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PRACTICE AND POLICY

Exploring the risks and benefits of flexibility in biodiversity offset location in a case study of migratory shorebirds

Nicole Shumway[1,2,3] | Megan I. Saunders[2,4] | Sam Nicol[5] | Richard A. Fuller[2] | Noam Ben-Moshe[6] | Takuya Iwamura[7] | Sun W. Kim[8] | Nicholas J. Murray[9] | James E. M. Watson[2,3,10] | Martine Maron[2,3]

[1]Centre for Policy Futures, The University of Queensland, St Lucia, Queensland, Australia

[2]Centre for Biodiversity and Conservation Science, The University of Queensland, St Lucia, Queensland, Australia

[3]School of Earth and Environmental Science, The University of Queensland, St Lucia, Queensland, Australia

[4]Queensland Bioscience Precinct, CSIRO Oceans and Atmosphere, St Lucia, Queensland, Australia

[5]Queensland Ecosciences Precinct, CSIRO Land and Water, Dutton Park, Queensland, Australia

[6]School of Zoology, Faculty of Life Sciences, Tel Aviv University, Tel Aviv, Israel

[7]Department F.-A. Forel for Aquatic and Environmental Sciences and Institute for Environmental Sciences, University of Geneva, Geneva, Switzerland

[8]Australian Research Council Centre of Excellence for Coral Reef Studies, School of Biological Sciences, The University of Queensland, St Lucia, Queensland, Australia

[9]College of Science and Engineering, James Cook University, Townsville, Queensland, Australia

[10]Global Conservation, Wildlife Conservation Society, Bronx, New York, USA

Correspondence
Nicole Shumway, Centre for Policy Futures, The University of Queensland, Building 39A, St. Lucia QLD 4067, Australia.
Email: n.shumway@uq.edu.au

Article Impact statement: Flexibility in offset location needs explicit evaluation to determine when flexibility enhances biodiversity gains and when it undermines it.

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Abstract
Biodiversity offsets aim to counterbalance the residual impacts of development on species and ecosystems. Guidance documents explicitly recommend that biodiversity offset actions be located close to the location of impact because of higher potential for similar ecological conditions, but allowing greater spatial flexibility has been proposed. We examined the circumstances under which offsets distant from the impact location could be more likely to achieve no net loss or provide better ecological outcomes than offsets close to the impact area. We applied a graphical model for migratory shorebirds in the East Asian–Australasian Flyway as a case study to explore the problems that arise when incorporating spatial flexibility into offset planning. Spatially flexible offsets may alleviate impacts more effectively than local offsets; however, the risks involved can be substantial. For our case study, there were inadequate data to make robust conclusions about the effectiveness and equivalence of distant habitat-based offsets for migratory shorebirds. Decisions around offset placement should be driven by the potential to achieve equivalent ecological outcomes; however, when considering more distant offsets, there is a need to evaluate the likely increased risks alongside the potential benefits. Although spatially flexible offsets have the potential to provide more cost-effective biodiversity outcomes and more cobenefits, our case study showed the difficulty of demonstrating these benefits in practice and the potential risks that need to be considered to ensure effective offset placement.

KEYWORDS
biodiversity offset, conservation policy, migratory shorebirds, no net loss

Estudio de los riesgos y beneficios de la flexibilidad en la ubicación de compensación de la biodiversidad en el estudio de caso de aves costeras migratorias

Resumen: Las compensaciones de la biodiversidad buscan contrabalancear el impacto residual que tiene el desarrollo sobre las especies y los ecosistemas. Los documentos guía recomiendan explícitamente que las acciones de estas compensaciones estén ubicadas cerca del lugar del impacto debido al potencial elevado de que haya condiciones ecológicas similares, aunque ya hay propuestas de una mayor flexibilidad espacial. Analizamos las circunstancias bajo las cuales las compensaciones alejadas del lugar de impacto tendrían mayor probabilidad de lograr pérdidas netas nulas o de proporcionar mejores resultados ecológicos que las compensaciones cercanas al área de impacto. Aplicamos un modelo gráfico para las aves costeras migratorias en el corredor aéreo asiático-australasiático del este como estudio de caso para estudiar los problemas que surgen cuando se incorpora la flexibilidad espacial a la planeación de las compensaciones. Las compensaciones espacialmente flexibles pueden mitigar los impactos más efectivamente que las compensaciones locales; sin embargo, los riesgos que esto involucra pueden ser considerables. En nuestro estudio de caso hubo datos insuficientes para concluir contundentemente sobre la efectividad y equivalencia de las compensaciones basadas en los hábitats distantes para las aves costeras migratorias. Las decisiones en torno a la ubicación de las compensaciones deberían estar impulsadas por el potencial para obtener resultados ecológicos equivalentes; sin embargo, al considerar compensaciones más alejadas, existe la necesidad de evaluar el incremento probable de riesgos junto a los beneficios potenciales. Aunque las compensaciones espacialmente flexibles tienen el potencial para proporcionar resultados más rentables y más beneficios colaterales, nuestro estudio de caso mostró la dificultad para demostrar estos beneficios en la práctica y los riesgos potenciales que necesitan considerarse para asegurar una ubicación efectiva de las compensaciones.

