victoria and spans 1,030 km^2. This area was selected based on its strong and consistent regional winds, proximity to existing industry that requires high-energy input (Portland Aluminium Smelter), and proximity to existing energy infrastructure (Portland Wind Farm [a land-based wind farm], and power transmission network for the Portland Smelter). As of 2025, a single feasibility license had been granted to the Spinifex Offshore Wind Farm, which has an anticipated output of 1.2 GW of offshore energy (Figure 3.3).

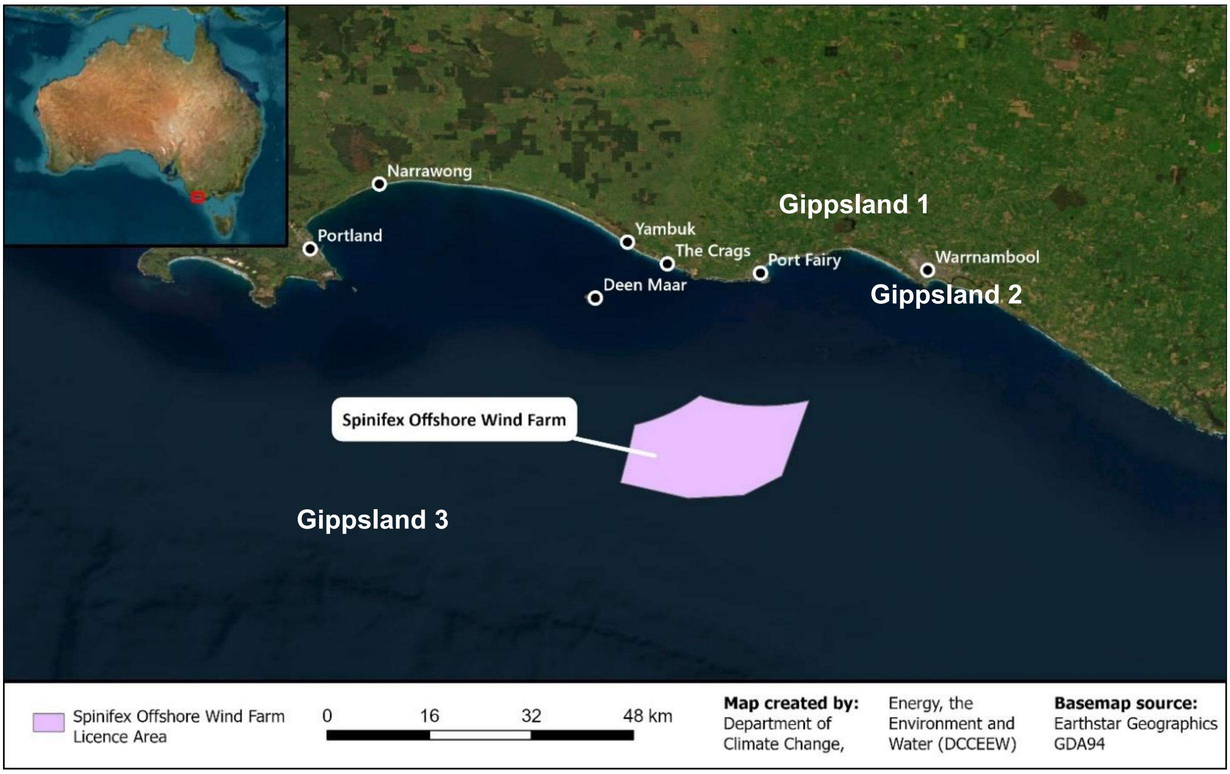

Figure 3.3. Map of Spinifex feasibility licence area in the Southern Ocean Offshore Wind Farm Area, Victoria (from DCCEEW website, 27/8/2025).

3.1.3. Bass Strait

The Bass Strait Offshore Wind Farm Area (Tasmania) spans 7,104 km^2 in central and southern Bass Strait (Figure 3.4). In 2025, no feasibility licenses were active for this region.

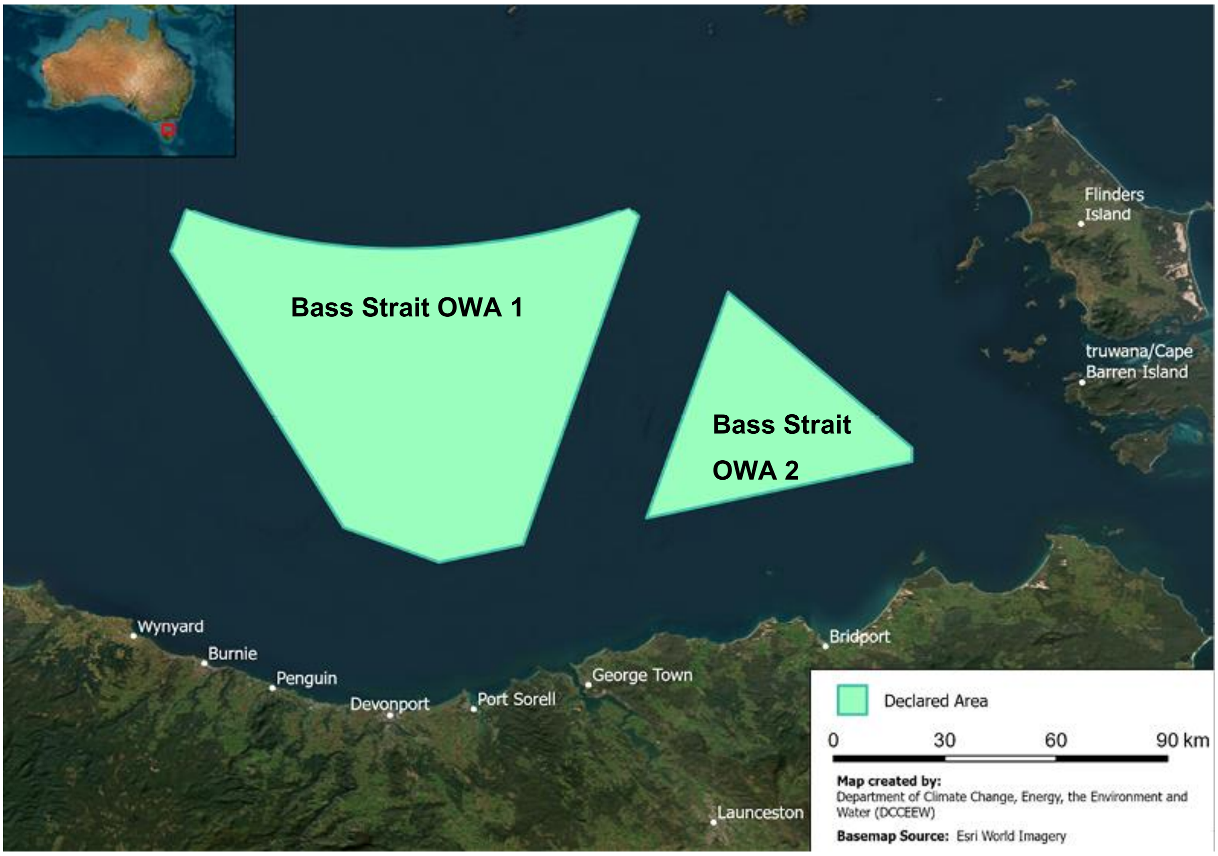

Figure 3.4. Map of the declared Bass Strait Offshore Wind Farm Areas (OWA), Tasmania (from DCCEEW website).

3.2. New South Wales declared areas

Along the east Australian coastline in New South Wales, there are two declared offshore wind development zones. They are in waters >100 m deep, which is deeper than the areas in Victoria and Tasmania (McLean et al. 2024). The submarine geomorphology of the NSW coast is also complex. There are many rocky reefs and outcrops, extensively mapped in the shallow coastal regions, but likely numerous and under-mapped in the deeper sections, which will be a challenge for developers in both NSW regions (McLean et al. 2024).

3.2.1. Hunter

The northernmost Hunter Offshore Wind Farm Area has an area of 1,854 km^2 (Figure 3.5). In 2025, the Novocastrian Wind Pty Ltd held a feasibility license for a wind farm in the south-west of this area that had an estimated power generation of 2 GW. A key oceanographic feature of the area is the East Australian Current (EAC), which has a southward flow, eddy circulations, and upwelling events that strongly influence marine communities along the NSW coast (McLean et al. 2024).

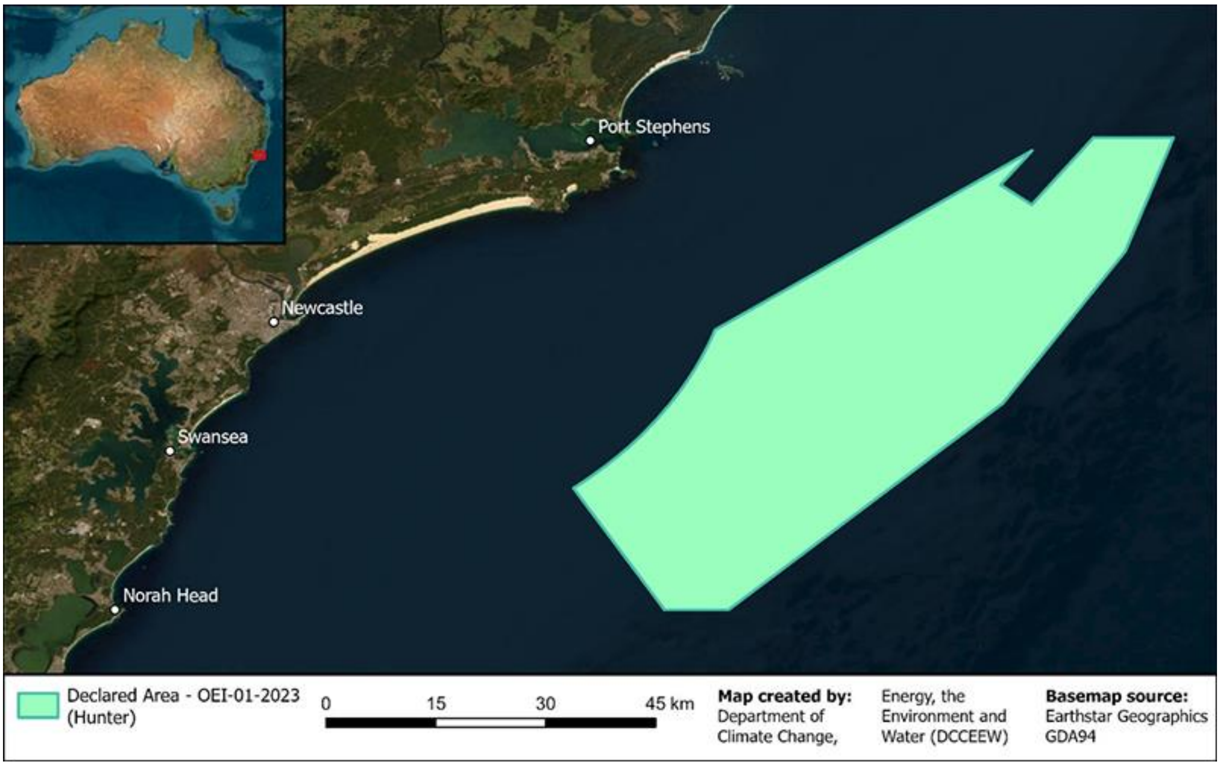

Figure 3.5. Map of the declared Hunter Offshore Wind Farm Area, NSW (from DCCEEW website).

3.2.2. Illawarra

Towards southern NSW, >20 km offshore from Wollongong and Port Kembla, the Illawarra Offshore Wind Farm Area has a total area of 1,022 km^2 (Figure 3.6). This area is offshore from existing industry that has high energy demand and a coal-fired power station that is to be decommissioned.

3.3. Western Australia declared area

3.3.1. Bunbury

Off the south-west coast of Western Australia, two areas either side of a shipping channel represent the Bunbury Offshore Wind Farm Area, which has a total area of 3,995 km^2 (Figure 3.7). This region is characterised by strong winds, deep water (up to 200 m), and high wave exposure (McLean et al. 2024). In 2025, preliminary feasibility licenses were offered for wind farms proposed in the eastern declared area. These were titled the Bunbury Offshore Wind Project (North and South) and Westward Wind Project.

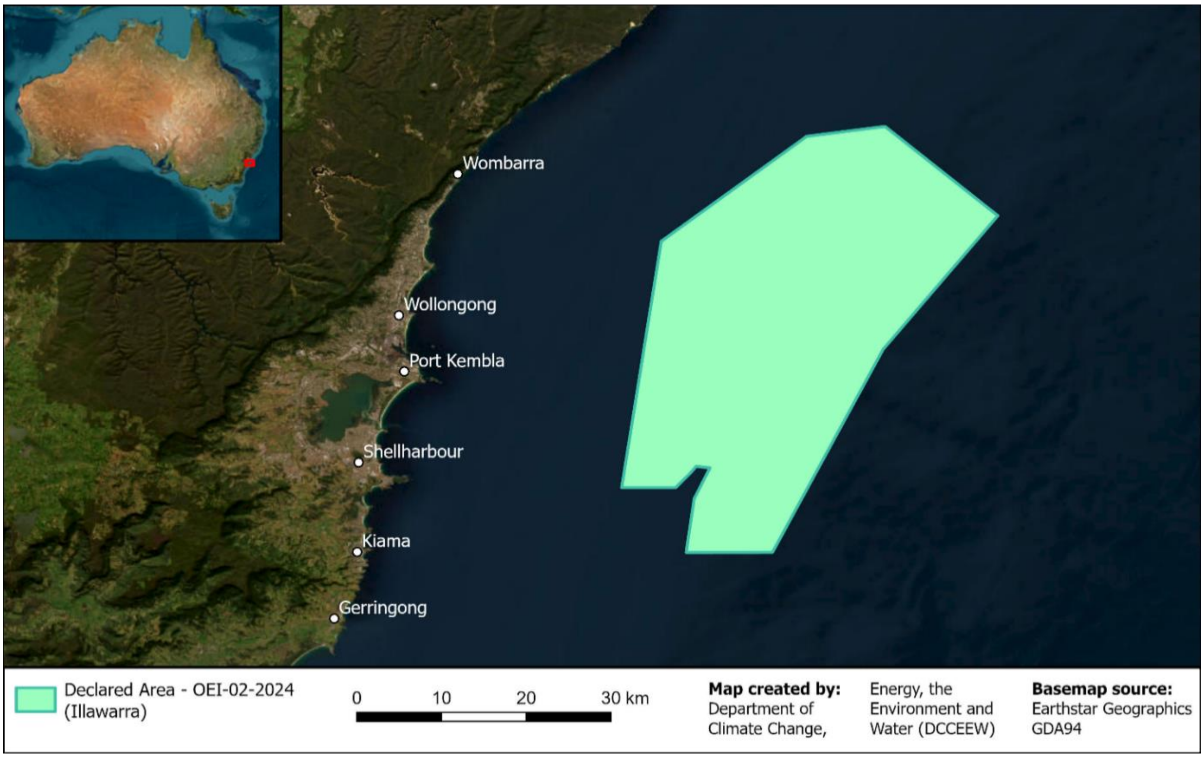

Figure 3.6. Map of declared Illawarra Offshore Wind Farm Area, NSW (from DCCEEW website).

