Exceptional Value Wetlands Subcommittee of the Wetlands Regulatory Advisory Committee

*01:00 PM - 03:00 PM Thursday October 29, 2026*

*Division of Water / Natural Resources and Environmental Control*

Hello, I am [redacted] from Middletown, Delaware. Thank you for this opportunity to share research regarding bird habitats that are currently at risk in Delaware and across the nation. In this particular piece, I am referring to the ocean, bays, and rivers as habitat and the risk as off-shore wind projects. Because you are charged with defining and protecting exceptional wetlands, I think this information is considered a tool for your decision making. We found that the evidence regarding adverse effects on marine birds is much stronger than that for non-marine birds. Additionally, off-shore wind projects threaten fish, fauna, crustaceans, vertebrae, and more due to various factors; most substantial is noise (from construction and ongoing operations). Retrospective analyses of **offshore wind** farm **impacts** on fisheries and benthic **habitat** interactions March **2026 finds that these projects are a great threat to habitat.**

Additionally, I think that it is important to place exceptional value on wetlands that are able to mitigate flooding, as provided below through published research. In Delaware, because you are charged to protect over 75,000 acres of wetland, I think that it is imperative to place value on wetlands with potential due to the high probability of false screening. In 2025, the State of Delaware stated that new housing construction is desired in order to attract young professionals for the purpose of increasing revenue for the State. For the record, I want to state that taxpayers want our government to first practice fiscal responsibility through spending cuts before we continue to mandate new housing construction and redefining wetlands. For these reasons, I implore you to place great effort into protecting all of our wetlands and not simply "some wetlands" as stated in your first meeting.

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1. **Can restoring tidal wetlands reduce estuarine nuisance flooding of coasts under future sea-level rise?**

PMCID: PMC12181935

We found restoration reduces the number of hours nuisance flooding occurs in downtown Coos Bay from 15 hours (present day conditions) to 0 hours (fully restored condition) under median sea-level rise (82 cm by 2100). Restoration had spatially variable impacts on reducing peak flood elevations with minimal impacts near the estuary mouth and greatest impact 32 km inland. The effectiveness of restoration was heavily dependent on future sea-level rise. Restoration was maximally effective in 2050 under all sea-level rise scenarios, less effective in 2100 under median SLR, and not effective under high SLR. Modeling results suggest increased tidal prism and accommodation space are driving reductions in tidal amplitudes.

We developed a new way to estimate the flood reduction co-benefits resulting from wetland restoration in coastal bays. This is accomplished through the use of harmonic analysis trained on computational hydrodynamic models, which helps reduce computational runtimes to allow long- term analysis and run a greater number of scenarios than with physics-based modeling alone. We then applied this methodology to a study site in Coos Bay, Oregon, USA. We found that restoration can significantly reduce expected flooding in both downtown regions and along major transportation corridors in 2100 under low to moderate sea-level rise scenarios. The expected magnitude of the flood impact reduction depended on location within the estuary and the sea- level rise scenario. Results indicate restoration is more effective at reducing tidal flooding at inland sites, with less impacts near the coast. We also found that restoration effectiveness was driven by increased flood accommodation space, allowing floodwaters to spread.

Coastal wetland restoration has many potential benefits beyond flood reduction. For instance, tidal wetlands in the PNW provide critical habitat for salmonids and migratory bird species, recreational opportunities that bolster tourism and resident access to green spaces, and water quality improvements through nutrient and sediment load absorption (Diefenderfer et al., 2016; Thom et al., 2018). Tidal marshes and swamps also have substantial carbon storage and sequestration benefits regionally (Peck et al., 2020; Kauffman et al., 2020; Fitch et al., 2022). Future studies that investigate the flood reduction benefits of wetland restoration should also examine the costs and benefits of these additional ecosystem services and compare them with gray infrastructure options to mitigate estuarine flooding.