PALABRAS CLAVE

aves costeras migratorias, compensación de la biodiversidad, pérdida neta nula, políticas de conservación

【摘要】

生物多样性补偿旨在抵消发展对物种和生态系统的残留影响。生物多样性补偿的指导文件明确建议, 补偿行动应在受影响地点的附近进行, 因为相似的生态条件具有较大的补偿潜力, 但也有人提出补偿地点的选择应允许更高的空间灵活性。我们研究了在什么情况下, 远离影响地点的补偿行动比靠近影响地点的补偿行动更有可能实现无净丧失或产生更好的生态结果。本研究以迁徙滨鸟在东亚-澳大利亚的飞行路径为例, 应用图形模型探究了将空间灵活性纳入生物多样性补偿规划时出现的问题。空间上灵活的补偿有可能比原地点附近的补偿更有效地减缓影响;然而, 也可能涉及巨大的风险。在我们的案例研究中, 没有足够的数据来对远距离的基于栖息地的迁徙滨鸟生物多样性补偿的有效性和等价性做出有力结论。补偿地点的选择应该由实现等价生态结果的潜力所驱动;然而, 当考虑更远距离的补偿时, 还需要评估可能增加的风险和潜在的好处。虽然空间上灵活的补偿有可能提供更具成本效益的生物多样性结果和更多的共同利益, 但我们的案例研究表明, 在实践中证明这些利益尚面临困难, 研究同时指出了为确保补偿地点的有效性需要考虑的潜在风险。**【翻译:胡怡思;审校:聂永刚】**

关键词: 生物多样性补偿, 保护政策, 迁徙滨鸟, 无净丧失

INTRODUCTION

Biodiversity offsets are increasingly used to counterbalance the residual impacts of development at one location by improving the biodiversity value of another location, in attempts to achieve "no net loss" of biodiversity (BBOP, 2012a). Ecological equivalence (like-for-like trades) between biodiversity losses and gains is a fundamental principle of biodiversity offsetting (BBOP, 2012a). Biodiversity values and habitat composition tend to be spatially autocorrelated, such that sites in close proximity have similar values (BBOP, 2012b); therefore, geographic location is frequently used as a proxy for ecological equivalence in biodiversity offsetting (Kiesecker et al., 2009). As a consequence, spatial constraints (e.g., offsetting in the same local government area) are common in biodiversity offset policies.

Spatial proximity between offset and impact sites (e.g., "the closer the better") is a central tenet of best practice in biodiversity offset exchanges (BBOP, 2012b; Bull et al., 2018), and offsetting off-site or outside the local area is often prohibited or considered unacceptable by stakeholders (Burton et al., 2017). However, some policies allow increased flexibility if it facilitates policy goals (e.g., no net loss), but some restrict flexibility if motivated by other factors, such as cost minimization. Thus, the flexibility allowed is determined by something intangible: the motivation behind offset location (zu Ermgassen et al., 2020). Therefore, there is continued debate about the circumstances under which offsetting close to the impact site is desirable (Bull et al., 2015; Kiesecker et al., 2009; zu Ermgassen et al., 2020) and when offsets that are flexible in space might be acceptable (Bull et al., 2017), more cost-effective (Pascoe et al., 2011; Wilcox & Donlan, 2007), or result in better biodiversity outcomes (Bull et al., 2015; Bull et al., 2017; Habib et al., 2013; Kujala et al., 2015). Researchers have used systematic conservation planning to examine the regional-scale impacts of offsetting at different geographic extents (Kiesecker et al., 2009; Kujala et al., 2015); however, the implications of relaxing the proximity principle have not yet been explored fully.

We synthesized the potential benefits and risks of allowing spatial flexibility in biodiversity offsets and used a case study of migratory shorebirds in the East Asian–Australasian Flyway (EAAF) to explore how these issues arise in practice when attempting to identify the suitability of spatially distant offsets.