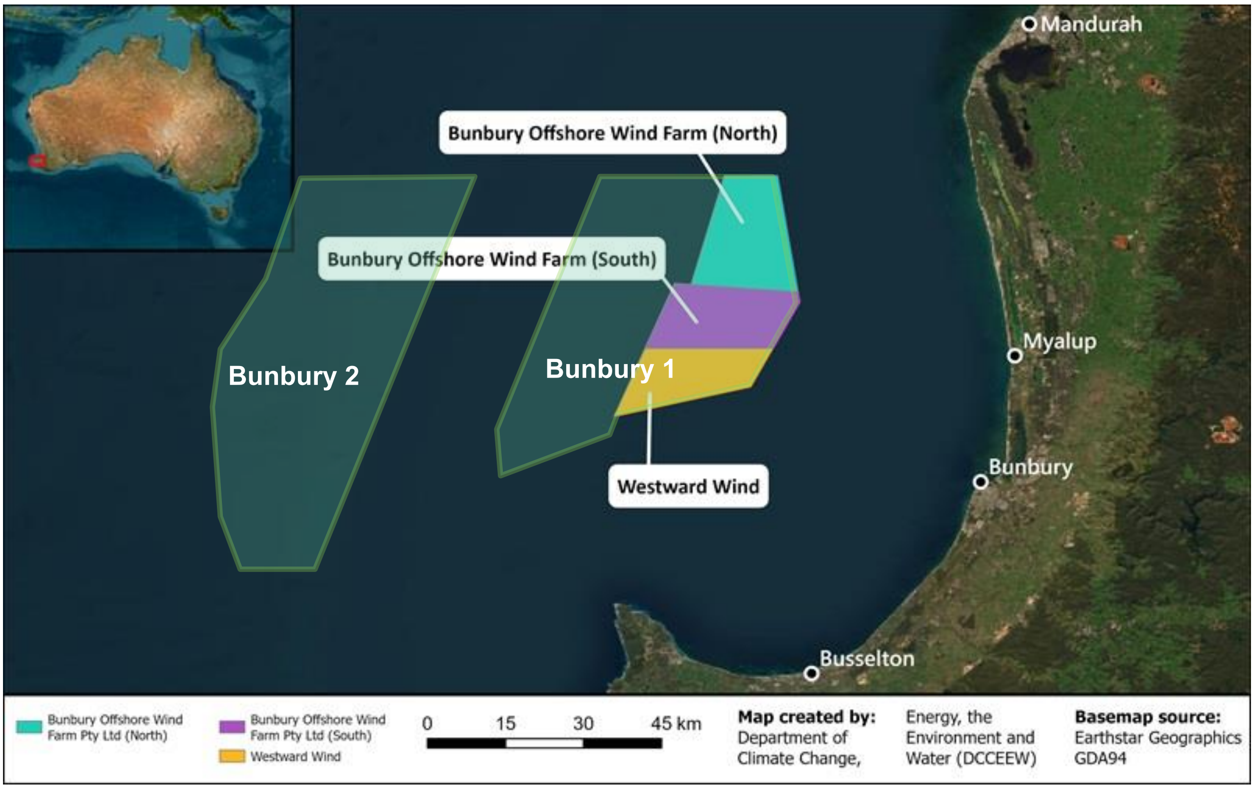

Figure 3.7. Map of declared Bunbury Offshore Wind Farm Area, Western Australia, and areas with feasibility licenses as of 2025 (adapted from DCCEEW website, 27/8/2025).

4. PINNIPEDS IN AUSTRALIA

Three otariid seal species breed in coastal areas and on islands around southern Australia (Table 4.1, Figure 4.1). These are the Australian fur seal, *Arctocephalus pusillus doriferus*, the Long-nosed (New Zealand) fur seal, *Arctocephalus forsteri*, and the Australian sea lion, *Neophoca cinerea* (Shaughnessy 1999).

Other seal species that commonly visit mainland Australian waters are two phocid seal species, Southern elephant seals (*Mirounga leonina*; occasional pupping) and Leopard seals (*Hydrurga leptonyx*) and one otariid, the Subantarctic fur seal (*A. tropicalis*) (e.g., Shaughnessy et al. 2012, 2014b) (Table 4.1, Figure 4.2). Southern elephant seals were resident in Australia prior to European colonisation, with breeding colonies in Bass Strait, but these colonies were eliminated by sealers in the 1800s (Cumpston 1973, Ling 2002). Rare visitors to Australian continental shelf waters are the phocids Crabeater (*Lobodon carcinophagus*), Weddell (*Leptonychotes weddellii*) and Ross seals (*Ommatophoca rossii*), and the otariid, the Antarctic fur seal (*A. gazella*). New Zealand sea lions (*Phocarctos hookeri*) have been recorded at Macquarie Island (~1,500 km southeast of Tasmania) and may visit mainland Australian waters but have not been recorded there to date.

Table 4.1. Pinniped seals in mainland Australian waters and speculative estimates of indicative numbers in 2025, based on available data.

Species	Common name	Occurrence in shelf waters around Australia	Indicative numbers
Family Otariidae			
Arctocephalus pusillus doriferus	Australian fur seal	Breeding	~90,000
Arctocephalus forsteri	Long-nosed (NZ) fur seal	Breeding	~120,000
Neophoca cinerea	Australian sea lion	Breeding	~12,000
Arctocephalus tropicalus	Subantarctic fur seal	Common visitor	~50
Arctocephalus gazella	Antarctic fur seal	Very rare visitor	0-1
Phocarctos hookeri	New Zealand sea lion	Possible visitor	0-1
Family Phocidae			
Mirounga leonina	Southern elephant seal	Common (some pupping)	~20
Hydrurga leptonyx	Leopard seal	Common visitor	~20
Lobodon carcinophagus	Crabeater seal	Rare visitor	0-2
Leptonychotes weddellii	Weddell seal	Very rare visitor	0-2
Ommatophoca rossii	Ross seal	Very rare visitor	0-1

Figure 4.1. Photographs of adult female otariid seal of the three species with breeding populations around southern Australia: a) Australian fur seal (with yearling pup), b) Long-nosed (NZ) fur seal, c) Australian sea lion (photos R. Kirkwood).

Figure 4.2. Photographs of the two phocid seal species that are regular visitors to waters around southern Australia: a) Leopard seal), b) Southern elephant seal (photos R. Kirkwood).

To properly assess the potential impacts of the locally novel anthropogenic activity of offshore wind farm developments on pinnipeds around mainland Australia, it is necessary to understand the natural history of the species, their specific behaviours, and other threats they experience. Such threats may be compounded by the addition of a novel threat, or the novel threat may be inconsequential compared with on-going threats. All three seals breeding around mainland Australia have been present for thousands of years and survived extreme oceanographic events, climatic conditions and anthropogenic activities. The greatest historic impact on the three species was commercial sealing during the 1800s (Cumpston 1973, 1974, Ling 2002). This industry decimated all seal populations in Australia, and it has taken >200 years for them to recover toward pre-harvest levels (Kirkwood et al. 2005, 2010, McIntosh et al. 2022). Contemporary impacts on seal populations in Australia include bycatch in fisheries, ecosystem interactions with fisheries, diseases, pollutants, entanglement in marine debris, and impacts of current climate change (Kirkwood and Goldsworthy 2013).

4.1. Local breeding species

4.1.1. Australian fur seal

Australian (and Cape) fur seals are distinguishable from other Southern Hemisphere fur seals, – including the Long-nosed fur seal, by their sea-lion-like characteristics. They vocalise like a sea lion, rest in contact with conspecifics (thigmotaxis) as do sea lions, and have the same body-size as sea lions, which is almost twice the size of most fur seals (Kirkwood and Goldsworthy 2013). Females and males weigh up to 120 and 350 kg, respectively, compared with maximum weights of 50 and 150 kg for the other Southern Hemisphere fur seals.

4.1.1.1. *Abundance and distribution*

Australian fur seals are endemic to south-eastern Australian waters where they pup at ~20 colonies, mostly on islands around Bass Strait (Pemberton and Kirkwood 1994, Kirkwood et al. 2005, McIntosh et al. 2022). They are the most abundant seal in south-eastern Australia but globally are one of the least abundant fur seals and have one of the smallest ranges. About 80% of Australian fur seal pups are born on five islands adjacent to the Victorian coast, and about 20% are born on Tasmanian islands, mostly in central and southern Bass Strait. Outside of Tasmania-Victoria, small colonies of Australian fur seals exist on an islet off Kangaroo Island in South Australia (Shaughnessy et al. 2014a), and on Baranguba Montague Island in southern New South Wales (McIntosh et al. 2018). Australian fur seals rest at a further 50+ haul-out sites across their range.

Australian fur seals arrived in southern Australian waters approximately 12 – 15,000 years ago (Malan et al. 2022). They derive from a trans-Indian Ocean crossing by Cape fur seals (*A. p. pusillus*) from Southern Africa (King 1983). Cape fur seals are predominantly pelagic feeders, but in Australia, Australian fur seals have adopted primarily benthic foraging strategies (Arnould and Hindell 2001). Their distribution on arrival was likely influenced by interactions with the three then resident species (Long-nosed fur seals, Australian sea lions and southern elephant seals), as well as site availability and Indigenous hunting pressures (Kirkwood and McIntosh 2021).

Commercial harvesting for fur and oil then decimated all seal populations in Australia in the early 1800s (Cumpston 1973, Ling 1999). By 1830, there were no longer sufficient seals to support an export industry; Australian fur seal numbers likely had dropped below 10,000 individuals (Ling 2002). On-going harvesting for local use continued until 1923, when, to assist pup survival, the open hunting season was switched from summer to winter (Lewis 1930, Warneke and Shaughnessy 1985). During the early 1900s, seal populations started to recover (Pemberton and Gales 2004). The rate of recovery was slow, however, due to ongoing lethal interactions with fishers and occasional culls (Arnould et al. 2003, McIntosh et al. 2022). Fishers continued to dispatch ‘nuisance seals’ until 1975, when all seals in Australian waters became listed as protected species under the *National Parks and Wildlife Conservation Act 1975* (Shaughnessy 1999). Thereafter, population recoveries were more rapid. From 1975 to 2007, the total number of Australian fur seals increased from <50,000 to ~120,000 seals (Warneke 1982, 1988, Shaughnessy et al. 2002, Kirkwood et al. 2005, Kirkwood et al. 2010). However thereafter, several of the larger populations in Bass Strait decreased (McIntosh et al. 2018). In 2017, when the most recent population-wide estimate was conducted, the total population was estimated to be about 90,000 individuals (McIntosh et al. 2022).

4.1.1.2. *Movement at sea*

Most information on movement at sea by Australian fur seals has come from tracking studies of adult females from colonies in northern Bass Strait (Littnan and Arnould 2002, Arnould and Kirkwood 2007, Kirkwood and Arnould 2012), particularly from Kanowna Island (>100 females over the period 1997 – 2025 (Arnould and Hindell 2001, Arnould and Hoskins 2014, Speakman et al. 2021, Bartes et al. 2024). Movement at sea from northern Bass Strait sites has also been recorded for juveniles and adult males (Kirkwood et al. 2002, 2006, Knox et al. 2018, Salton et al. 2019, 2021). Several studies have tracked seals from outside of Bass Strait, including male seals interacting with a trawl fishery on the west coast of Tasmania (Tilzey et al. 2006) and females on the NSW coast (Salton et al. 2021, 2024). Studies have indicated that Australian fur seals forage almost exclusively in continental shelf waters, the greatest abundances of Australian fur seals at sea are in Bass Strait, and their range extends from the Great Australian Bight in the west, around Tasmania and to northern NSW.

4.1.2. Long-nosed Fur Seal

Apart from size differences (see section 4.1.1), it can be difficult to distinguish between Australian and Long-nosed fur seals. However, compared with the larger and ‘browner’

Australian fur seals, Long-nosed fur seals appear more uniform dark-grey in colour, their coat appears ‘thicker’, their head and snout are narrower and more pointed. Also, their eyes face more forward compared to a more lateral eye position for the Australian fur seals.

4.1.2.1. *Abundance and distribution*

Long-nosed fur seal populations occur from south-western Western Australia, across southern Australia and around New Zealand (Kirkwood and Goldsworthy 2013). In Australia, there are >40 colony locations although ~80% of pup production occurs at five sites in South Australia: North and South Neptune Islands, Liguanea Island, and two locations on Kangaroo Island, Cape du Couedic and Cape Gantheaume (Shaughnessy et al. 1994, Shaughnessy et al. 2014a, Goldsworthy et al. 2019). Long-nosed fur seals also have colonies in Western Australia, Victoria, Tasmania and NSW, and more than 100 haul-out sites throughout their range (Brothers and Pemberton 1990, Shaughnessy et al. 1994, 2001, Kirkwood et al. 2009).