2. Offshore wind farm impacts on marine fauna across taxa and ecological levels: A global review

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Frequently examined exposure type (24%). Of these, **55% (n = 81) reported negative impacts,** while 43% (n = 63) found no measurable change, suggesting that although many species exhibit resilience or tolerance, sound-sensitive taxa may be affected (Figures 8 and 10; Table S1). **Negative impacts mainly involved behavioral traits such as feeding (75%), avoidance (86%), acoustic communication (64%), and other behavior (73%).** At broader ecological levels, effects were **also observed on population structure (100%) and community diversity (100%).** These findings are consistent with the well-established **sensitivity of some fishes to anthropogenic noise, which can disrupt communication, orientation, and foraging efficiency.** Species such as **Acanthopagrus schlegelii, Gadus morhua, Dicentrarchus labrax, and Larimichthys crocea were particularly affected.** Overall, noise emerges as one of the **most consistently impactful** OWF-related stressors for fish.

**Noise can be generated during both the construction and operational phases of an OWF.** It arises from pile driving and other construction activities, turbine rotation, and increased vessel traffic in the surrounding area. The intensity and periodicity of this noise are highly variable and depend largely on turbine mooring type, turbine size and density, and local oceanographic conditions. **The widespread sensitivity of marine organisms to anthropogenic noise and the pervasive nature of its ecological effects have been documented for decades.**

Consistent with other recent reviews,7,9,20 most study sites were in the North Sea and adjacent European waters (particularly in the United Kingdom, Germany, Denmark, and the Netherlands), which together accounted for most of the total research.

This pattern suggests that, although **many invertebrate responses** to wind-farm exposures are neutral —**certain physiological and behavioral outcomes remain consistently vulnerable, calling for targeted research and monitoring efforts.**

**Our results align with previous reviews highlighting the sensitivity of invertebrates to anthropogenic sound, particularly regarding physiological and behavioral responses in molluscs and crustaceans.** However, to date, studies investigating hearing ability and the effects of anthropogenic noise have examined only a small fraction of

marine invertebrate diversity. As suggested by Popper et al.and Hawkins et al., future research should therefore focus on a restricted number of species of commercial or conservation interest, classify them according to shared physical or physiological characteristics, and determine whether these shared traits translate into common responses to acoustic exposure from OWFs.

Studies suggest that while structural elements may provide ecological
benefits for some species, **others may experience localized negative impacts.** This variability may result from differences in local ecological conditions, local species ecology (site fidelity, prey preference, and sensitivity to disturbance), OWF design (size, foundation type, and layout), and non-linear interactions
among stressors (e.g., noise, habitat change, and prey distribution).

Taken together, the evidence indicates that OWFs may pose substantial risks to marine mammals, primarily through noise and vessel disturbance, whereas impacts from contaminants and electromagnetic exposure remain largely underexplored. At the same time, structural elements of OWFs can generate localized ecological benefits, but these appear to be species and site specific.

Further, many of the available studies emphasize short-term or immediate responses (e.g., behavioral change, displacement, and feeding) rather than long-term demographic effects (survival, reproduction, and population dynamics). As such, the high proportion of negative outcomes in traits like acoustic behavior and avoidance raises concern that sublethal, chronic stress could accumulate over time, leading to declines in reproductive success, increased mortality, or habitat abandon ment48—outcomes that may not be detectable over the limited temporal and spatial scales of most studies.

Given the rapid global expansion of OWFs—often involving larger turbines, more dense installations, and greater vessel traffic—cumulative and synergistic effects may intensify over time. Without systematic, long-term, multi-species monitoring, it remains impossible to assess whether structural ‘‘benefits’’ (e.g., habitat provisioning) ultimately offset acoustic and behavioral stressors at the population or community level.