POTENTIAL BENEFITS OF SPATIAL FLEXIBILITY IN BIODIVERSITY OFFSETTING

Offsets that are flexible in space have been proposed to achieve better outcomes for biodiversity (Bull et al., 2015; Kujala et al., 2015). For example, many species have long-distance migrations or large variable threats throughout their range. Therefore, if an impact occurs where threats to a species are generally low, the expected benefits of offsets near the impact site or sites may also be low, and offsets implemented where the threat is greater or easier to abate may be more beneficial. This could be particularly true for highly mobile or migratory species for which static, area-based offsets are insufficient to address biodiversity impacts. For example, offsets have been proposed that create mobile protected areas that track the vulnerable calving locations for the migratory Saiga antelope (*Saiga tatarica*) in Uzbekistan (Bull et al., 2013). Geographic flexibility may also be more cost-effective (Habib et al., 2013). For example, offsetting the incidental catch of migratory seabirds from the Australian longline fishery through island predator removal on seabird breeding colonies is 10–23 times more cost-effective than fishery areas closure (Pascoe et al., 2011; Wilcox & Donlan, 2007).

In other cases, threats associated with impact sites may extend beyond the boundaries of the development footprint or be spatially correlated. Indeed, some types of development tend to cluster spatially and spread across an area over time, such as natural gas and mineral mining operations (Kiesecker et al., 2009). For example, mine sites often have a spillover effect in which the indirect footprint grows over time to support mining infrastructure, transport, and associated urbanization (Sonter et al., 2014). These indirect impacts are usually outside the development footprint and result from complex impact pathways (Raiter et al., 2014) and are often not included in the impact assessment process (or are cumulative impacts), which typically focuses on project-level mitigation (Quetier et al., 2015). This impact "contagion" could lead to an increased risk of future loss or degradation for offsets located close to the impact site (Raiter et al., 2014), but offsets not subject to those threats might increase the likelihood of success. Similarly, evaluating these impacts over larger spatial scales could significantly improve the efficacy of no net loss policy (Kujala et al., 2015; Whitehead et al., 2017).

Protecting or enhancing a location or habitat on which a population depends, regardless of impact location, could deliver superior conservation outcomes than protecting a more generic location or habitat type. For example, the southeast subspecies of the red-tailed black cockatoo (*Calyptorhynchus banksii graptogyne*) has distinct feeding and nesting habitats, but feeding habitat is the most depleted and likely to be population limiting (Maron, 2005). Therefore, an impact on nesting habitat could potentially be offset by creating a gain of the more depleted feeding habitat, even if that feeding habitat was far from the impact location. Spatially flexible offsets could also benefit species that exhibit large-scale aggregation behavior (Wilcox & Donlan, 2007). These species aggregations can be highly vulnerable to disturbance or exploitation; their loss could rapidly escalate extinction risk and have cascading effects elsewhere (Heyman et al., 2019). Atlantic Goliath grouper (*Epinephelus itajara*) migrate to predictable seasonal spawning aggregation sites and have been nearly extirpated from all these sites (their primary source of reproduction) in the United States as a result of targeted fishing (Heyman et al., 2019). However, these aggregations also present an opportunity to concentrate offset efforts. Offsets that can target locations critical to a species lifecycle could deliver conservation outcomes with more benefits than offsets located near the impact site or sites (Squires et al., 2018; Appendix S1), in this case by improving population viability for the entire species.

RISKS OF INCORPORATING SPATIAL FLEXIBILITY

The many potential benefits of spatial flexibility in offsets do not come without risks. For example, spatial proximity is often used as a proxy for establishing ecological equivalence (Kujala et al., 2015). However, with increasing distance between an impact and offset sites, ecological equivalence between the biodiversity affected and the biodiversity offset is likely to be reduced, increasing the importance of robust evidence of equivalence. For example, a given habitat in a particular landscape may support a certain number of individuals and therefore, a nearby area with similar habitat might support the same number. However, similar habitats, far away and in a different landscape context, are more likely to vary in their value to species in ways one cannot account for completely.