Long-nosed fur seals potentially colonised Australia’s southern coastline about 1 million years ago (Wynen et al. 2001). Sea level rises and falls would have shuffled the seals’ distributions. Indigenous hunting likely altered distributions through the last 50,000 years and arrival of the Australian fur seal in Bass Strait about 12,000 years ago influenced the local Long-nosed fur seal distributions.

Over the past 200 years, population trajectories in Australia of Long-nosed and Australian fur seals have been similar. Both were decimated by sealers in the early 1800s. The thicker under-fur of the Long-nosed fur seal made them the sealers’ preferred local species. Following collapse of commercial sealing around continental Australia around 1830, sealers continued to live on Kangaroo Island in South Australia and hunted seals from there and along much of the southern Australian coast. Hunting of Long-nosed fur seals for fur and oil ceased in the 1920s. However, rates of populations recovery were stalled by ongoing lethal interactions with developing fisheries. After 1975, when the seals received full legislative protection, populations started to recover at a faster rate (Kirkwood et al. 2009). Populations continued to increase in South Australia until the mid-2010s, when the most recent pup-production estimates were made at several of the larger populations (Goldsworthy et al. 2019). Based on the estimates of pup numbers up to 2014, the Long-nosed fur seal population in Australia was then approximately 117,400 seals (Chilvers and Goldsworthy 2015).

4.1.2.2. *Movement at sea*

Long-nosed fur seals are generalist predators that may forage benthically on the continental shelf or pelagically on or off the shelf (Page et al. 2008, Hoskins et al. 2017). Individuals generally range further between resting locations than Australian fur seals, and some individuals have been recorded to move between Australia and New Zealand (Shaughnessy and Goldsworthy 2019, Salton et al. 2021).

4.1.3. Australian Sea Lion

The Australian sea lion is an endangered species endemic to Australia, with a current estimated pup abundance of 2,739 across about 80 breeding sites (Goldsworthy et al. 2021). Around 85% of the pups are born in South Australia and the remainder in Western Australia. The median pup production per breeding site is just 15, and the largest colony, Dangerous Reef in southern Spencer Gulf, South Australia, produces >300 pups. Australian sea lions have a 17 – 18 month breeding cycle and each population runs on a unique schedule (Gales and Costa 1997, McIntosh and Pitcher 2021). Genetic studies revealed that both male and female Australian sea lions are highly philopatric and hardly disperse. Males showed a slightly higher tendency than females to move between close colonies (Ahonen et al. 2016).

4.1.3.1. *Abundance and distribution*

Australian sea lions were the first of the three currently extant otariid species to colonise southern Australia's coast: they likely were resident in the region 1 – 2 million years ago (Berta et al. 2018). They would have been redistributed through multiple sea level changes that cyclically exposed and then inundated the continental shelf, and re-adapted to the range of islands, foraging environments, and prey availabilities that these presented. Along with the fur seals, Australian sea lions were harvested to near-extinction by sealers in the early 1800s. Populations that existed in Bass Strait and were eliminated by the sealers have not re-established (Gales and Costa 1997).

Currently, the breeding distribution of the Australian sea lion extends from the Houtman Abrolhos Islands off the west coast of Western Australia to The Pages Islands, just east of Kangaroo Island in South Australia (Goldsworthy et al. 2021). Monitoring population trends has been difficult due to the unique breeding schedules, which vary between sites, and remoteness of sites. Concerted efforts in recent decades have identified trends in many populations (Goldsworthy et al. 2021). While some populations were increasing, overall, there was an estimated 64% reduction in pup abundance from 1980 to 2020. An important contributor to adult sea lion mortality through this period was entanglement in gill-nets (Goldsworthy et al. 2022). Switching to an alternative method (long-lines) reduced this fishery-related mortality.

4.1.3.2. *Movement at sea*

Australian sea lions are central place foragers year-round and tend to forage near breeding sites or near-by haul-out sites (Lowther et al. 2013, Ahonen et al. 2016). Individual females tend to exhibit fine-scale foraging site fidelity (Lowther et al. 2012) and unique prey hunting strategies (Angelakis et al. 2023), suggesting a high level of spatial knowledge and reliance on constant prey availabilities in limited areas. Their foraging ranges may extend inshore from the islands, further offshore across the continental shelf, or near to the shelf slope, where they exploit different benthic habitats, such as macroalgae reefs, bare sand, and invertebrate reefs (Angelakis et al. 2024).

4.2. Current threats to seals in Australia

Threats to Australian fur seals include diseases, disturbance, fisheries interactions and impacts from rapid climate change.

4.2.1. Disease threats

Diseases from parasites or pathogens are present in Australian seal populations. Several infection agents influence individual survival with population-level consequences. Examples include *Mycobacterium sp.* (tuberculosis), *Brucella* (brucellosis), *Mycoplasma*, *Coxiella burnetii*, *Uncinaria sanguinis* (hookworm), and *Toxoplasma gondii* (Woods et al. 1995, Lynch et al. 2011a, Lynch et al. 2011b, Marcus et al. 2014, Gardner et al. 2022, 2023, 2024). Pollutants may also affect health and survival rates of seals in Australia (Lynch et al. 2012, Taylor et al. 2021, Hall et al. 2023).

4.2.2. Disturbance threats

Seals are aquatic mammals and are better adapted to being in the water than on land. When on land, they can be highly vulnerable to disturbances, such as vessel or human approaches, or unfamiliar sights, sounds or odours (Cowling et al. 2015, Back et al. 2018, Taylor et al. 2024). The strength of the response to a disturbance differs between species and varies with age (experience), condition, sense of isolation, time of year, as well as atmospheric and oceanographic conditions. Generally, behavioural observations of the fur seals in southern Australia suggest that they respond more rapidly and defensively to disturbance on land (i.e., appear flightier) than the Australian sea lion (e.g., Osterrieder et al. 2017, Back et al. 2018).

In the water, seals are faster and more agile than on land. They do not appear to sense danger to the same degree as they do on land. They will allow closer approaches before fleeing, and they may become inquisitive and, in seeking potential prey capture opportunities, may investigate vessels, fishing equipment or other structures (Pemberton and Shaughnessy

1993, Arnould et al. 2015). For example, it is common for seals to haul out on marine structures, such as jetty pylons or trusses, marina pontoons, or large marker buoys.

4.2.3. Fisheries and aquaculture threats

Fishery interactions include spatial and temporal overlaps of fishing and foraging areas (e.g., they target the same species or species within the same trophic network), entanglement in fishing debris, direct bycatch, unintended provisioning (e.g., seals feeding from trawl nets) and measures to mitigate interactions that alter behaviours, including relocation from fish-farm leases (Pemberton et al. 1992, Goldsworthy et al. 2003, Shaughnessy et al. 2003, Robinson et al. 2008, Lyle et al. 2015, McIntosh et al. 2015, Goldsworthy et al. 2022). Each year between 2018 and 2024, fishing interaction reports from south-eastern Australia documented ~150 – 250 fur seal deaths: 75% of those identified to species were Australian fur seals[9].

Of relevance to interpreting the potential impacts of underwater noises from offshore wind farms on seals in Australia is that attempts to deter Australian fur seals acoustically from fin-fish aquaculture pens in southern Tasmania have been largely ineffective (Pemberton and Shaughnessy 1993). Since fish farms were established in southern Tasmania in the 1980s, on-going attraction of fur seals to farms has resulted in the establishment of new seal haul-outs nearby and growth in the number of fur seals using these haul-outs (McIntosh et al. 2022).

4.2.4. Rapid climate-change threats

Climate change impacts include inundation and loss of breeding habitat and haul-outs on low-lying sites, increases in atmospheric and sea temperatures, increased storm frequencies, and ecosystem changes, such as shifting ranges of important prey (Kirkwood et al. 2008, McLean et al. 2018, Speakman et al. 2020, Geeson et al. 2022, Kliska et al. 2022, Geeson et al. 2025).

4.3. Spatial overlap with wind farm areas

The range of Long-nosed fur seals overlaps with all six offshore wind farm areas, the range of Australian fur seals overlaps with all except the Bunbury Area in Western Australia, and the range of Australian sea lions only overlaps with the Bunbury Area (Figure 4.3).

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[9] https://www.afma.gov.au/protected-species/endangered-and-threatened-species-reporting

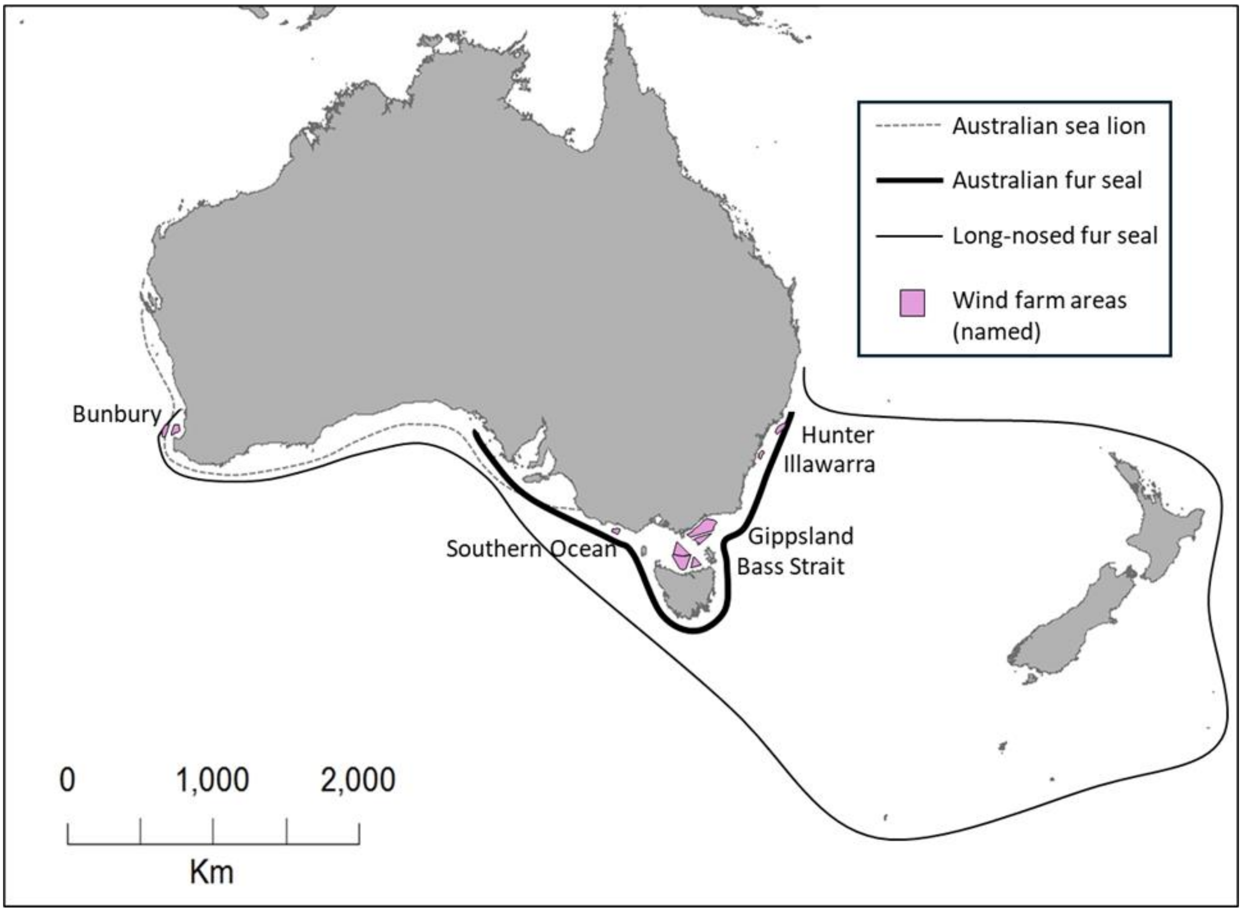

Figure 4.3. Ranges of seals that breed at sites around southern Australia and declared offshore wind farm areas (in pink).

The declared areas that overlap with the greatest numbers of seals are those in the Bass Strait region, where Australian fur seals are most abundant, Long-nosed fur seals are common and Australian sea lions occasional occur (Table 4.2). Along the NSW coast both fur seal species are common, while Australian sea lions are very rare visitors. In south-western Western Australia, Long-nosed fur seals are common, male Australian sea lions occasionally pass through, and Australian fur seals have not been recorded.

Table 4.2. Approximate numbers of seals that could be present at a time in each declared offshore wind farm area.

	Hunter	Illawarra	Gippsland	Bass Strait	Southern Ocean	Bunbury
Australian fur seal	10-100	10-100	>1,000	>1,000	>1,000	0
Long-nosed fur seal	10-100	10-100	100-1,000	10-100	10-1,000	10-100
Australian sea lion	0	0	0	0	0-10	1-10

4.3.1. Bass Strait region

About 95% of Australian fur seal pups are born at colonies in the Bass Strait region (McIntosh et al. 2022). The most recent record of breeding sites and numbers for Australian fur seals comes from 2017 (McIntosh et al. 2022). There are also colonies of Long-nosed fur seals in the Bass Strait region (Figure 4.4). Since the local extirpation of Long-nosed fur seals by sealers in the early 1800s, they have recolonized the Bass Strait region and numbers there may be increasing (Arnould et al. 2000, Kirkwood et al. 2009, Reinhold 2023).

