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Research article

A conceptual approach to integrate management of ecosystem service and disservice in coastal wetlands

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Abstract: Management of coastal wetlands is increasingly difficult because of increasing pressure arising from anthropogenic causes. These include sea level and climate change as well as coastline development caused by population growth and demographic shifts, for example, amenity migration where people move to coastal communities for lifestyle reasons. Management of mangroves and salt marshes is especially difficult because maintaining ecosystem values, including the goods and services provided, is countered by the potential of enhancing or even creating ecosystem disservices, such as unpleasant odour and mosquito hazards. Here we present, explain and apply a conceptual model aimed at improving understanding of management choices that primarily focus on mitigation of disservice while enabling improvement in ecosystem services. The model was developed after more than 30 years of habitat management following modification of a salt marsh to control mosquito production. We discuss the application of the model in a mangrove forest known to produce mosquitoes and outline the benefits arising from using the model.

Keywords: Mangrove rehabilitation; ecosystem service; ecosystem disservice; conceptual model; wetland management; habitat modification

1. Introduction

Ecosystem services are the products of ecosystems that benefit people [1] and are fundamentally important to our wellbeing and survival [2]. Coastal ecosystems are particularly important, as a third of the world's population lives in coastal areas, at double the density of inland populations [3]. A wide range of goods and services are provided by coastal wetlands, both valuable to the human economy and intrinsic as nature. For example, many mangroves provide raw materials and food, coastal protection, erosion control, maintenance of fisheries, nutrient cycling, carbon sequestration, and recreation, education and research [4]. In addition, mangroves include a unique set of flora that supports both obligate and facultative users. Rog et al. found the importance of mangroves was greatly understated when it came to small mammals, reptiles and amphibians that were facultative users of mangroves [5]. They also suggested that mangroves become more important for facultative users if their primary habitats are lost.

At a global scale, there have been large losses in natural capital and associated ecosystem service. Costanza et al. reported losses between 1997 and 2011 of 22% in the area of tidal marshes and mangroves that mostly resulted from land use change [2]. Population pressure on coastal areas has been increasing over past decades due to a phenomenon described as amenity migration, where people move for amenity reasons. In coastal areas the amenity is a coastal lifestyle, creating considerable development pressure [6]. Recognition of the significant role of development as a driver of mangrove degradation, and hence ecosystem service loss, was found in 82% of mangrove rehabilitation research papers reviewed by Dale et al. [7]. Historically, widespread salt marsh and mangrove loss has been due to land reclamation, both for development, including urban, industrial and utility uses (e.g., airports), and to remove mosquito habitat (e.g., in the USA) [8]. Sea level and climate change are also contributing to the loss. For example, along Australia's east coast mangrove encroachment in response to rising sea level has become a major cause of salt marsh loss [9].

Whereas the extent of coastal wetlands is declining, the value of services provided is increasing. Costanza et al. reported an increase from $14,000 to $194,000 $/ha/yr between 1997 and 2011 due to a reassessment of the values of storm protection, erosion control and waste treatment services provided [2]. It follows, that as the collective worth of property being protected increases, so too, does the value of the protection service being provided.

As people move closer to coastal wetlands, they become increasingly exposed to any negative impacts or disservices emanating from the wetland. These disservices are ecosystem products that have a negative impact and/or cost for people and/or society [10]. For those living near a mangrove forest with poor water quality, odour may be a major concern reducing lifestyle amenity. Coastal mosquitoes are another disservice because their biting directly reduces lifestyle amenity. Mosquitoes also transmit disease posing a health hazard and creating associated health care costs, and loss of productivity. These disservices create a cost both personally and for those required to manage the problem.