Allowing offsets that are spatially flexible could lead to the local loss of ecosystem services for local beneficiaries (Bull et al., 2018) to other geographic locations where the offset benefits accrue. For example, the development of a coastal habitat could lead to the loss of associated services, such as storm protection or water purification, whereas spatially flexible offsets could allow that benefit to accrue elsewhere. Most projects do not explicitly consider ecosystem services as part of the offsetting process (Sonter et al., 2018). Social barriers to offsetting are considered exceptionally complex, and incorporating additional flexibility could lead to increased social inequity and the loss of cultural values that may be unacceptable (Griffiths et al., 2019). At an international level, it could promote policies where economically developed countries export their environmental degradation to less developed, but more biodiverse countries. Where such offsets restrict opportunities for local people, they could exacerbate existing global inequalities, create perverse social outcomes, and significantly increase the chance of offset failure (Bull et al., 2018).

Biodiversity offsets that span multiple geopolitical boundaries could pose regulatory risks. Geopolitical boundaries often hinder effective management through fragmented governance and coordination, especially for migratory species (Runge et al., 2014). Although many initiatives exist to foster biodiversity conservation at an international scale (e.g., the Convention on Migratory Species), it is unclear how offsets at this scale would be regulated because there is limited legal capacity to do so. For a region such as the European Union (EU) that already has an offsets framework in place through the Birds and Habitat Directive (European Commission, 2007; Regnery et al., 2013; Wende et al., 2018), offsetting between countries might be possible; however, this would depend on the legislative alignment between the jurisdictions. Where the impact and offset occur in different jurisdictions, it is unclear how offsets would be regulated, what the legal capacity for regulation is, and whether such trades would be socially acceptable (Bull et al., 2017; Burton et al., 2017). The difficulty of tracking, monitoring, and managing offsets across jurisdictions is likely to increase (Vaissière et al., 2014). To address this issue, Mudbank was developed. Mudbank is a global portfolio of critical habitat sites where offset investment can improve the conservation of migratory waterbird species. It is administered and managed by Wetlands International and supported by relevant companies, governments, nongovernmental organizations, and stakeholders (Wetlands International, 2019).

Allowing spatially flexible offsets could undermine the integrity of the mitigation hierarchy. Biodiversity offsets are a market-based instrument for conservation that incorporates environmental degradation into the cost of development to incentivize the reduction of environmental impacts (Gonçalves et al., 2015). However, where offset credits are scarce or expensive, there is often industry pressure to increase flexibility for offset trades to reduce transaction costs and stimulate supply (Apostolopoulou & Adams, 2017). Although this may improve market functionality, it can also lead to reduced incentive to avoid impacts and more out-of-kind trades, reducing outcomes for the affected biota (zu Ermgassen et al., 2020). The difficulty and expense of genuinely achieving no net loss should incentivize the rigorous application of the mitigation hierarchy. However, allowing greater flexibility in offset exchanges inaccurately reflects the scarcity of biodiversity values and undermines the use of avoidance (zu Ermgassen et al., 2020). The difficulty and expense of genuinely achieving no net loss should incentivize the rigorous application of the mitigation hierarchy; however, allowing greater flexibility in offset exchanges can inaccurately reflect the scarcity of biodiversity values and undermine the use of avoidance (zu Ermgassen et al., 2020).

When deciding whether spatially flexible offsets are appropriate, potential benefits should be weighed against potential risks to evaluate the trade-offs involved and whether relaxing spatial proximity rules improves or undermines biodiversity outcomes. We attempted to relax this proximity principle by modeling suitable offsets for migratory shorebirds throughout the EAAF to identify which ecological problems arise in practice and their implications.

CASE STUDY OF MIGRATORY SHOREBIRDS IN THE EAAF

Millions of shorebirds migrate annually between arctic breeding grounds and nonbreeding habitat in Australia through the EAAF (Iwamura et al., 2013). These shorebirds use specific stopover sites across coastal eastern Asia and Australasia to rest and feed. Tidal wetlands have declined globally (16% since 1984), with particularly severe declines in the Yellow Sea (65%), creating a significant bottleneck at the center of the EAAF that constrains shorebird populations throughout the flyway (Murray et al., 2019a; Studds et al., 2017). Targeting habitat offsets toward these key stopover points could potentially provide greater benefit for highly connected populations of shorebirds and aid in the continued survival of multiple species throughout the flyway (Appendix S1).