## Impact scores

The IS is an index that integrates species susceptibility (the proportion of studies reporting negative impacts relative to the total number of studies available for that species), IUCN conservation status, geographic range, and data reliability (a score representing the number of available studies on that species). The obtained score ranges from a minimum of 0 to a maximum of 3.3,
where 0 indicates no documented negative impact and 3.3 represents the maximum potential risk. Across the three taxonomic groups examined, clear differences emerged in both the magnitude and distribution of ISs associated with the four exposure types. Invertebrates had an average IS, across all the investigated species, of 0.86 (±0.91 SD). They exhibited the widest range of responses, with numerous species showing moderate to high ISs due to noise and marine traffic, and chemical pollution (in the few species investigated), while the physical presence of OWFs and electromagnetism produced predominantly none to moderate ISs.

## Summary

The expansion of offshore wind farms (OWFs) is central to global decarbonization strategies, yet their effects on marine biodiversity are only partially understood. This systematic review synthesizes 221 publications up to June 2025 to assess the ecological impacts of OWFs on marine fauna living below the sea surface. The evidence base is uneven, heavily focused on North European waters, fish, and invertebrates, while expanding OWF regions and marine mammals remain underrepresented. Most studies examine short-term, individual-level responses, limiting inference on long-term effects. Impacts vary widely by stressor, taxon, and biological outcome. Invertebrates often show positive responses linked to reef effects, though key functional traits are vulnerable. Fish responses are largely neutral except under noise, while marine mammals exhibit the most consistent negative impacts. The impact score developed here highlights taxon-specific vulnerability and offers a scalable risk-assessment tool for data-poor regions. The review calls for standardized, long-term field monitoring to support OWF expansion while safeguarding biodiversity.

## 3. Mapping the Evidence for Cumulative Adverse Effects of Offshore Wind Installations on Birds

PMID: 42629499

Understanding the cumulative adverse effects of OSW installations on birds is crucial given the global growth in development worldwide (Lees et al., 2022; Wang et al., 2024). Addressing gaps in our understanding of cumulative adverse effects can help prevent the discovery of unexpected biological effects, which could cause unnecessary delays in the transition away from fossil fuels or in meeting growing energy demands. We show that the evidence base developed over the past three decades is highly uneven across various lines of evidence required to inform cumulative adverse effects, leaving some as "known knowns" and others as "known unknowns". Among the three broad categories of evidence described in the Goodale and Milman (2016) framework, hazards—consideration of the physical changes from anthropogenic actions by which cumulative adverse effects could manifest—was by far the least frequently addressed in birds. As OSW installations continue to expand, our lack of understanding of cumulative adverse effects could lead to unwise decisions that worsen the plight of vulnerable species. At the same time, under the precautionary principle (Searle et al., 2025), development of this important resource could also be unnecessarily slowed or restricted where knowledge of cumulative impacts is uncertain. While uncertainty is inevitable, filling gaps as we identify here will allow for greater clarity, benefiting vulnerable species and ecosystems as well as the clean energy transition.

Perhaps the most pressing "known unknown" subcategory among the lines of evidence we evaluated relates to "Effect Pathways". This subcategory describes whether mortalities caused by bird encounters with OSW facilities are additive (effects are the sum of installed OSW farms), synergistic (effects are more than the sum of installed OSW farms), or countervailing (effects are less than the sum of installed OSW farms). We found four publications that addressed "Effect Pathways" with more than just a brief mention. However, the depth of analysis varied, with few offering detailed examinations of the likely effect pathways for several mechanisms of OSW

impact on birds (e.g., Boon et al., 2010). Several other publications assumed an additive-effect pathway (e.g., Piet et al., 2021), but few provided evidence to justify their choice. At least one acknowledged the lack of evidence supporting their decision (Piet et al., 2021). While we found that additive mortality is the default assumption for effect pathways, if the actual effect pathway is multiplicative or countervailing, then any estimate of cumulative adverse effects for a population would be under- or over-estimated, respectively (Goodale and Milman, 2016). Within a single OSW farm, effect pathways between different impact categories are often considered features in collision risk models. For example, these models expressly account for the fact that birds that avoid OSW farms are less susceptible to collision (Brabant et al., 2015). Expanding this nuanced understanding to interactions among multiple installations and other anthropogenic stressors would enhance our understanding of cumulative adverse effects.