A variety of mosquitoes use intertidal wetlands, including salt marshes and mangroves, as larval stage habitats, with emerging female adults producing the disservice, yet disservices are rarely considered in rehabilitation literature. A brief literature review (Web of Science, November 16, 2016) using the general term "disservice" in the title yielded 94 references dating from 1966. The majority were not in the area of ecology. The first appearance of the term in association with "ecosystem" was in 2008 and in total, there were only 24 ecosystem-based references. Only one focused on mangroves as reflected in the title—Friess—who comprehensively reviewed historical 19th century colonial information on mangrove ecosystem services and disservices [11]. Friess found that 59% of the 329 papers reviewed described disservices. These included mangroves as dark and gloomy, as places of danger (snakes and alligators), with sickness and bad air (particularly mosquito-borne disease). Friess also found that current research focuses on service provision without accounting for disservices [11]. However, Lyytimaki argued for the need to consider both disservices and services because doing so makes it possible to consider both under a common assessment framework [12]. This is particularly important when managing ecosystems, such as coastal wetlands, where a disservice product is caused, or exacerbated by some compromised ecosystem services. Integrating management of service and disservice ensures management is focused on change in both service and disservice, and able to respond to the changing status of both over time. As Lyytimaki et al. argued, the relative significance of the service verses disservice is not fixed, but dependent on the context and people involved [13]. This is the case where the increasing proximity of people to coastal wetlands has made disservice, such as mosquitoes, a more significant concern both for residents directly affected and for authorities dealing with the disservice. As such, an understanding of the spatial context of service/disservices in terms of both production area (coastal wetland), and impact zone is also needed [14], particularly where the disservice becomes independently mobile and therefore widespread.

Coastal development can also create or exacerbate disservice, especially if there is no practical consideration of the potential for disservices. The same can apply to rehabilitation projects [7]. For mangrove rehabilitation, where there is a saltwater mosquito risk, the heaviest burden of disservice frequently occurs in degraded mangrove systems [15]. This is because the mosquito is unaffected by poor water quality (anoxia and low pH), and favours these conditions that prohibit access for predator fish [16]. With appropriate awareness, information and consideration of potential hazards, rehabilitation need not be accompanied by increased disservices [15]. For example, Webb suggested several strategies that, if taken into consideration during rehabilitation, may reduce the mosquito hazard [17].

Here we present a conceptual model that integrates management of service and disservice with key ecosystem functions and management, so that both service and disservice are considered in decision-making and thus improve management. The model has three components: a service-disservice interaction concept model, hypothetical service-disservice management outcome scenarios, and a holistic integrated conceptual model to facilitate best practice outcomes for managing service and disservice. The model comes out of more than 30 years of habitat management following modification of a salt marsh to control mosquito production. We discuss the application of the model in a mangrove forest known to produce disease vector mosquitoes and outline the benefits arising from using the model. First, we give a brief history of mosquito management and a description of current practice as undertaken in Queensland, Australia.

2. Managing the mosquito disservice in practice

Mosquito control is the usual method of reducing the vector-borne disease disservice. It is currently dominated by expensive, repeated chemical applications on a large scale. Early attempts at managing mosquito numbers in coastal wetlands, particularly in the USA, began with engineering works in the 1910s with various forms of ditching of coastal marshes. Ditching continued into the 1930s when it was superseded by flooding of marshes [18,19]. These early approaches often destroyed the wetland and later, in the 1960s and onwards, led to attempts to restore wetland function, but without also recreating the mosquito hazard. In Florida, these source reduction methods have evolved into Rotational Impoundment

Management (RIM) [19-21]. RIM as a technique aims to control mosquito production, at its source, by managing system hydrology to make the environment unsuitable for the mosquito, but can be tuned to achieve other environmental goals, such as waterfowl management [19].

However, the early destruction of marshes in the USA led to concern in Australia and efforts to avoid similar destruction of Australian wetlands. The need to address the competing pressures from protecting coastal wetlands and also controlling mosquitoes provided the impetus for a minimal, but effective, environmentally acceptable, habitat modification process. This resulted in successful pilot work, initiated in the mid-1980s, demonstrating that modest hydrologic adjustment (runnelling) in intertidal salt marshes could sustain ecosystem services and reduce disservices (mosquito production) in those habitats [22]. The key objective was to modify tidal flushing across the marsh sufficiently to reduce mosquito production but not so that the marsh was adversely affected. As a result of the success of the runnelling approach [23] it has been incorporated into mosquito management strategies and formal policy for salt marshes [24].