Moreton Bay (Queensland, Australia) is a Ramsar designated wetland and a site of international importance in the EAAF, regularly supporting more than 30,000 individuals and 28 migratory shorebird species. However, a proposed development affecting the wetland (Toondah Harbor, Environment Protection and Biodiversity Conservation [EPBC] Act referral 2018/8225; Figure 1) would destroy 34 ha of foraging habitat for migratory shorebird populations, including 2 critically endangered and 1 vulnerable species (EPBC Act 1999): Great Knot (*Calidris tenuirostris*), the Eastern Curlew (*Numenius madagascariensis*), and Bar-tailed Godwit (*Limosa lapponica baueri*). Shorebirds face a range of threats throughout their migration, including habitat conversion, degradation from pollution, loss, and disturbance; hunting; and climate change (Sutherland et al., 2012). It is difficult to predict the potential impact of a specific development on the overall persistence of a species when they are exposed to a range of impacts throughout their migration; as such, the

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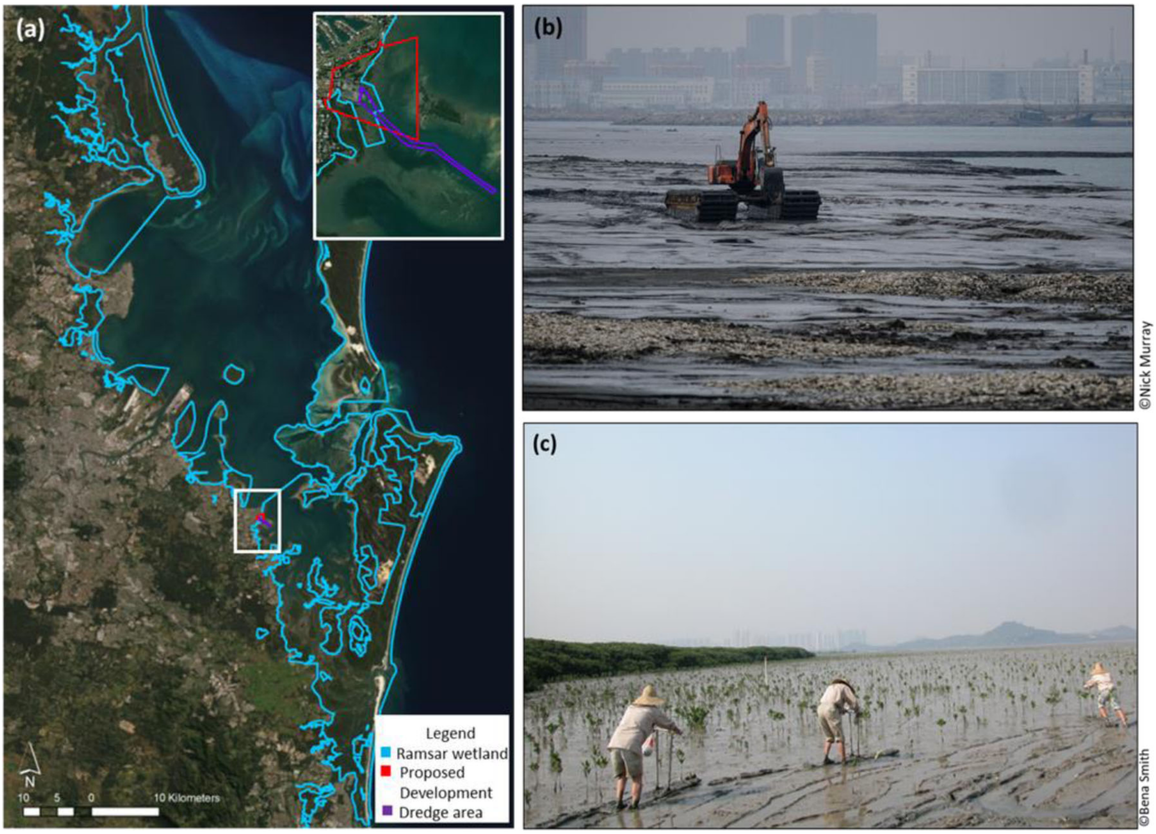

FIGURE 1 Coastal development and restoration throughout the East Asian Australasian Flyway: (a) proposed development in a Ramsar-listed wetland in Queensland, Australia, (b) coastal development and land reclamation in the Yellow Sea, and (c) restoration of mudflat habitat at Mai Po Ramsar site, Hong Kong

area of habitat lost is used as a proxy for impact on the affected species.

Offsets are a requirement in Queensland (*Environmental Offsets Act 2014*) and in Australia (*EPBC Act 1999*) for impacts to matters of state or national environmental significance, respectively. Offsets for impacts on shorebird habitat have hitherto been done near the sites of impact within Australia. However, habitat-based offsets in the Yellow Sea were initially suggested (though ultimately discarded) by Moreton Bay project proponents. Therefore, this is an ideal case study to explore how the potential risks and benefits of spatially flexible offsets emerge in practice and identify data needs to support such decision-making.