We found that the evidence base regarding cumulative adverse effects on marine birds is much stronger than that for non-marine birds. Understanding the effects of OSW facilities on marine birds has long been considered essential (Furness and Wade, 2012; Garthe and Hüppop, 2004), as they rely on ocean habitats for foraging, dispersal, and resting. However, many non-marine bird species may be at risk from OSW facilities during their annual over-ocean migrations (e.g., Green-Tkacenko et al., 2025; Hüppop et al., 2016; Reid et al., 2023). We observed that measurements of the cumulative effects of multiple anthropogenic sources (e.g., other wind farms) and of baseline population status prior to construction were rarely included in existing *Tethys* publications for non-marine birds. Moreover, we found that evidence supporting thresholds beyond which populations decline, and the setting of temporal and spatial limits for the OSW facilities themselves, was completely absent for non-marine birds. We acknowledge that some evidence on non-marine birds might have been missed if they were included in the broader "birds" publications, which address both non-marine birds and marine birds. Although the taxonomic focus of these publications varies, most of the species discussed are marine birds. The lack of measured evidence on the cumulative adverse effects of OSW on non-marine birds could result from a bias towards breeding-season research (Marra et al., 2015), while their aerohabitat above the ocean is less well studied than that of marine birds (e.g., Hüppop et al., 2016). In addition, small birds, such as passerines, that migrate over the ocean are often too small to be readily tracked with high-accuracy, high-frequency geolocation devices such as GPS tags (Courbis et al., 2023). Instead, our understanding of migration over water in many non-marine birds requires methodologies such as light-level geolocators, radar, and Motus tags, which do not provide the same level of spatial or (for radar) taxonomic resolution (Courbis et al., 2023).

Furthermore, understanding changes in non-marine migratory birds can be complicated by a lack of baseline information due to limited available methods. Robust impact studies, such as before-after-control-impact studies, often require data that are not available even for many well-studied seabirds (Watson et al., 2025).

For instance, petrels, shearwaters, and albatrosses (Order Procellariformes) frequently utilize offshore ocean habitats and have significantly higher species richness in the Pacific Ocean compared to the Atlantic Ocean (Chown et al., 1998). Moreover, the East Asian-Australasian flyway is the most diverse and threatened migratory bird corridor in the world (Yong et al., 2015), and is home to critically endangered migratory species, such as the Spoon-billed Sandpiper (*Calidris pygmaea*; Birdlife International, 2021). Therefore, because the evidence of cumulative adverse effects has so far been documented only in a few locations within *Tethys*, the database contains limited recorded evidence of effects on these other species groups. This evidence gap is especially noteworthy given the recent rapid expansion of OSW across the Pacific (McCoy et al., 2024; Wang et al., 2024).

Many reports focus on mapping species at the scale of a single OSW facility and its buffer zone. In contrast, peer-reviewed studies often examine multiple facilities or broader spatial scales, sometimes covering entire countries' exclusive economic zones. In general, this highlights the importance of considering both “gray” literature and peer-reviewed studies when evaluating the breadth of evidence for cumulative adverse impacts.

To that end, we encourage increased efforts to gather both new and existing evidence across all categories and subcategories identified as important for understanding OSW's cumulative adverse effects on birds. Such a “build-out” of the evidence base would not eliminate uncertainty, but it would lead to a richer understanding of potential impacts beyond the local project level and bring clarity to highly uncertain regional management decisions. Birds face risks worldwide, with nearly half of all species experiencing population declines, and climate change presents a significant future threat (Lees et al., 2022). Because of these risks, reducing carbon emissions is a top priority, but changes to land and seascapes necessary to meet this challenge will also create new issues (Lees et al., 2022). Evidence syntheses, such as this one, highlight a pathway to direct resources towards taxa and risks that are currently poorly understood. In particular, our results suggest that incorporating gray and peer-reviewed literature from poorly represented countries into accessible databases would be especially beneficial. Building a more

balanced evidence base on the impact of offshore wind on birds will support efforts to decarbonize the electrical grid while also reducing overall adverse effects on biodiversity.