The original approach was limited to salt marshes. However, the process that evolved over more than 30 years is the basis for the models described in Section 3 and applied as set out in Section 4 below. Mangrove forests have been a more difficult subject to study than salt marshes mainly because of difficulty in describing forest internal structure, hydrology and mosquito population patterns (see Stage 2 in Figure 3). Until very recently, obtaining the detailed topographic data and detailed hydrology necessary to plan modest habitat modifications, similar to those used in salt marshes, was difficult if not impossible. These difficulties have now been overcome by the advent and availability of high-resolution LiDAR data and affordable, lightweight, and accurate water depth data loggers [16,25].

3. The Model

The model (Figure 1) shows the desired change in service and disservice in response to successful management, such as rehabilitation of wetland water quality. The model is applied when there is a disservice that requires remedying. In general, the existence of a significant disservice coincides with a low service provision state, such as restricted tidal connection leading to stagnation, poor water quality and anoxia.

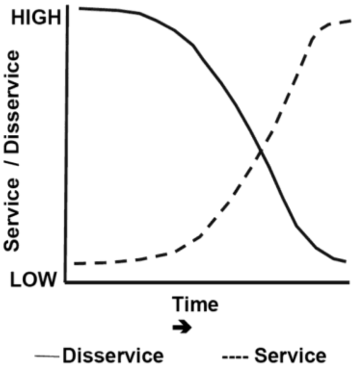

Figure 1. Conceptual model of desired change in services and disservices in response to habitat management intervention, such as rehabilitation, producing an increased level of service and accompanying decrease in disservice. Note that the high-level service and low-level disservice are maintained (i.e., are sustainable).

The aim is to shift the disservice from high to low and the services from low to high in response to management action. The shift should be sustainable over time, but not all management strategies deliver sustainability. By assessing the initial state of the wetland and identifying the nature of the disservice, attention can be focused on the functional aspect of the wetland that is to be altered and specific measures can be developed to determine success.

We illustrate three management scenarios (Figure 2) that relate specifically to mosquito disservice: A, direct control with no change to ecosystem function (currently the most common strategy), B, scenarios that achieve partial solutions and C, habitat modification that provides long-term mosquito control, plus improved wetland function.

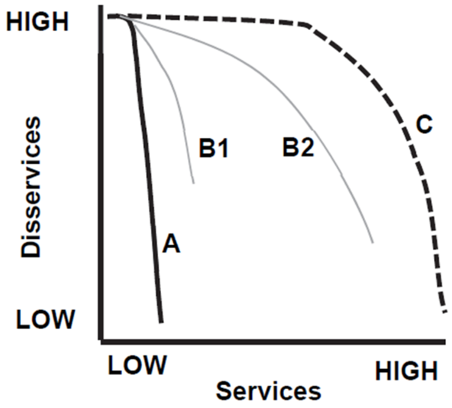

Figure 2. Impact of different management scenarios on ecosystem service/disservice provision. The starting point in all scenarios is a high level of disservice and a low level of service. Scenario A represents management of disservice (such as mosquito production) using chemical application without change to the ecosystem. Scenario B represents 2 intermediate strategies where constraints lead to different levels of disservice and service outcomes. Scenario C represents management of the disservice by undertaking a strategy of improving ecosystem functions that creates effective mosquito control after a threshold in ecosystem function is reached.

Scenario A (Line A, Figure 2) shows the consequence of managing the disservice directly but without managing the causal ecosystem function. For example, aerial application of chemicals to control the mosquitoes produces a sudden reduction in disservice but only a slight improvement in ecosystem services (an improvement in amenity and human health) without altering the ecosystem function that enables mosquito production. This is a temporary effect and must be repeated when mosquito numbers increase.