Modeling shorebird offsets

Modeling the potential effectiveness of alternative impact/offset combinations could help identify additional risks and benefits of incorporating spatial flexibility into biodiversity offsetting, though there are major challenges to this, particularly at the land–sea interface (Shumway et al., 2018). We attempted to explore the outcomes for shorebirds of a spatially flexible offsetting strategy for the Moreton Bay development by adapting a published graph theory model for shorebird migration in the EAAF. In the model, a node is a geographically defined area of important wetland sites and an edge is a function that connects 2 nodes and has direction and weight representing the flow of birds between nodes (Iwamura et al., 2013; Nicol et al., 2015; Appendix S2). We identified 6 shorebird taxa that migrate through the EAAF (Figure 2) and would be affected by the development and that had enough data available to determine their population sizes and model their migratory pathways (Supporting Information S3). We developed a modeling approach that linked bird population size and habitat availability to simulate impacts from development activities (removing habitat at one location) and benefits from offsets at locations in the network to determine the net outcomes of alternative impact/offset pairs. A successful offset for each taxa was considered as an offset in which net outcomes were at least as positive for the birds' flyway population as a scenario in which no impact (or offset) occurred. In these scenarios, we assumed habitat extent was the main factor driving population change (Murray et al., 2019a).

To identify the most effective location for a habitat offset throughout a migratory network, at a minimum, data are needed on habitat area, species population, and rates of change for both, along with carrying capacity (Table 1). We used a machine learning classifier to map the extent of intertidal area at 83 internationally important sites from 1992 to 2016. We used every