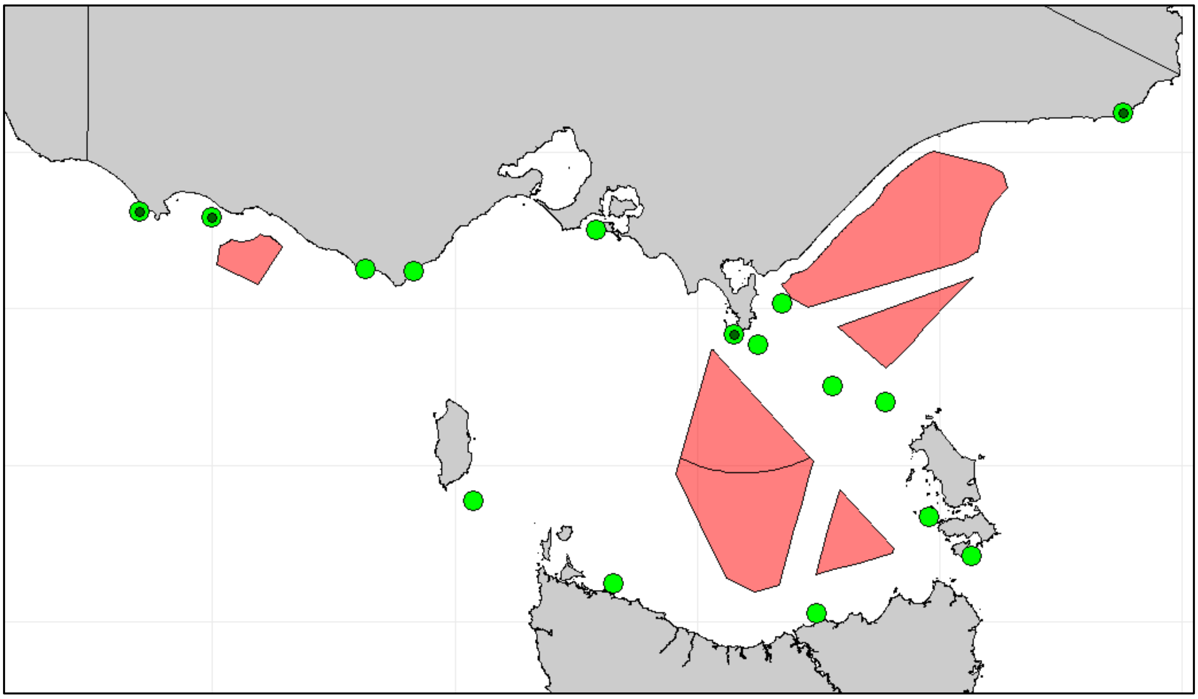

Figure 4.4. Locations in Bass Strait region of declared wind farm areas (in pink) and fur seal breeding sites, light green = Australian fur seals, black centre = Long-nosed fur seals.

4.3.1.1. *Gippsland*

Several colonies of Australian fur seals are in the vicinity of the Gippsland Offshore Wind Farm Area. Most information on seal movement within the area come from tracking studies out of Kanowna Island (Arnould and Kirkwood 2007). While most seals tracked from Kanowna foraged south, into central Bass Strait, many utilised areas within Gippsland Offshore Wind Farm Area 3. A proportion moved east through the Gippsland Offshore Wind Farm Areas 1 and 2 (Figure 4.5). The closest seal colony is at Rag Island, 8 km west of the Gippsland Offshore Wind Farm Area 1 (Table 4.3). About 9,000 Australian fur seal pups (~70% of the total production for the species) are born at islands within 100 km of a Gippsland Offshore Wind Farm Area.

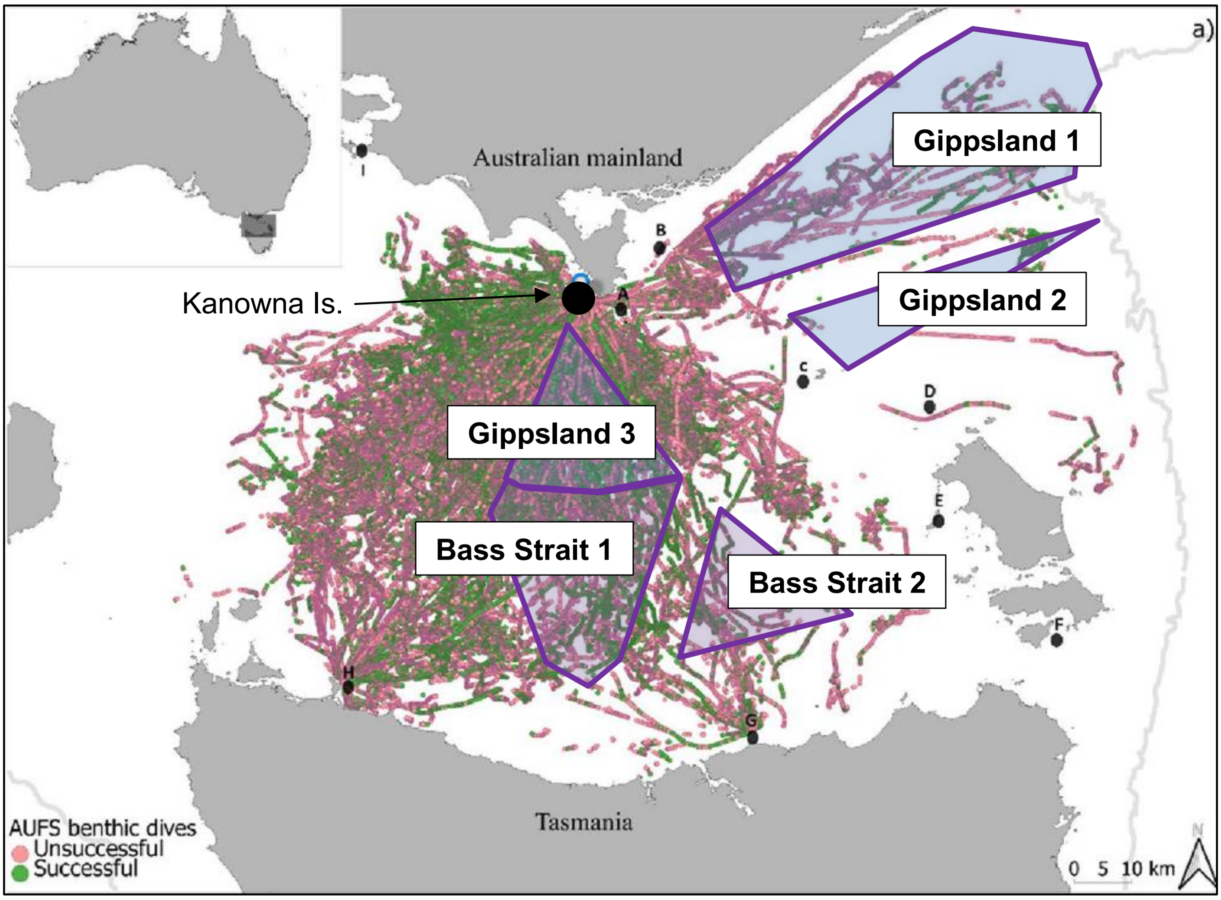

Figure 4.5. Locations of benthic dives (colour-coded by prey-capture success) by female Australian fur seals from Kanowna Island (blue circle), small black dots are other colonies (figure from Bartes et al. 2024, licensed under the Creative Commons Attribution 4.0 International license (CC BY 4.0), location of Kanowna Island and the Gippsland and Bass Strait Offshore Wind Farm Areas were added).

Table 4.3. Fur seal colonies (AFS = Australian, LNFS = Long-nosed) within 100 km of each Gippsland Offshore Wind Farm (GOW) Area. Pup numbers from McIntosh et al. (2022) or are approximations.

Colony	Seal	Lat. (S)	Long. (E)	Pups	GOW 1 - km	GOW 2 - km	GOW 3 - km
Rag Is	AFS	38˚58’	146˚42’	351	8	45	59
Wright Rocks	AFS	39˚36’	147˚33’	289	79	23	65
Judgement Rocks	AFS	39˚30’	147˚07’	1,752	59	34	46
West Moncoeur	AFS	39˚14’	146˚30’	256	40	58	26
Kanowna Is	AFS	39˚10’	146˚18’	3,239	48	20	73
Double Rocks	AFS	40˚20’S	147˚55’E	346	>100	>100	96
The Skerries	AFS	37˚45’	149˚31’	1,611	98	>100	>100
The Skerries	LNFS	37˚45’	149˚31’	<100?	98	>100	>100
Answer Island*	LNFS	39˚08’S	146˚19’E	>100?	46	71	21

* John Arnould, personal communication

4.3.1.1. *Bass Strait*

The Bass Strait Offshore Wind Farm Areas are in deeper waters (60 – 80 m) of central Bass Strait. Australian fur seals tracked from both Seal Rocks and Kanowna Island foraged in these areas, occasionally resting between foraging trips at Bull Rock and Tenth Island off the north coast of Tasmania (Arnould and Kirkwood 2007, Kirkwood and Arnould 2012, Salton et al.

2019, Bartes et al. 2024). Eight Australian fur seals colonies are within 100 km of these declared areas (Table 4.4).

Table 4.4. Fur seal colonies (all are Australian fur seals, AFS) within 100 km of each Bass Strait Offshore Wind Farm Area (BSOW). Pup numbers from McIntosh et al. (2022) or are approximations.

Colony	Seal	Lat. (S)	Long. (E)	Pups	BSOW 1 - km	BSOW 2 - km
Tenth Is	AFS	40˚57’	146˚59’	240	34	28
Bull Rock	AFS	40˚46’	145˚18’	<20	73	>100
Moriarty Rocks	AFS	40˚35’	148˚16’	82	>100	55
Double Rocks	AFS	40˚20’	147˚55’	346	90	34
Wright Rocks	AFS	39˚36’	147˚33’	289	65	70
Judgement Rocks	AFS	39˚30’	147˚07’	1,752	53	72
West Moncoeur	AFS	39˚14’	146˚30’	256	88	>100
Kanowna Is	AFS	39˚10’	146˚18’	3,239	96	>100

4.3.1.2. *Southern Ocean*

The Southern Ocean Offshore Wind Farm Area is situated near Deen Maar (Lady Julia Percy Island), where there is a large Australian fur seal colony (2,866 pups in 2017) and a small Long-nosed fur seal colony (<10 in 2017) (McIntosh et al. 2022). The Australian fur seal colony at Deen Maar was the largest for the species (Shaughnessy et al. 2002, Kirkwood et al. 2005), with >5,574 pups in 2007 (Kirkwood et al. 2010), but in the two censuses, in 2012 and 2017 there were 2,659 and 2,866 pups, respectively (McIntosh et al. 2018, 2022). The cause of the drop in numbers is unknown.

Tracked Australian fur seal females and juveniles from Deen Maar frequently moved through the proposed wind farm area and foraged extensively within it (Arnould and Kirkwood 2007, Kirkwood and Arnould 2012, Salton et al. 2019) (e.g., Figure 4.6). Deen Maar is the location of the largest seal colony in the area (Table 4.5).

Table 4.5. Fur seal colonies within 100 km of the Southern Ocean Offshore Wind Farm (SOOW) Area. Pup numbers from McIntosh et al. (2022) or are approximations.

Colony	Seal	Lat. (S)	Long. (E)	Pups	SOOW - km
Deen Maar	AFS	38˚25’	142˚00’	*2,866	20
Deen Maar	LNFS	38˚25’	142˚00’	<10	20
Cape Bridgewater	AFS	38˚23’	141˚24’	169	61
Cape Bridgewater	LNFS	38˚23’	141˚24’	~100	61
Cape Volney	AFS	38˚46’	143˚16’	<10	64
Marengo Reef	AFS	38˚46’	143˚67’	5	100

*Deen Maar had >5,000 pups in 2002 and 2007.

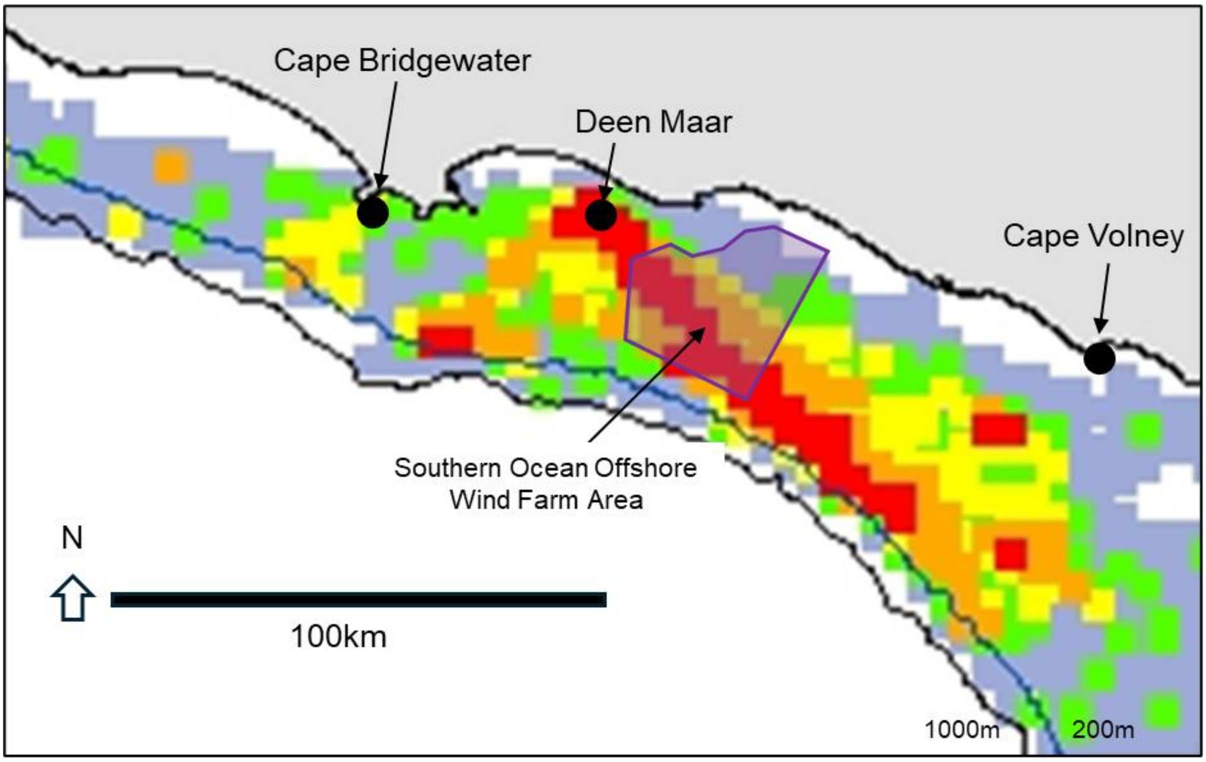

Figure 4.6. Relative time in 10 x 10 km^2 areas (red highest, grey-blue lowest) by Australian fur seal females tracked from Deen Maar (also known as Lady Julia Percy Island). Figure from Kirkwood and Arnould 2012, reproduced with CSIRO Publishing permission. It is acknowledged that the original source material was not published under an Open Access licence, and further reuse requires permission. Additions - Southern Ocean Offshore Wind Farm Area (purple), and fur seal breeding sites Deen Maar, Cape Bridgewater and Cape Volney.