Scenario B (lines B1 and B2, Figure 2) depicts two outcomes which are suboptimal. B1 represents a scenario where there is neither significant mosquito control nor habitat improvement. B2 represents a scenario where habitat modification has produced partial service improvement and reduction in disservice. In these situations application of chemicals may be required to reduce the disservice to acceptable levels, with only a small amenity increase (as in line A) and this would be expensive.

Scenario C (Line C, Figure 2) shows an improvement in ecosystem function that precedes and causes a reduction of the disservice. This is because the improvement in ecosystem function modifies the system to reduce its suitability for mosquito production over the longer term. For example, a threshold in ecosystem function is reached (e.g., water quality improvement) after which the system can support a population of larvivorous fish sufficient to control mosquito production. This is a sustainable solution.

4. Integrating service and disservice management

Figure 3 illustrates the integration of the service/disservice management system. Problematic high levels of ecosystem disservices associated with low levels of ecosystem services (Stage 1 in Figure 3) may be ameliorated by a process involving science-based research, community capacity building and policy development (Stages 2–4) to yield best practice environmental outcomes (Stage 5). These are outcomes with high levels of ecosystem services and low levels of disservices. Thus, if ecosystem health is poor, as a result of environmental change or directly related to human activities, there may be low levels of ecosystem services (Stage 1). For example, there may be a scarcity of resources for fish (e.g., low Dissolved Oxygen (DO), impeded tidal-flooding—reducing frequency and duration) and, without fish, there may be high levels of mosquito larvae (which breathe through the surface of water via syphons and hence are not affected by low DO). Thus, the disservice level is high because of the low levels of ecosystem services needed by a predator.

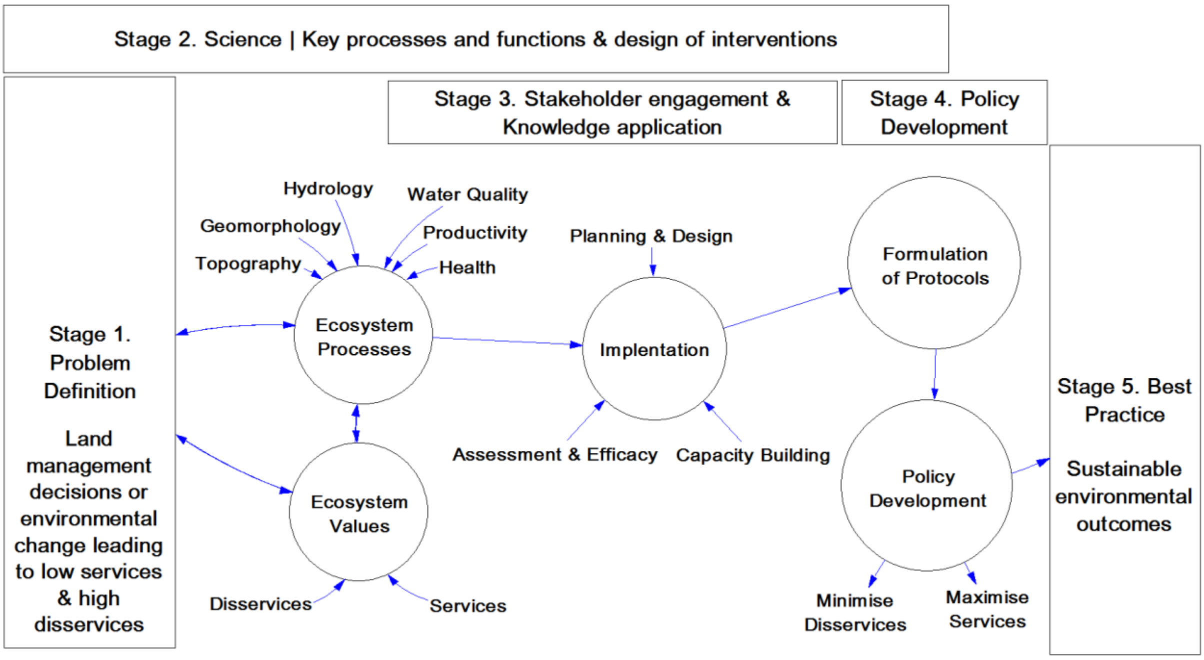

Figure 3. The five stage strategy focusing on integrated service and disservice objectives.