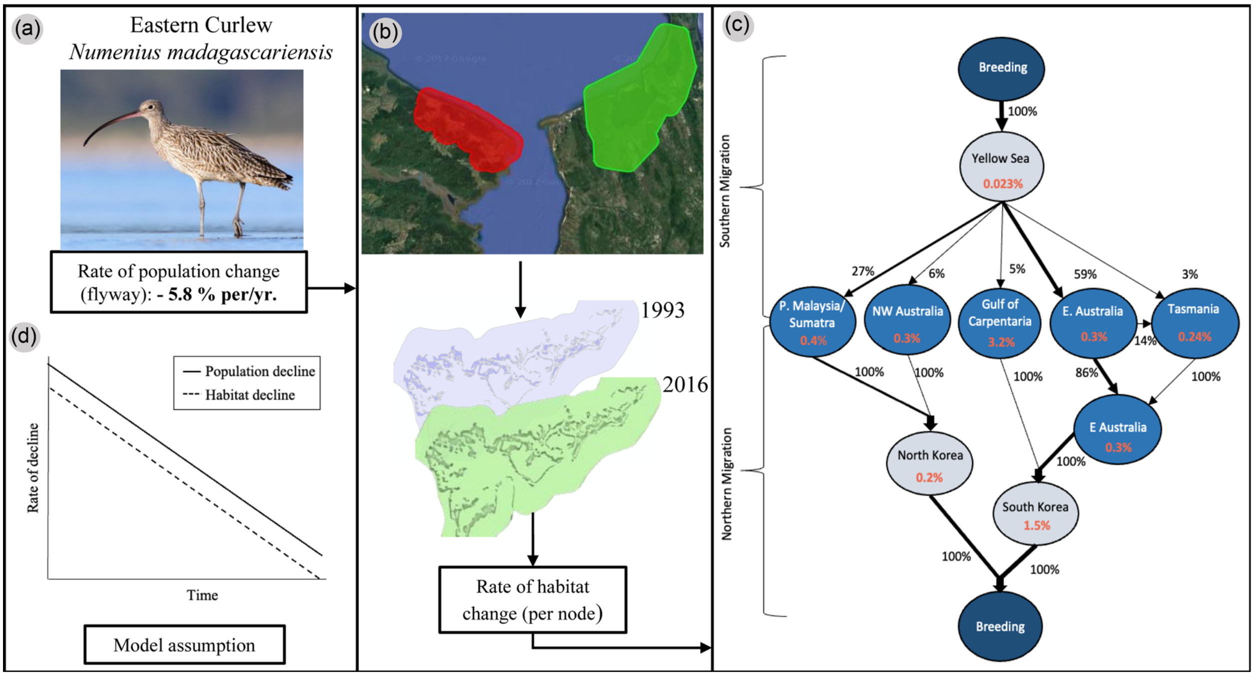

FIGURE 2 Key components of spatial analysis of offset flexibility for the (a) critically endangered eastern curlew (*Numenius madagascariensis*) with a flyway rate of population decline of −5.8% per year; (b) change in intertidal area from 1993 to 2016 from machine learning classifier (bottom: purple, intertidal area in 1993; green, intertidal area in 2016; top: color, classification of different sites in the EAAF); (c) a graph theory model representing migratory network use (arrows, percent movement of population between nodes; red, rate of habitat change identified for that node); and (d) the assumed linear relationship between habitat and population, such that a simulated offset wherever habitat is declining more than population is declining (i.e., bottleneck node) allows a greater flow of birds through the network (no location exceeded the rate of population change)

TABLE 1 Data needed to model spatial flexibility for offsets with a maximum flow network model

Data type	Data need	Scale	Availability	Units	Method
Population	Population size	Network	✓	Number of individuals	Total population estimates based on count data (Iwamura et al., 2013)
		Site	✓	Number of individuals	Expert elicitation estimate of percent of total population moving between sites (Iwamura et al., 2013)
	Rate of change	Network	✓	Percent/year	Flyway-level population trend estimates (Studds et al., 2017)
		Site	No	Percent/year	Site-level population trend estimates (unavailable)
Habitat	Habitat size	Site	✓	ha or km	Polygon data of sites supporting more than 1% of the flyway population ($n = 83$) (Iwamura et al., 2013) and Landsat data of intertidal extent (Murray et al., 2019)
	Rate of change	Site	✓	Percent/year	Proportional rate of decline (PRD) calculated using Landsat data of intertidal extent from 1992 to 2016 (Murray et al., 2019)
	Condition	Site	No	Quality metric	Change in condition through time (unavailable)
Carrying capacity	Carrying capacity of impact site	Site	✓	Individuals/ha	Assumed that if the rate of population decline was higher than rate of habitat decline, then excess capacity existed at those site (Appendix S3)
	Carrying capacity of offset site	Site	✓	Individuals/ha	
Migration	Migratory network	Network	✓	Individuals/percentage of original population	Mixture of banding and flagging information, satellite tracking, and expert elicitation (Iwamura et al. 2013)
Threats	Other threats	Site	No	Unknown	Impact on species (unavailable)

available Landsat 4, 5, 7, and 8 satellite image taken within 1 km of the coastline (methods available in Murray et al. [2019b]) and used this extent to calculate rate of habitat change (per node) with (SSG, using) the R package redlistR (Lee et al., 2019; Appendix S3). We assumed a linear relationship between the change in habitat extent and the change in the population size at each node. Therefore, wherever habitat was declining at a greater rate than the population, habitat was assumed to be the limiting factor, and a simulated habitat offset benefit (such as through restoration) at that bottleneck location would then allow greater flow of birds through the network. However, rate of population decline for each species was only available at the flyway level (Studds et al., 2017). Therefore, we assumed the rate of decline for each node was the same as the flyway-level estimates (Appendix S3) and that additional habitat at stopover nodes would be equivalent to a proportional increase in carrying capacity (Nicol et al., 2015).

Data shortfalls for assessing spatially flexible offsets for migratory shorebirds

When comparing the rate of habitat change at each node and the rate of population change at the flyway level, there was a large disparity. The rate of population decline for each of the species was much greater than the rate of habitat decline (Figure 2; Appendix S4). This meant that an increase in habitat could not generate a detectable effect on the modeled shorebird population; thus, our model predicted no benefit from any habitat-based offsets.

Offsetting in which habitat is a proxy relies on an established relationship between the habitat and the population of the species in question. Despite the considerable data available, they were not enough to support a realistic model of the link between site-level habitat and flyway-level bird populations. We assumed that habitat quality was uniform across the mapped intertidal area. Although extent of intertidal habitat is a useful starting point for exploring the dynamics of offsetting, real-world application would need careful exploration of variation in quality among different tidal flats. The disparity between rates of habitat and population change could be driven by several factors. Although shorebird declines in the EAAF have been attributed mostly to the loss of tidal flats, certain types of habitat (e.g., upper tidal flat) are likely to be disproportionately important for the population, and loss of habitat could cause increased resource competition. Additionally, nonhabitat-related threats (e.g., hunting) may be contributing to impacts (Gallo-Cajiao et al., 2020; Mu & Wilcove, 2020). Therefore, more research is needed to understand location-specific relationships among threats, habitat loss, and carrying capacity (Shaffer et al., 2019). Obtaining this information would require developing site-specific carrying capacity models for the flyway, which is possible but data intensive due to the difficulty in measuring food resources (e.g., vertebrate biomass) and establishing the relationship between resources and bird abundance. Although habitat relationships have been modeled for other migratory species (Mattsson et al., 2012), these models require detailed estimates of demographic parameters based on environmental and habitat correlates that are not yet available in the EAAF.