4.3.2. New South Wales

Prior to European colonisation of Australia, fur seals were likely present on Australia's east coast to as far north as the NSW-Queensland border. There may even have been breeding colonies, but these were not recorded at the time. Sealing was one of the first colonial industries and this extirpated seals from the NSW coast (Ling 1999). Since legislative protection of pinnipeds in Australia in 1975 came into force, both Australian and Long-nosed fur seal numbers increased elsewhere in their ranges, and both species have returned to the NSW coast (Salton et al. 2021). Currently in NSW, both species have a conservation status of 'Vulnerable'. Sightings of seals along the NSW coast increased each decade from 1985 to 2025 (NSW Government 2025[10], NSW DCCEEW 2025[11]) (Figure 4.7).

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[10] https://experience.arcgis.com/experience/c0b233c28faf405f9276356937aa4027

[11] https://www.marine.nsw.gov.au/news-and-more/newsroom/news/2025-news/key-findings-from-the-great-seal-reveal

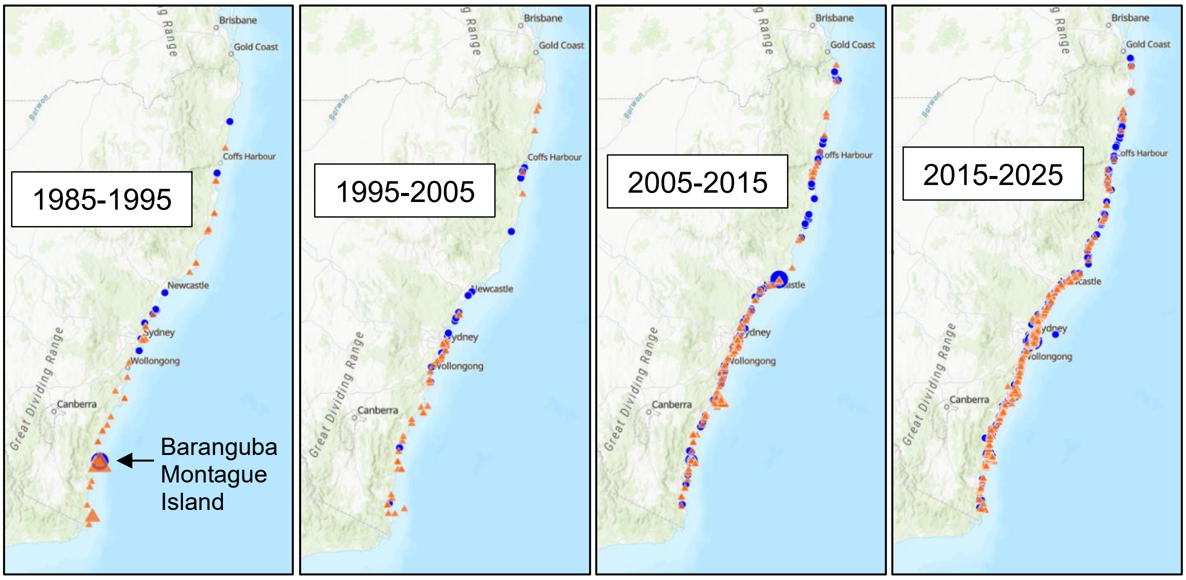

Figure 4.7. Decadal maps of seal sightings along the NSW coast, orange triangles - Australian fur seals, blue circles - Long-nosed fur seals. Larger shapes indicate more seal individuals (maps from NSW Government website, 2025).

Both Australian and Long-nosed fur seals breed at Baranguba Montague Island, on the south coast of NSW (Irvine et al. 1997, Shaughnessy et al. 2001, McIntosh et al. 2018). A single Australian fur seal pup was recorded there in 1993 (Irvine et al. 1997) and 2002 (Kirkwood et al. 2005), 2 pups in 2007 and 2008, then 19 pups in 2013 (McIntosh et al. 2018). A single Long-nosed fur seal pup was recorded in 2000 (Shaughnessy et al. 2001), then 35 pups in 2013 (McIntosh et al. 2018). The numbers of adult seals have varied seasonally and annually but the largest numbers are present in September. In September 2024, 689 Australian fur seals and 152 Long-nosed fur seal were recorded (NSW DCCEEW 2025, op. cit.). Further monitoring is needed to assess trends of both species at this site.

There are >10 locations along the NSW coast where fur seals haul out (Figure 4.8). Most haul-out sites and most seals at haul-outs are to the south of the declared offshore wind farm areas. Haul-outs with the greatest numbers of either species are in the vicinity of Jervis Bay (Burleigh et al. 2008). The haul-outs are occupied mostly by juvenile and male seals, while adult females and pups tend to haul out at breeding locations (Hardy et al. 2017).

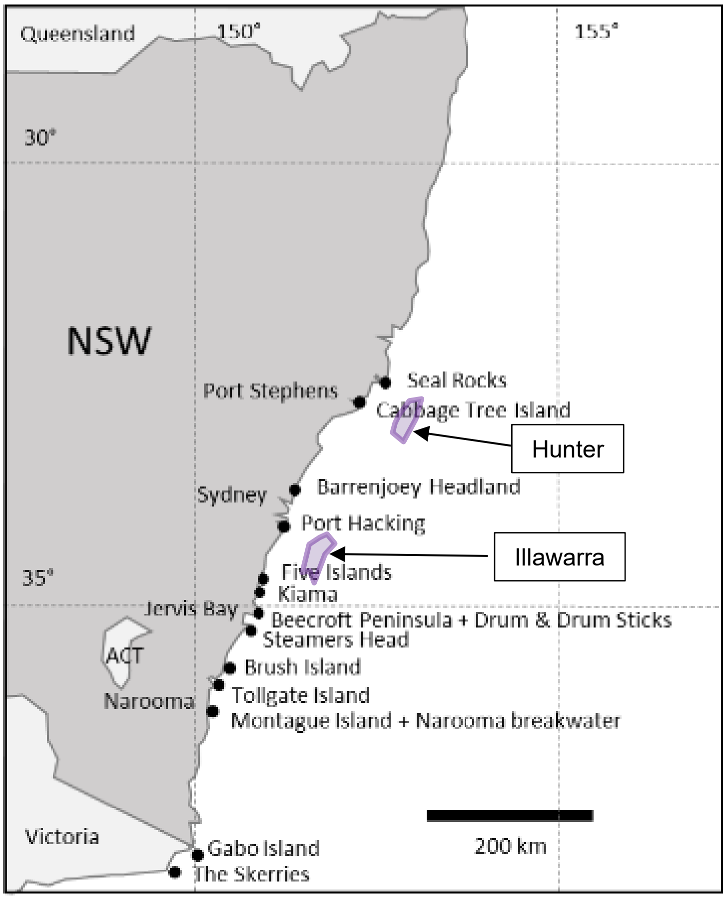

Figure 4.8. Sites along the Australian east coast where fur seals regularly haul out, including Baranguba Montague Island, a breeding location for both Australian and Long-nosed fur seals, and the locations of the declared Hunter and Illawarra Offshore Wind Farm Areas (purple).

Female Australian fur seals tracked while supporting pups at The Skerries, Victoria (see Figure 4.8), foraged up the east coast to as far north as Jervis Bay (Kirkwood and Arnould 2012). Male Australian fur seals tracked from a haul-out near Jervis Bay remained on the continental shelf and foraged benthically (Salton et al. 2021). Males from Jervis Bay also moved south into Bass Strait, around southern Tasmania and even to Kangaroo Island in South Australia. Male Long-nosed fur seals from Jervis Bay foraged on and off the shelf along the east coast, and spent time foraging epi-pelagically in the Tasman Sea, or moved to New Zealand (Nee Islet, South Island), or around southern Tasmania and to South Australia (Salton et al. 2021, 2024). Species-specific diets and movement may change if fur seal populations continue to increase and compete at breeding colonies and haul-out sites along the NSW coast (Salton et al. 2024).

Anthropogenic threats known to fur seals in NSW waters include entanglement in or ingestion of marine debris associated with commercial and recreational fishing operations, climate change, chemical exposure (e.g., oil spills), pollutants and contaminants, intentional harm from people and, rarely, vessel strikes (Hall et al. 2023, Jackson 2025).

4.3.2.1. *Hunter*

The declared Hunter Offshore Wind Farm Area is situated ~30 km south of the seal haul-out at Seal Rocks and 25 km east of the Cabbage Tree Island haul-out area near Port Stephens (Figure 4.8). These are both small haul-outs of mostly Long-nosed fur seals. It is likely that seals foraging from these haul-outs will move through the offshore wind farm area. Male fur seals tracked from Baranguba Montague Island and Jervis Bay have foraged this far north (Salton et al. 2021, 2024).

4.3.2.2. *Illawarra*

The declared Illawarra Offshore Wind Farm Area is ~200 km north of Baranguba Montague Island (Figure 4.8). Haul-out sites within 20 km of the area include Five Islands, Martin Islet, Bass Point and Kiama. Martin Islet is the largest of these, with at times >100 seals hauled out there (Esteban 2019), and haul-outs at Jervis Bay are 50 km to the south. The continental shelf in the Illawarra Offshore Wind Farm Area is within the core foraging range for fur seals from both Jervis Bay and Baranguba Montague Island (Salton et al. 2021, 2024).

4.3.3. Western Australia

4.3.3.1. *Bunbury*

At Cape Naturaliste, ~30 km south-east of the Bunbury Offshore Wind Farm Areas, there are two sites for Long-nosed fur seals where several pups may be born each year (DBCA 2023) (Figure 1.1). Seal numbers at Cape Naturaliste peak at ~200 in September (DBCA, unpublished data), which is prior to the commencement of breeding in this species, suggesting it is mainly a haul-out site. There are also three haul-out sites for Long-nosed fur seals and six haul-outs for male Australian sea lions within 100 km north of the wind farm areas (between Shoalwater Bay and Rottnest Island, DBCA 2023). One of 15 Australian sea lion males fitted with satellite tracking devices at these haul-outs in November 2022 passed through Bunbury Offshore Wind Farm Area during the eight days it was tracked (Salgado Kent et al. 2024). Sea lions hauling out in the region probably come from colonies in Jurien Bay, 200 – 300 km north.

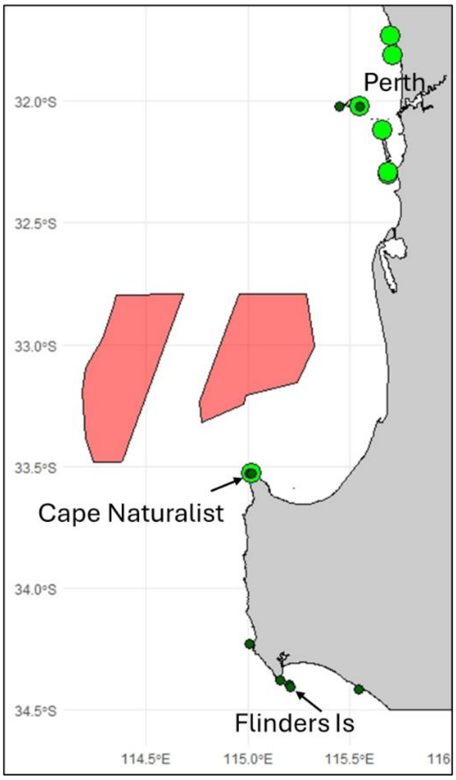

Figure 4.9. Bunbury Offshore Wind Farm Areas (pink polygons) and nearby sites along the coast of Western Australia where Long-nosed fur seals (black) and Australian sea lions (light green) haul out to rest. Occasionally, fur seal pups have been recorded at Cape Naturaliste and Flinders Island.

Table 4.6. Long-nosed fur seal (LNFS) and Australian sea lion (ASL) haul-outs within 100 km of each Bunbury Offshore Wind Farm (BOW) Area (sites between 32–34°S, see Figure 4.9).

Colony	Seal	Lat. (S)	Long. (E)	BOW 1 - km	BOW 2 - km
Cape Naturaliste	LNFS, ASL	33˚32	115˚00’	30	56
Penguin Is	ASL	32˚18’	115˚16’	66	>100
Seal Is	ASL	32˚07’	115˚40’	82	>100
Cathedral Rock	LNFS, ASL	32˚01’	115˚27	87	>100
Dyer	LNFS, ASL	32˚01’	115˚33’	89	>100

5. POTENTIAL IMPACTS OF WIND FARMS ON PINNIPEDS

Seals are high trophic level predators within marine ecosystems. Anthropogenic activities in water, or on land where they rest and breed, may impact them directly. However, they may also respond to impacts on other species within their trophic network.

5.1. Hearing in pinnipeds

Pinnipeds rely on sound for communication, navigation, foraging, and predator detection in both air and water. Understanding their hearing sensitivity is critical for assessing the potential impacts of anthropogenic noise, such as from offshore wind farm construction, seismic surveys, and shipping—particularly in coastal and nearshore habitats where seals are commonly found.

To quantify auditory thresholds, animal hearing may be studied by behavioural or psychophysical testing, or electro-physiological techniques (McFadden et al. 2022, Houser 2025). Also, advances in imaging-based numerical hearing models have enabled non-invasive predictions of hearing sensitivity in species with limited experimental data (Wei and Erbe 2024). Results are presented as audiograms – line graphs of hearing threshold (dB) against sound frequency.