Implementing the concept through Stages 2–4 leads to the best management strategies (Stage 5). The science needs to be clearly articulated. To maximise the value from the science (Stage 2) there is a need to engage with a range of operational players (Stage 3). Stage 3 is especially important, as knowledge transfer must be tailored to the interest of the stakeholder, including local communities, politicians, and government agencies. This will allow the integration of existing data and of assessment practices to be undertaken routinely by agencies and regulators and, where appropriate, enhance processes for data collection to comply with scientific requirements.

Translating scientific evidence into policy (Stage 4) can be a difficult process because of disparate roles and changing agency responsibilities (see for example [26] referring to institutional fragmentation in coastal wetland management). Capacity building (Stage 3) will maximise the potential success of Stage 4.

5. Application of the model in a case study

This is an overview of how the model can be implemented for a mangrove system with low service and high disservice status. The example mangrove habitat modification was a site at Terranora in northern New South Wales, Australia (28°13.5′ S, 153°30.3′ E). Each stage, numbered in Figure 3, is addressed below.

Stage 1. Problem definition: Land Management

The mosquito related ecosystem disservice was recognised. The local human population was experiencing nuisance mosquito biting, and consequently was exposed to the risk of mosquito-borne diseases, such as Ross River virus [27]. Part of the problem related to local land management activities. The mangrove system had been impacted by recent development as well as by historical actions such as nearby ditch construction in the 1970s.

Stage 2. The science

The project commenced in 2009 with the objective of achieving outcomes with minimal impact on the mangrove system. A team, comprising local and state government and community stakeholders and scientists, was assembled to assess the issue. The research included mosquito larval surveys, fish surveys, detailed topographic mapping, modelling tidal dynamics and monitoring of water quality. As a result, it was found that the access to tidal water was restricted, particularly in the back basins areas, because there was a berm forming the seaward edge of the basin that blocked most tides except for very high tides. Consequently, water quality was found to be generally poor, highly acidic ($pH < 3$; Knight, unpublished data) and anoxic [28]. This meant that the ecosystem service that supported fish was largely suppressed and fish were rarely observed [29]. Thus, without predators, mosquito larvae could develop into flying adults to bite and potentially infect the nearby human population. The problem was understood.

The solution to the issue was to increase tidal access (both frequency and duration) to the problem areas (back basins). This would remedy the acid and anoxic conditions, provide physical access to fish and potentially reduce the mosquito larval populations. In turn, this would reduce the disservice while increasing the level of ecosystem service (Stage 5 in Figure 1).

In order to carry out the proposed habitat modification, there remained further stages in the process: to obtain community support by building capacity and trust; to negotiate the policy issues and secure permits; and to construct the modification. These are considered next.

Stage 3. Capacity building

Initially the team comprised five people including three local government mosquito control agency staff and two researchers. However, while researching the site, the need for additional skills and perspectives became apparent. State government agencies, additional researchers (fish ecologists), and representatives of the local fishing community were identified and invited to be involved in discussions and to participate in the research. The team expanded to 11 people with interests in addressing the mosquito hazard (i.e., minimising the disservice), and/or improving fishing (i.e., maximising the service). Site visits and meetings provided opportunities for questions and concerns to be discussed across all aspects of the project. It was a mutual learning experience and one that also built trust among the team members. Involvement across all aspects of the project maximised opportunities for team members to understand tasks, management objectives and outcomes from a range of perspectives. The project also included specific activities aimed at capacity building both within the team and in the broader community. Examples included: enhancing monitoring and data recording skills of the mosquito control team members (to include water quality monitoring); extensive discussions in-situ in the mangrove forest regarding ecology, hydrology and mosquito habitats; and public presentations to explain the research and potential benefits to local residents, environment groups and the fishing community.