We found that the geographic distribution of publications qualifying for inclusion in our review was highly skewed toward Europe, with 250 publications (71%). This was followed by North America, with 92, and Australasia, with four. This geographic distribution aligns with *Tethys*'s general bias towards publications in English and other European languages. There were 49 publications where we could not assign the measurements they contained to a single country. For those where we could (305), the United Kingdom had the greatest number at 104, followed by the United States at 89 (Fig. 3). Four other countries had ten or more publications qualifying for inclusion: Belgium, Denmark, Germany, and the Netherlands. Comparing the number of publications to the number of turbines in each country revealed that the United States and the United Kingdom were particularly well represented, whereas China and Vietnam were notably underrepresented among publications deposited in *Tethys* (Fig. 4)

We found more evidence on other subcategories within the vulnerable receptors and exposure groups—identifying species that are most at risk, based on their status before construction, geographic occurrence, and annual cycle—constituting our "known knowns". Given this relatively robust evidence base, we suggest that a clear next step for these well-documented effects is to estimate effect sizes and identify pertinent factors influencing them via formal meta-analysis (e.g., Lamb et al., 2024). Meta-analysis cannot replace direct measurement of location-specific characteristics, and continued changes and development of OSW technology may mean that impact responses themselves change over time. Still, meta-analysis and other evidence synthesis approaches can help characterize the relative magnitude of species responses to OSW and guide site-specific sampling toward the species and effects that are most important (Lamb et al., 2024). Even as the sited locations and turbine design continue to change, information from such approaches may eventually serve to alleviate the need to direct resources towards studying species with responses that are already well known.

We found that the evidence base regarding cumulative adverse effects on marine birds is much stronger than that for non-marine birds. Understanding the effects of OSW facilities on marine birds has long been considered essential (Furness and Wade, 2012; Garthe and Hüppop, 2004), as they rely on ocean habitats for foraging, dispersal, and resting. However, many non-marine bird species may be at risk from OSW facilities during their annual over-ocean

migrations (e.g., Green-Tkacenko et al., 2025; Hüppop et al., 2016; Reid et al., 2023). We observed that measurements of the cumulative effects of multiple anthropogenic sources (e.g., other wind farms) and of baseline population status prior to construction were rarely included in existing *Tethys* publications for non-marine birds. Moreover, we found that evidence supporting thresholds beyond which populations decline, and the setting of temporal and spatial limits for the OSW facilities themselves, was completely absent for non-marine birds. We acknowledge that some evidence on non-marine birds might have been missed if they were included in the broader "birds" publications, which address both non-marine birds and marine birds. Although the taxonomic focus of these publications varies, most of the species discussed are marine birds. The lack of measured evidence on the cumulative adverse effects of OSW on non-marine birds could result from a bias towards breeding-season research (Marra et al., 2015), while their aerohabitat above the ocean is less well studied than that of marine birds (e.g., Hüppop et al., 2016). In addition, small birds, such as passerines, that migrate over the ocean are often too small to be readily tracked with high-accuracy, high-frequency geolocation devices such as GPS tags (Courbis et al., 2023). Instead, our understanding of migration over water in many non-marine birds requires methodologies such as light-level geolocators, radar, and Motus tags, which do not provide the same level of spatial or (for radar) taxonomic resolution (Courbis et al., 2023). Furthermore, understanding changes in non-marine migratory birds can be complicated by a lack of baseline information due to limited available methods. Robust impact studies, such as before-after-control-impact studies, often require data that are not available even for many well-studied seabirds (Watson et al., 2025).