5.1.1. Hearing in otariids

With regard to its hearing capabilities, the best-studied otariid, is the California sea lion, *Zalophus californianus* (Schusterman et al. 1972, Schusterman 1974, 1976, Schusterman and Moore 1978, Moore and Schusterman 1987, Kastak and Schusterman 2002, Mulsow et al. 2011, Reichmuth and Southall 2012, Reichmuth et al. 2017) followed by the Steller sea lion, *Eumetopias jubatus* (Kastelein et al. 2005, Mulsow and Reichmuth 2010, Mulsow et al. 2011). While there are several publications, the studies were often conducted on the same individuals. In total, hearing capability has been studied in 5 x Californian sea lions and 1 x Steller sea lion. The California sea lions detected air-borne sounds over a broad frequency range, from ~0.2 to 38 kHz, with greatest sensitivity between 8 and 16 kHz, measured at the 60 dB re 20 µPa level. The Steller sea lion had a comparable aerial behavioural hearing threshold of 60 dB re 20 µPa across a 0.25 – 30 kHz range, and greatest sensitivity between 5 and 14.1 kHz.

The imaging-based numerical model of Wei and Erbe (2024) is the only estimate of aerial hearing sensitivity of the Australian sea lion, predicting a functional range from 0.35 – 20 kHz, with greatest sensitivity near 10.5 kHz. This modelled result is broadly consistent with the empirical data from the Northern Hemisphere sea lions (Figure 5.1).

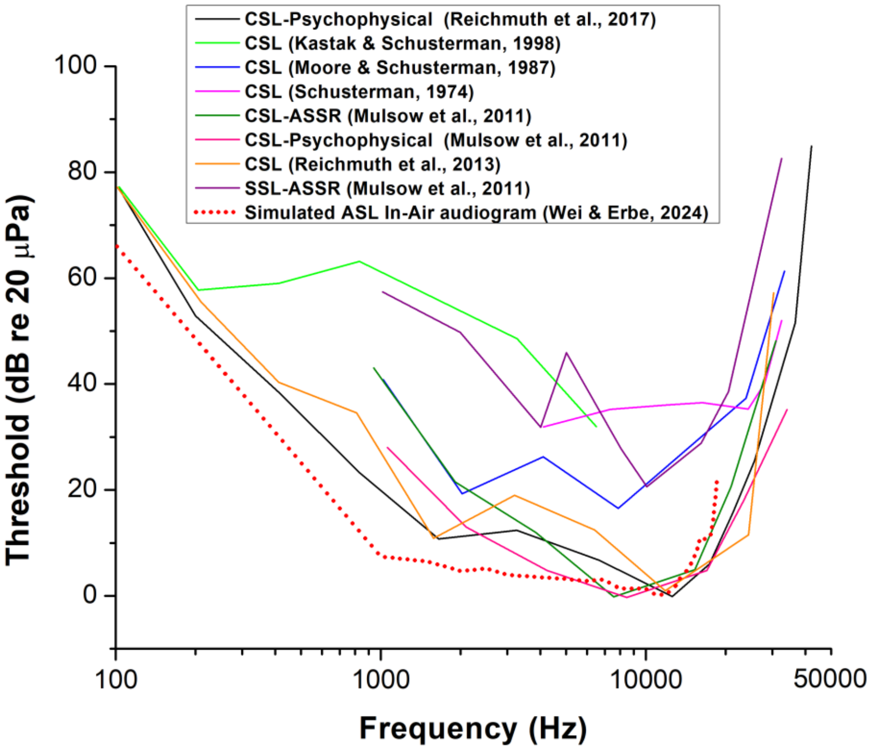

Figure 5.1. Aerial hearing thresholds of individual California sea lions (CSL) and Steller sea lions (SSL) by psychophysical methods and auditory steady-state response (ASSR) – shown as solid lines, compared to the modelled Australian sea lion (ASL) audiogram – shown as dotted lines.

Under water, California sea lions possess greatest sensitivity at 8 – 12 kHz. Underwater audiograms have been published for at least five individuals, and while all showed similar overall bandwidths, there was notable inter-individual variability in sensitivity, likely due to differences in testing environments and methodologies. More recently, Kastelein et al. (2023) fitted an auditory weighting function to multiple datasets to produce a generic audiogram for this species, integrating thresholds from multiple California sea lions to support standardised noise impact assessments. Steller sea lions have comparable underwater hearing capabilities, though with slightly reduced sensitivity at certain frequencies. For Australian sea lions, the only audiogram estimate is the imaging-based numerical model from Wei and Erbe (2024) predicting peak sensitivity near 5 kHz with thresholds around 58 dB re 1 μPa (Figure 5.2).

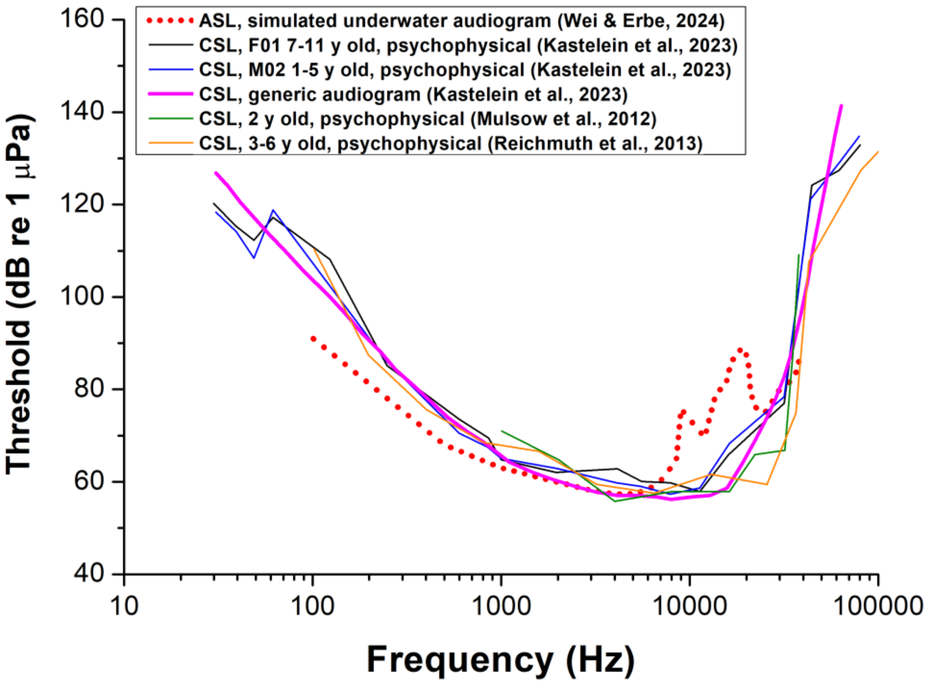

Figure 5.2. Underwater hearing thresholds of individual California sea lions (CSL) by psychophysical methods and auditory steady-state response (ASSR) – shown as solid lines, compared to the modelled Australian sea lion (ASL) audiogram – shown as dotted lines.

5.1.2. Hearing in phocids

With regard to hearing, the Harbour seal (*Phoca vitulina*) is perhaps the best studied phocid seal (Renouf 1980, Terhune 1988, 1989, Turnbull 1994, Wolski et al. 2003, Kastelein et al. 2009, Kastelein et al. 2011, Kastelein et al. 2013b, Lucke et al. 2016). Behavioural studies using psychophysical methods have demonstrated that Harbour seals can detect air-borne sounds over a frequency range of ~0.1 – 32.5 kHz, with peak sensitivity around 3.2 kHz and thresholds near ~4 dB re 20 µPa. Their greatest sensitivity (defined as within 10 dB of the peak) extends from ~0.8 – 12 kHz (Reichmuth et al. 2013). An overview of aerial audiograms of phocids is presented in Figure 5.3.

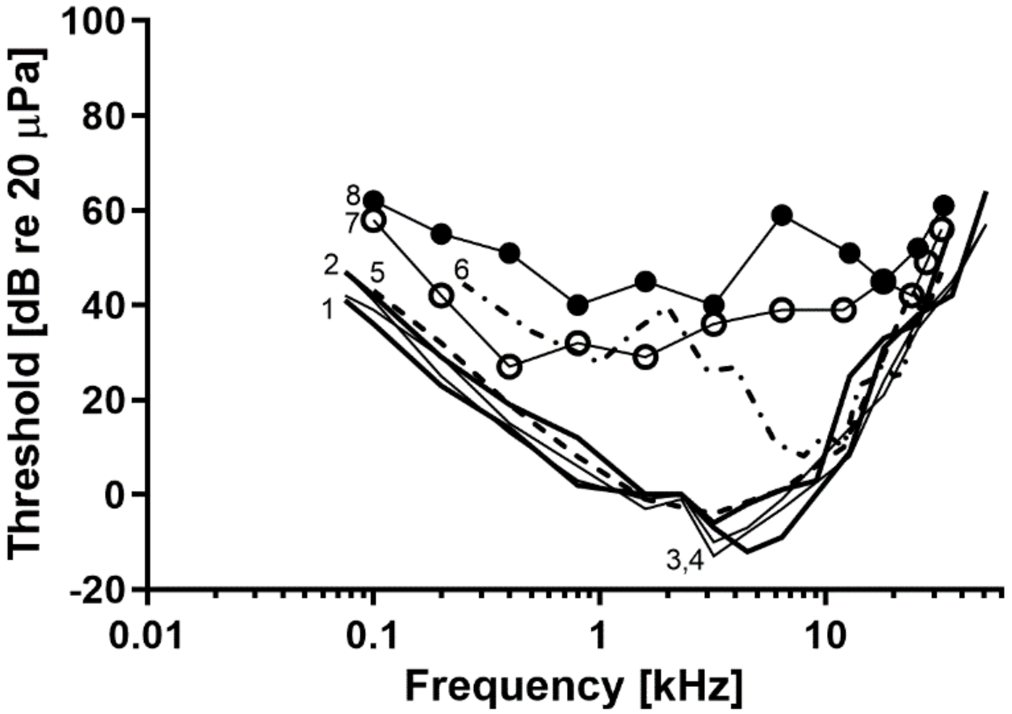

Figure 5.3. Example aerial behavioural audiograms of phocid seals: 1,2 thick lines, Ringed seal, *Pusa hispida* (Sills et al. 2015); 3,4 thin lines, Spotted seal, *Phoca largha* (Sills et al. 2014); 5 dashed line, Harbour seal (Reichmuth et al. 2013); 6 dot-dash, Harbour seal (Wolski et al. 2003); 7 thin open circles, Northern elephant seal, *Mirounga angustirostris* (Reichmuth et al. 2013); 8 filled circles, Hawaiian monk seal, *Monachus schauinslandi* (Ruscher et al. 2021) (figure from Houser 2025, reproduced under CC BY 4.0).

Early research by Møhl (1968) demonstrated that Harbour seals are markedly better adapted for detecting underwater sound than air-borne sound, both in terms of frequency range and auditory sensitivity. Peak sensitivity occurs around 18 kHz with thresholds near 55 – 59 dB re 1 µPa (Kastelein et al. 2009, Reichmuth et al. 2013). Their greatest sensitivity (defined as within 10 dB of the maximum sensitivity) is at 0.5 – 40 kHz, covering more than six octaves (Kastelein et al. 2018b). A comparison of behavioural audiograms of phocid seals under water is presented in Figure 5.4.

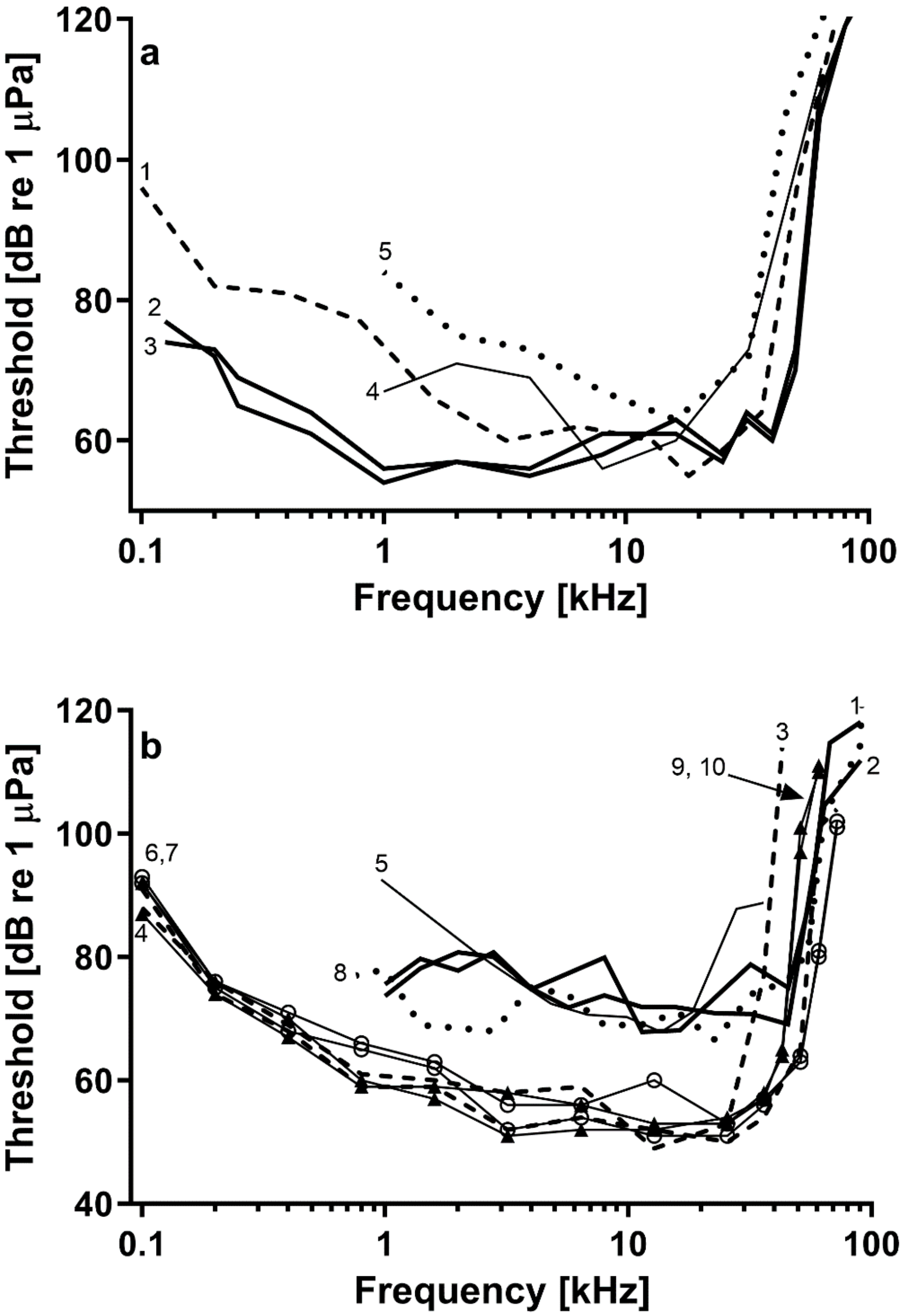

Figure 5.4. Example underwater behavioural audiograms of phocid seals: a) Harbour seals - 1 dashed line (Reichmuth et al. 2013); 2,3 thick lines (Kastelein et al. 2009); 4 thin line (Terhune 1988); 5 dotted line (Møhl 1968). b) Other northern seals - 1,2 thick lines, Ringed seal (Terhune and Ronald 1975); 3,4 dashed lines, Ringed seal (Sills et al. 2015); 5 thin line, Caspian seal, *Pusa caspica* (Babushina 1997); 6,7 thin lines, open circles, Spotted seal (Sills et al. 2014); 8 dotted line, Harp seal, *Pagophilus groenlandicus* (Terhune and Ronald 1972); 9,10 thin line, filled triangles, Bearded seal, *Erignathus barbatus* (Sills et al. 2020) (figure from Houser 2025, reproduced under CC BY 4.0).