For spatially flexible offsets to be appropriate, at a minimum, ecological equivalence needs to be established. Our case study demonstrates the challenges of establishing spatially flexible offsets that are ecologically equivalent, particularly when using habitat as a proxy for particular species. For shorebirds, the following are needed: adequate data to parameterize a suitable system model (Table 1), estimates of the total population of each species along with detailed data on migration routes, species movement among sites, effects of threats at each location, and species' response to conservation actions, which is often uncertain (Evans et al., 2015). Understanding the relative magnitude of different threats and how they affect declining populations can be time consuming and costly and likely not feasible for many species (Waldron et al., 2013). Modeling the impacts of land use and associated management actions is a challenge across conservation, particularly where species are affected by multiple, confounding threats (Bal et al., 2018). It is not enough to know the location of threats and actions to mitigate those threats (Tulloch et al., 2015); understanding the relationship between the threat and the conservation action and the action and a desired outcome is vital for effective conservation interventions (Carwardine et al., 2012). However, additional data do not always lead to more certainty or to better conservation decisions, and here value-of-information analysis is useful in examining when additional data might reduce uncertainty and lead to better management outcomes (Nicol et al., 2019).

We used habitat as a proxy for shorebirds. However, to evaluate the equivalence of impacts and offsets, the relationship between habitat and populations needs to be understood. Our case study showed the difficulty of establishing these relationships in practice—it cannot be assumed that species will be conserved along with their habitats or that habitat is a perfect proxy in its value to species. Therefore, determining equivalence at separate geographic locations at the flyway scale in the EAAF is currently not possible given the available data and understanding of the links between habitat and population. Conservation interventions for shorebirds are likely to be most beneficial at a highly connected bottleneck (e.g., Yellow Sea). However, offsetting makes explicit that biodiversity gains must be measurable and ecologically equivalent, and this could not be adequately demonstrated for migratory shorebirds in the EAAF.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Decisions around offset placement should be driven by the ecological outcomes that can be achieved. However, when choosing between providing local versus distant offsets, there is a need to evaluate the risks and the potential benefits. For migratory shorebirds in the EAAF, the benefits of increased offset flexibility include the potential to channel compensatory conservation actions to the places where impacts to shorebirds are greatest and where they could provide the most benefit, specifically by improving shorebird populations throughout the flyway. However, because we were unable to quantify the relationship between habitat availability and population abundance at the local scale, we could not predict the impacts of trading losses and gains between different geographic locations. Therefore, there were inadequate data to provide robust evidence of the effectiveness of distant offsets or to show that their benefits outweigh the risks outlined, in particular high uncertainty around offset gains if ecological equivalence could not be established. Combined with other risks, such as the loss of local ecosystem services, regulating offsets across international boundaries and community preference for local actions (Burton et al., 2017), we suggest that the challenges around spatially flexible offsets currently outweigh the potential benefits for migratory shorebirds in this case.

Where the appropriate evidence base exists and where the risks discussed can be minimized, spatially flexible offsets still have the potential to provide better conservation outcomes at the spatial scale over which species occur. Models of the type we used have great potential as tools for identifying sites where conservation benefits from a given action could be greater than if the same action was done close to the impact site and for exploring the implications of associated uncertainties and assumptions. Where evidence is lacking and the ability to model outcomes at large spatial scales is constrained, it seems advisable to provide offsets locally. However, the trade-offs involved in allowing increased flexibility despite the potential loss of ecological equivalence should be examined to understand when increased flexibility is facilitating no net loss and when it is undermining it (zu Ermgassen et al., 2020). The acceptability of these trade-offs will likely depend on the circumstances, including legislative alignment between jurisdictions, the biodiversity value being offset, and the risks around achieving equivalent biodiversity gains given the often-large knowledge gaps. Although allowing more spatial flexibility in offset location can be an appealing notion for achieving better biodiversity outcomes, our case study shows that demonstrating this in practice is challenging.

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ORCID

Nicole Shumway https://orcid.org/0000-0003-3582-6841
Nicholas J. Murray https://orcid.org/0000-0002-4008-3053

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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