We found a clear bias in *Tethys* publications toward evidence from Western Europe and Eastern North America. This bias is expected due to the way the Tethys database has been constructed over time, with the database originally indexing only English-language publications. Tethys has expanded to include publications from many European nations, as reflected in our dataset; however, literature from Asia remains underrepresented. Less than 10% of the reviewed publications considered bodies of water other than the Atlantic Ocean and its associated seas, mainly the eastern Pacific and the Great Lakes. No publications provided evidence of cumulative adverse effects on birds in China's offshore waters, which currently hosts the largest number of OSW turbines (Wang et al., 2024). Additionally, there were no publications from Vietnam, another country experiencing rapid OSW development (Wang et al., 2024). This lack of information from China and Vietnam confirms that industry reports from these countries are rarely, if ever, deposited in *Tethys*, even when produced. Nonetheless, addressing and correcting

this evidence bias is essential to gaining a clear understanding of the cumulative adverse effects of OSW on birds in Asia and globally. Because of global biogeographical patterns, this spatial bias also translates into a taxonomic bias. For instance, petrels, shearwaters, and albatrosses (Order Procellariformes) frequently utilize offshore ocean habitats and have significantly higher species richness in the Pacific Ocean compared to the Atlantic Ocean (Chown et al., 1998). Moreover, the East Asian-Australasian flyway is the most diverse and threatened migratory bird corridor in the world (Yong et al., 2015), and is home to critically endangered migratory species, such as the Spoon-billed Sandpiper (*Calidris pygmaea*; Birdlife International, 2021). Therefore, because the evidence of cumulative adverse effects has so far been documented only in a few locations within *Tethys*, the database contains limited recorded evidence of effects on these other species groups. This evidence gap is especially noteworthy given the recent rapid expansion of OSW across the Pacific (McCoy et al., 2024; Wang et al., 2024).

We found that both peer-reviewed and unpublished reports commonly gathered evidence supporting categories of cumulative adverse effects, though with a few notable differences. Reports are much more likely than peer-reviewed articles to include a clear baseline population status for target bird species. This outcome is likely because regulatory agencies typically require baseline field data on species abundance and distribution before approving an OSW project (e.g., European Commission, 2020). Similarly, discussions of the time frame over which species are exposed to the effects of OSW activity are more than twice as common in reports as in peer-reviewed articles. Conversely, peer-reviewed articles more frequently address the spatial boundaries of both the population and the development area than reports do. We believe these differences stem from the different spatial scales at which species are considered and mapped in reports versus peer-reviewed research. Many reports focus on mapping species at the scale of a single OSW facility and its buffer zone. In contrast, peer-reviewed studies often examine multiple facilities or broader spatial scales, sometimes covering entire countries' exclusive economic zones. In general, this highlights the importance of considering both “gray” literature and peer-reviewed studies when evaluating the breadth of evidence for cumulative adverse impacts.

Viewing the continued rapid expansion of OSW globally through the “cumulative lens” will be fundamental to fully understanding the environmental trade-offs involved across regions of the world. To that end, we encourage increased efforts to gather both new and existing evidence across all categories and subcategories identified as important for understanding OSW's cumulative adverse effects on birds. Such a “build-out” of the evidence base would not eliminate

uncertainty, but it would lead to a richer understanding of potential impacts beyond the local project level and bring clarity to highly uncertain regional management decisions. Birds face risks worldwide, with nearly half of all species experiencing population declines, and climate change presents a significant future threat (Lees et al., 2022). Because of these risks, reducing carbon emissions is a top priority, but changes to land and seascapes necessary to meet this challenge will also create new issues (Lees et al., 2022). Evidence syntheses, such as this one, highlight a pathway to direct resources towards taxa and risks that are currently poorly understood. In particular, our results suggest that incorporating gray and peer-reviewed literature from poorly represented countries into accessible databases would be especially beneficial. Building a more balanced evidence base on the impact of offshore wind on birds will support efforts to decarbonize the electrical grid while also reducing overall adverse effects on biodiversity.