5.2. Noise impacts on pinnipeds

Pinnipeds are acoustically sensitive marine mammals that rely on sound for critical behaviours, such as navigation, foraging, predator avoidance, and social communication in both air and water. Offshore wind energy developments introduce both air-borne and underwater noise into pinniped habitats, which may result in auditory masking, behavioural disturbance, stress, or hearing impairment (Erbe et al. 2025a). This section reviews available evidence on the impact of wind farm-related noise on sea lions and seals.

The impacts on seals and the seals' responses to underwater sound will be individual, species and context specific. For example, seals returning to a breeding colony to birth or feed a pup are probably more likely to push through areas of high-impact disturbance than a seal exploring a novel area. Also, individuals of some seal species will tolerate levels of underwater sound that will be damaging to their hearing ability if they know prey is potentially available (e.g., seals ignoring acoustic deterrents at fin-fish farms; Pemberton and Shaughnessy 1993).

Generally, the level of exposure to, and impacts of, anthropogenic sounds for a seal depends on the level and frequency of the sound at the source. Factors influencing the received exposure levels include the distance from the source, sound propagation properties of the waters, the duration of the sound production, and the ability of the seal to hear the sound, i.e., if it is within the seal's hearing range and not masked by sounds from wave action, other marine fauna or shipping (Götz et al. 2009). Sound attenuates over distance, so, the further the seal is from a sound source, the less chance of it hearing the sound and being affected by it. Accordingly, the levels of response/impact increase the closer the seal is to the sound source.

Far from the sound source, it may not be audible above local ambient noise. Closer to the source, its spectral levels will rise above those of the ambient sound and, depending on the hearing abilities of the seal, the seal will detect the sound, but might not respond to it (Figure 5.5). Once audible, the sound will start to mask other signals potentially of importance to the seals, such as the communication sounds of distant conspecifics or the sounds of predators and prey. At a certain received level, which will vary with the individual seal's age and history of experience with anthropogenic sounds, the seal might respond behaviourally (Richardson et al. 1995). Such responses may include stopping the current behaviour (e.g., feeding or transiting) and moving out of the area (seals can detect the direction of sound in air and water), or remaining near the surface where received levels may be lower due to the pressure-release effect at the water-air interface (Kirkwood et al. 2015). With higher received levels, a seal may experience a temporary threshold shift (TTS), which is recoverable with time after the cessation of exposure. Recovery may take minutes or weeks, depending on the individual and the exposure level. At a certain level, the individual may suffer permanent auditory damage (permanent threshold shift, PTS), resulting in a permanent reduction of sensitivity at a range of frequencies. Very high sound exposure levels, such as from underwater explosions, could cause surges in circulatory or spinal fluid pressures, rupture internal organs or tissues, and may be lethal (Schuknecht 1993, Ketten 1995).

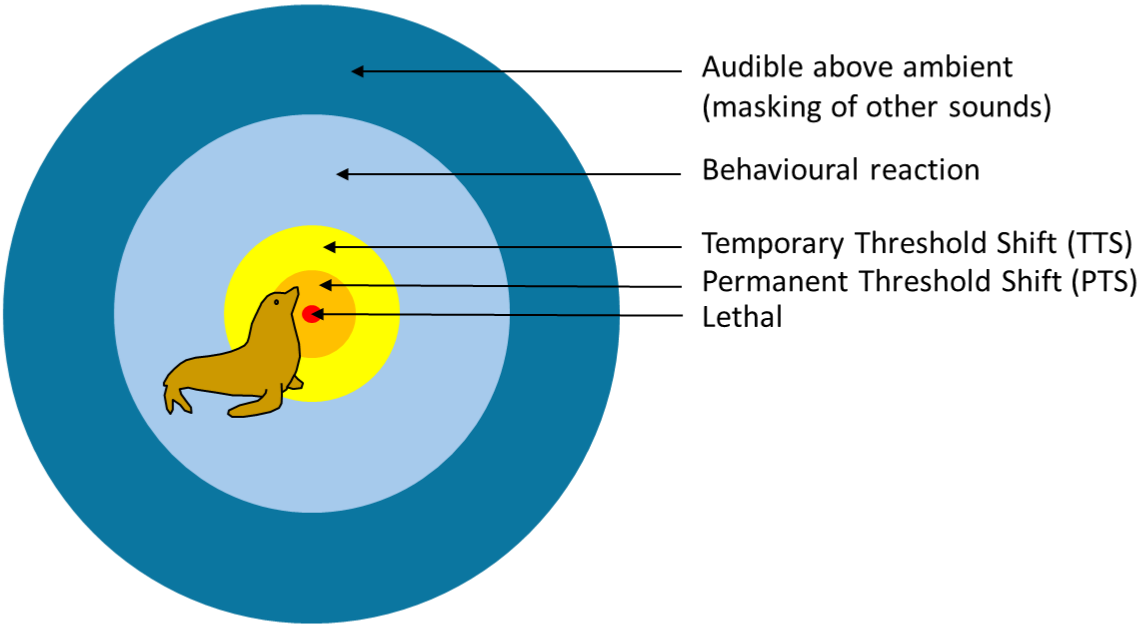

Figure 5.5. Diagrammatic representation of increasing consequences for a seal with increasing received levels.

5.2.1. In-air noise impacts

5.2.1.1. *Otariids*

Motor-boat noise was played back to Australian fur seals hauled out at their breeding colony at Kanowna Island, Bass Strait, resulting in changes in physical, acoustical, and functional behaviour. Specifically, changes in body position, increases in alertness, increases in aggression towards each other, avoidance of the sound source, and differences in call types such as increases in barking behaviour were observed at received levels of 75 to 85 dBC – decibels with a C-weighting filter applied to mimic human hearing (Tripovich et al. 2012). At the same colony, experimental boat approaches to within 75 m led to a reduction in resting behaviour, and approaches to within 25 m reduced colony attendance (i.e., animals entered the water); it is not known whether the visual presence and proximity of the boat, its air-borne noise, or both were the drivers (Back et al. 2018).

Noise from aircraft, vehicles, and construction activities disturbed Northern fur seals (*Callorhinus ursinus*) on Alaskan colonies within a 300 m range (Insley 1990, Williams 1997). Playback of boat and car noise changed Cape fur seal behaviour at a breeding colony in Namibia, reducing nursing and resting time at received levels of 60 – 80 dB re 20 µPa. Individuals returned to pre-exposure behaviours within a few minutes (Martin et al. 2022). However, repeated disturbances, including those that led to reduced haul-out time, could ultimately impact thermoregulation, energy balance, reproductive behaviour, and pup rearing success.

5.2.1.2. *Phocids*

Harbour seals are the best studied phocid seal with regards to noise impacts. Boat approaches elicited vigilance in hauled out Harbour seals (Henry and Hammill 2001) and Ringed seals (Niemi et al. 2013), and the flushing of Harbour seals into the water (Jansen et al. 2010, Andersen et al. 2012, Blundell and Pendleton 2015, Lomac-MacNair et al. 2019, Paterson et al. 2019). Only 52% of Harbour seals hauled out again within 30 min. after boat disturbance (Paterson et al. 2019). Others remained in the water for up to 5 h (Andersen et al. 2012).

During the period of pile-driving for an offshore wind farm in Denmark (which included deployment of acoustic deterrents underwater), numbers of Harbour and Grey seals hauled-out at a nearby site were reduced, suggesting some seals had moved out of the area. Two years after the wind farm had been constructed, there was no evidence of the drop in numbers that had occurred (Edrén et al. 2010). Similar multi-year displacement of some Harbour seals from a haul-out and breeding site at Scroby Sands in the UK occurred during the construction nearby of an offshore wind farm, although in this instance the return of the Harbour seals may have been retarded by Grey seals that moved in after construction, and increased shipping in the area (Skeate et al. 2012).

Unmanned aircraft significantly increased vigilance and decreased resting in hauled out Harbour seals (Pérez Tadeo et al. 2023), although responses varied depending on the type of equipment, flight altitude, and prevailing weather conditions. Similar but weaker effects have been reported with Weddell seals (Laborie et al. 2021).

A study of Northern elephant seals (*Mirounga angustirostris*) at breeding sites investigated whether the animals exhibit a Lombard response, whereby individuals increase the intensity of their vocalisations in response to rising background noise levels (Southall et al. 2019a). The seals were found to already vocalise ‘at the top of their voice’ and increases in ambient noise did not induce a Lombard effect.

5.2.2. Underwater noise impacts

5.2.2.1. *Otariids*

Geotechnical site investigations using air guns might affect otariids as demonstrated by a study of a marine seismic survey in New Zealand fur seal habitat. Behavioural responses were observed at 200 m range from the seismic vessel, but it could not be determined if the noise or the visual presence of the vessel and air gun array were responsible (Lalas and McConnell 2016).

5.2.2.2. *Phocids*

Ship traffic (whether acoustically or visually perceived) affects phocids at sea. In response to passing vessels, changed behaviours, such as altered diving profiles, slowed swim speeds, disrupted rest, and more time spent at the surface, have been evident for Northern elephant seals, Harbour seals, Grey seals, and Ringed seals (*Pusa hispida*) (Fletcher et al. 1996, Burgess et al. 1998, Chen et al. 2017, Mikkelsen et al. 2019, Prawirasasra et al. 2022).

Offshore pile-driving decreased the number of seals in the vicinity (distance varied with sound level and seal species) and changed swim and dive behaviour (Russell et al. 2016, Aarts et al. 2018, Whyte et al. 2020, Brasseur et al. 2022). The number of Harbour seals within 25 km of pile-driving for a wind farm in the Wash, United Kingdom, decreased by ~50% (95% confidence intervals, 19 – 83%) where received levels were between 166 and 178 dB re 1 μPa peak-to-peak, and significant decreases in seal density were predicted from cumulative received levels above 140 – 155 dB re 1 μPa^{2}s, based on the quietest and loudest part of the water column (Russell et al. 2016, Whyte et al. 2020). Seal numbers recovered to pre-piling numbers within 2 h of cessation of pile-driving. Changes in surfacing times as well as swim direction and speed occurred at up to 36 km distance and were stronger closer to the pile driver (Aarts et al. 2018, Brasseur et al. 2022). A likely decrease in the number of foraging dives occurred at single-strike sound exposure levels of 130 – 150 dB re 1 μPa^{2}s (Aarts et al. 2018, Hastie et al. 2021, Brasseur et al. 2022). The disturbance of diving behaviour may affect foraging success and could ultimately impact energy balance and vital rates (Costa et al. 2016, Schwarz et al. 2016, Booth and Heinis 2018). Lower lipid mass in southern elephant seals impacted pup survival rates and ultimately effected a decline in population size of ~10% over 30 years in a population-consequences model (New et al. 2014).

Marine seismic survey impacts were studied with Ringed, Bearded, and Spotted seals observed from a seismic vessel during no air gun, one air gun, and full seismic array operation. Seals tended to be farther away from the vessel during full array operation, but no other changes to swim and dive behaviour were found (Harris et al. 2001). Elsewhere, Ringed seals flushed from ice sheets during a marine seismic survey (Stemland et al. 2019).

A mild Lombard response has been documented in Harbour seals, whereby animals increased the amplitude of their calls by 0.16 dB for every 1 dB increase in ambient noise of 87 – 107 dB re 1 µPa in the 40 – 500 Hz band (Matthews et al. 2020). Animals were unable to match the noise increase in loudness, and so, the higher the ambient noise, the greater the masking. Similarly, Spotted and Bearded seals increased the amplitude of some of their calls with ambient noise levels but reached a call threshold at ~100 – 105 dB re 1 µPa, failing to increase call level beyond this in higher ambient noise (Fournet et al. 2021, Yang et al. 2022).

Seals may suffer noise-induced hearing loss after intense or prolonged noise exposure. Playbacks of pile-driving noise to two captive Harbour seals induced a temporary hearing loss (TTS) at their frequencies of best sensitivity (4 and 8 kHz) (Kastelein et al. 2018a). The exposure specifications were: 127 ms pulse duration, 2,760 strikes per hour (46 per min, 1.3 s inter-pulse interval), ~9.5% duty cycle, 180 and 360 min exposure durations, 151 dB re 1 µPa^{2}s average single-strike unweighted sound exposure level, 190 and 193 dB re 1 µPa^{2}s cumulative sound exposure levels (Kastelein et al. 2018a). TTS was only observed after the 360 min exposures: 2.8 and 3.9 dB at 4 kHz, 2.6 and 2.4 dB at 8 kHz, in the two individuals respectively. Hearing fully recovered within an hour after exposure. In a separate study, Harbour seals received significant TTS from exposure to non-impulsive noise at exposure levels of 170 – 178 dB 1 µPa^{2}s for 1 – 4 min. (Kastelein et al. 2013b). The chance of permanent auditory damage (PTS) increased when sound exposures were ~22 dB above onset levels for TTS (Kastelein et al. 2013a).

5.3. Potential ecosystem changes

Seals are top-order predators within marine ecosystems and therefore may respond to changes to habitats and trophic structures in their foraging range. Construction and operation of offshore wind farms are expected to produce sound levels that are detectable by fish (Wahlberg and Westerberg 2005, Thomsen et al. 2006, Kikuchi 2010, Bergström et al. 2014). While some species may be deterred by the noise produced from an operational wind farm, it is more likely that overall fish numbers will increase due to the creation of habitat (structures will act as 'fish-attracting-devices') and the exclusion of some fishing activities (Reubens et al. 2014, van Hal et al. 2017, Methratta and Dardick 2019) (Figure 5.6). Water turbulence around wind farm structures may alter currents, turbidity, and trophic relationships for zooplankton and fish, causing localised ecosystems to establish within wind farms (van Berkel et al. 2020).

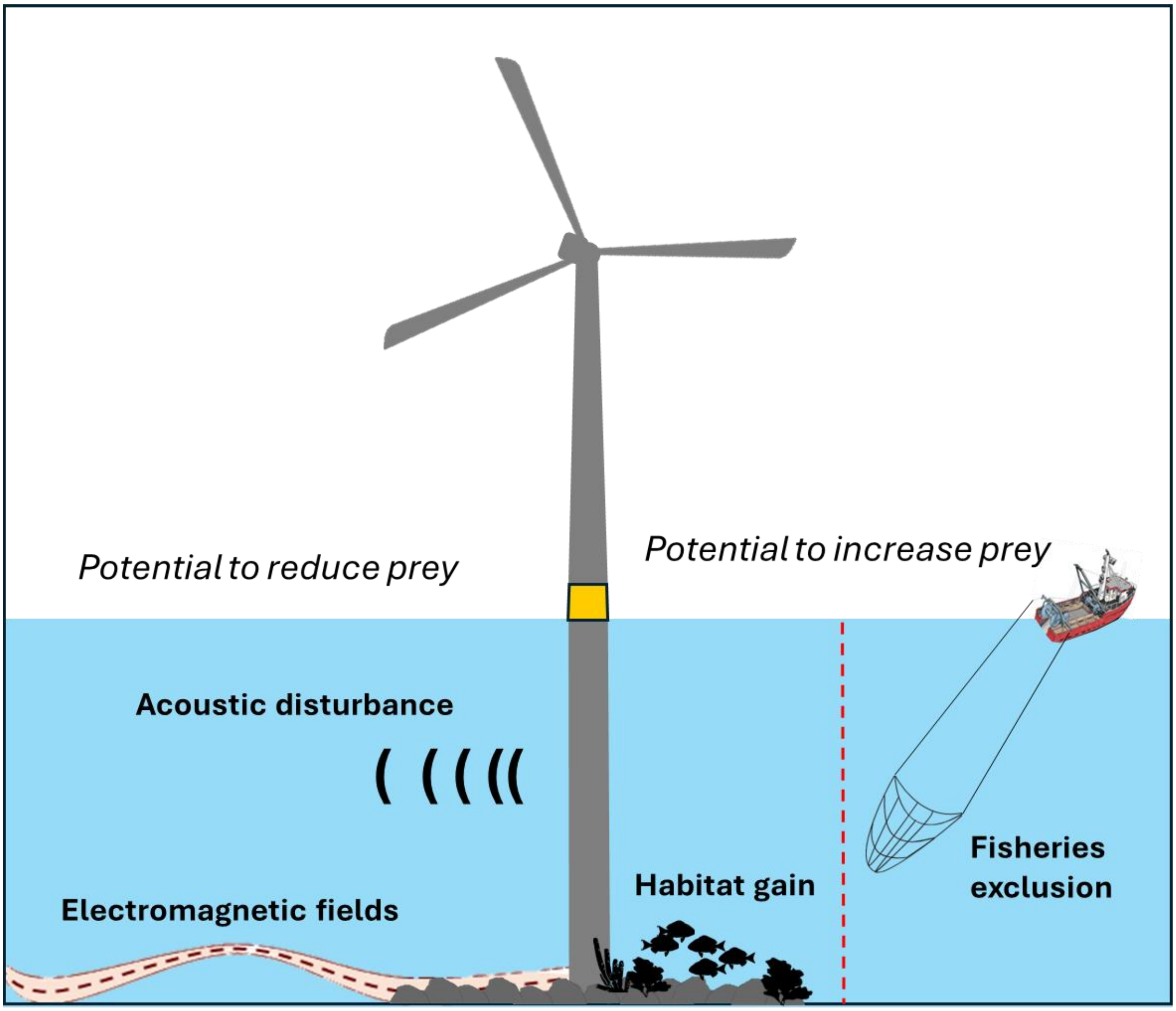

Figure 5.6. Schematic diagram of potential positive and negative pressures on the abundance of seal prey caused by an operational offshore wind farm (figure adapted from Bergström et al. 2014).

Monitoring of fish abundances around the Horns Reef wind farm in Denmark recorded increases within the wind farm of rocky reef species, likely attracted to the rocky scour-pads, and no decrease of sand bottom species. Outside the wind farm where fishing activities continued, however, commercial fish species declined (Mosegaard et al. 2015). Similarly, within the Block Island wind farm in the USA, monitoring of fish stocks before, during and after installation, recorded either increases or no change in fish abundance and species composition in the wind farm (Wilber et al. 2022).

In the North Sea, satellite-tracked Grey and Harbour seals were attracted to wind farms, where they navigated directly from one tower to the next, likely searching for prey around the towers and scour-pads (Russell et al. 2014). Australian fur seals are known to be attracted to anthropogenic structures, such as cable and pipe-lines, and oil and gas platforms (Arnould et al. 2015) and may forage around offshore wind farm installations if these sites have enhanced prey availabilities.

In summary, wind farms are likely to cause localised ecosystem changes. Seals will investigate the sites and may encounter enhanced prey availability and adopt the areas as routine foraging locations. It would be difficult to record such an impact, although, potentially, if prey availability for the seals increased, an increase in seal numbers at nearby haul-out sites could be expected.

5.4. Collision with vessels

Compared with other marine mammals, there are few reports of vessels colliding with seals (Byard et al. 2012, Schoeman et al. 2020, Jackson 2025), although they can be vulnerable to collision with propellors when foraging behind fishing vessels (Iriarte and Winter 2025). Byard et al. (2012) reported a small-vessel propellor injury that killed a young New Zealand fur seal in the vicinity of a boat-ramp. Collisions with seals at sea may go unnoticed or unreported. Seals undertake multi-day trips to sea and rest at the surface for up to several hours, often in rafts with other seals or entwined in kelp for camouflage from predators. While resting, they may not detect or respond in time to avoid approaching vessels. The degree to which wind farm operations could alter the collision risk to seals from vessels in Australian waters is unknown.

6. CONCLUSIONS

Otariid seals are common to abundant in all of Australia’s declared offshore wind farm areas. Australian fur seals are abundant year-round in all declared offshore wind farm areas in the Bass Strait region, are common along the east coast of Australia, and do not occur in the Bunbury area off Western Australia. Long-nosed fur seals are likely to be common in all areas. Australian sea lions are likely to occur in the Bunbury area, as occasional visitors to the Bass Strait region and very rare visitors to the NSW coast. Individuals of subantarctic and Antarctic breeding seals, mostly Leopard seals, Southern elephant seals and Subantarctic fur seals, will occasionally transit through each offshore wind farm area.

Potential impacts of offshore wind farm developments on the seals may include displacement from foraging space, as seals may be startled by unusual underwater noises and (temporarily) move away from them, and from structural alterations to their foraging environments, such as changes to prey availability and creation of alternative foraging habitat. Underwater sound during construction and operation of wind farms is expected to be detected by the seals. Most studies of impacts of underwater sound from offshore wind farms on seals have focused on species in the Family Phociidae, which behave differently to species in the Family Otariidae. There is limited knowledge of the hearing ability of otariid species and impacts on them of underwater sound.

All seals within 10-20 km of loud activities, such as unshielded pile-driving, are expected to detect the noise underwater. Sound exposure levels received by the seal will be influenced by source levels, mitigation measures in place (e.g., bubble curtains), distance from the source, and duration of exposure. The responses by individual seals to each noise exposure will vary depending on the sound levels and frequencies received, the individual’s motivation for moving through the area (e.g., foraging, transiting, exploring), and its previous experience with the noise and other anthropogenic sounds.

7. GAP ANALYSIS

There are broad knowledge gaps regarding the location, timing, and structural design of offshore wind farms in Australia. Understanding and mitigating impacts of offshore wind farm developments on seals will rely on knowledge of seal use of wind farm areas and consequences of exposure to underwater sounds produced in those areas. This analysis identifies knowledge gaps in these two fields.

Knowledge gaps – Bunbury, Western Australia.

1. How much does offshore spatial usage by both Long-nosed fur seals and Australian sea lions that haul-out in the vicinity (near Cape Naturaliste) overlap with the Bunbury wind farm area?

Knowledge gaps – the Bass Strait region (Southern Ocean, Gippsland and Bass Strait).

1. Seal numbers now are unknown – for example, the most recent meta-population census for Australian fur seals was in 2017, there has not been a complete census of Long-nosed fur seals in Bass Strait. (What are potential sources of funding for meta-population monitoring?)
2. What has caused recent declines in Australian fur seal numbers and body condition at several major populations in Bass Strait, and could wind farm developments compound these issues?
3. There are other drivers of change that may compound or mask the impacts of offshore wind farm developments:
    a. Ecosystem change due to ongoing climate dynamics.
    b. Imminent introduction of a sardine purse-seine fishery.
    c. Interactions with fishing operations (e.g., capture in trawl nets in south-east Australia).
    d. Potential H5N1 (avian influenza) impacts.
4. Most knowledge of movement comes from several sites in northern Bass Strait region, but not all data are published or otherwise available for comparison. Data are lacking for other important sites. For example, where do seals from Judgement Rock (central Bass Strait) and Reid Rock (south-western Bass Strait) forage?
5. What may be the positive benefits of artificial reefs created by offshore wind farm structures? Could these have population-level consequences?
6. Knowledge is needed of habitat use and flexibility in habitat use by seals.

7. Are there any insidious environmental consequences, e.g., from ongoing shipping, use of dynamic positioning by ships, leakage of petroleum products, chemicals, anti-fouling paint components off towers that could influence the environment, bio-accumulation of toxins over the long-term (decades)?

Knowledge gaps – NSW (Hunter, Illawarra)

1. What is the spatial usage of seals within the declared wind farm areas?
2. What are the conditions of seal populations in NSW? Are both Australian and Long-nosed fur seal numbers still increasing?

Knowledge gaps – sound impacts

1. What is the level of prior exposure and learning of seals to underwater noise? Seals in Australia are not naïve to anthropogenic sound. Have geophysical seismic surveys for oil and gas explorations, or shipping activity, influenced seal spatial distributions, habitat use, or movement? Have seals habituated or been sensitised?
2. Could noise-induced hearing loss occur in Australian seals during offshore wind farm construction or their operation? What could be the highest sound levels, based on techniques currently planned (mooring/pile-driving, with bubble curtains, pile diameters)?
3. Do seals in Australia use sound to locate prey and avoid predators? Currently, most knowledge of in-water hearing ability of seals comes from studies of phocid seals, which behave differently to otariids.
4. Could hearing loss (short or long-term) influence body condition and survival? Or could hearing loss impair a mother's ability to recognise the call of her pup, reducing suckling times and affecting pup survival?
5. Does noise cause physiological stress? Noise exposure may raise stress hormone levels in pinnipeds (Houser 2025b), with negative effects on reproduction, immune function, and survival.
6. What will be the responses of wild seals on encountering high levels of underwater sound for the first time? Could this have immediate health consequences for the individual or that of dependent pups?
7. How will behavioral responses change over time, would this involve habituation, so reduced responses, or sensitisation, so increased responses? Some individuals may tolerate potentially damaging sound levels to access a known food source or explore the source, while other individuals may depart immediately and continue to avoid the area long after the sound ceases.

8. What are possible indirect impacts, e.g., on prey species or competitors?
9. Most studies have focused on the construction phase, could there be insidious operational phase impacts? For example, seals from Deen Maar in western Victoria are highly reliant on the area of the declared Southern Ocean Offshore Wind Farm, for foraging and transit to foraging areas. Their hesitancy to use this area, due to experiencing a disturbance from construction or operation activities, would have population-level consequences.
10. Are there potential long-term impacts of noise pollution on seals – avoidance of areas, any impact on health, breeding success? Could wind farm operation noise have insidious, population-level consequences? Ten years after construction of an offshore wind farm in Denmark, Harbour porpoise echolocation activity had not recovered to pre-installation levels (Teilmann and Carstensen 2012).
11. Is it possible to detect hearing damage in free-ranging seals?
12. Hearing sensitivity varies between individuals yet hearing ability studies are necessarily based on small numbers of captive and trainable individuals. Achieving large sample sizes is difficult with large animals in the wild.
13. There are no noise exposure criteria for Australian seal species. These criteria are essential for refining exposure thresholds and assessing species-specific vulnerability to wind farm noise. In their absence, noise impact assessments and management plans have applied thresholds developed for North American species (Southall et al. 2019b), which may be inappropriate.
14. We need better knowledge on the effectiveness of strategies to deter Australian seal species from an area prior to emission of high-impact sounds that may damage their hearing. The seals might habituate. Acoustic deterrents and ‘soft-start’ procedures may be ineffective, physical separation and noise barriers, such as peak-level absorbers (e.g., bubble curtains) may be more effective. Existing impact models often oversimplify and extrapolate from other scenarios, other sound propagation environments, and other species, leading to high uncertainty in defining safety regions or exposure zones.
15. We need refined noise emission and propagation models for the latest and next-generation turbines and exposure models that are relevant to the acoustic ecology of pinnipeds in Australia.

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