Stage 4. Policy development

The site at Terranora is a wetland protected under the New South Wales State Environmental Planning Policy No 14—Coastal Wetlands (SEPP14). This has the potential to prevent any modification. However, the relevant State agencies were represented in the project team, and were involved in the field research. Therefore, they were able to understand that the proposed modification would enhance rather than diminish the value of the system. The agencies reviewed the application to modify the system, prior to submission, reducing the time between application and approval. Implementation of policy can be flexible. If ecosystem services could be enhanced and disservices suppressed, then this outcome is consistent with the policy. In the longer term, new policy may be developed specifically for this type of approach, (as was done for the salt marsh example referred to in section 2 above [24]).

Stage 5. Best practice sustainable environmental outcomes

The modification was carried out in August 2011, during winter, because of the lower mosquito hazard in that season. A small short channel was dug across the edge berm, by hand, to connect the tidal source to the system. Pools within the system were connected by similar channels or by pipes. The modifications enhanced the tidal flushing frequency and lengthened the duration of tidal connection. Early reports from the mosquito survey team (mosquito control at Tweed Shire Council) described finding relatively few larvae at the site. Since then the system has been monitored and mosquito numbers have remained much lower than those in other nearby and similar sites. This is also reflected in the reduced need for chemical treatments at the site—a reduction of >50% with cost savings and benefits to the environment by reduced input of larvicides. The works undertaken have been found to remain operational for 5 years with a scheduled maintenance program planned for 2017. A further benefit is that a wider application of the method is being explored for other mangrove areas with high levels of disservice and low levels of ecosystem services.

The process is adaptable. If the planned outcomes (Stage 5) had not been achieved, then the process would have returned to the initial land management and science stages (Stages 1 and 2) to assess what further actions might be needed in order to achieve the desired outcomes. If the modification had been unsuccessful the site could easily be restored to its original state, by filling in the small channels.

6. Discussion

Whereas ecosystem services provided by coastal wetlands are well recognised in both the research literature and policy, disservices generally have received relatively little attention [11]. This means that there is a risk that management actions, including rehabilitation to restore services, may inadvertently create or increase disservices [7]. The integrated conceptual model presented and exemplified has the potential to avoid this by including both services and disservices.

A basic decision relates to the availability and allocation of resources: time, money and in-kind contributions. For the Terranora project reported here, most of the value (estimated at $730K) was provided by in-kind contributions from several sources. These included personnel costs provided by Griffith University, Tweed Shire and New South Wales government agencies. The resources were spread over four years with most of that time being used for research into the mangrove ecosystem. Planning the intervention took some months and construction took just a few days. Post construction monitoring continues to be carried out regularly, mainly by Tweed Shire Council staff—a further in-kind contribution. Amounts of $20K, $10K, $40K and $58K were provided by the Mosquito and Arbovirus Research Committee, Tweed Shire Council, Griffith University and the NSW Recreational Fishing Trust, respectively. The money was used mainly for travel, analysis and equipment. Yet, the greatest challenge was in understanding the source of the problem and the factors contributing to it (the mosquito habitat), which became the basis for developing the modification.

While the conceptual approach and its application have the potential to provide benefits to both the environment and to society there may be some barriers. These include institutional inertia (reluctance to change), fear of the unknown, concern over the impact on the environment, and about compliance with environmental regulations. Capacity building has the potential to minimise these barriers, particularly when there is collaboration between researchers, community and regulators [30].

There are also opportunities. Many areas close to human settlement have been directly and indirectly impacted by development activities and restoring these areas can bring back ecosystem services. However, unless disservices are also included in any restoration strategy, the success of rehabilitation may be jeopardised. It may not gain initial public approval at all.

The application of the concept to an established case study demonstrated that the concept is useful: it showed that habitat modification satisfied the dual objective of mitigating development impacts as well as reducing the mosquito problem. The mosquito problem was managed, using ecosystem processes, to create conditions that disrupt the mosquito's lifecycle. Rehabilitating the wetland ecosystem to improve services required an understanding of the range of the ecosystem processes involved in producing the service/s of interest. The strategy that achieved both objectives had to deal with the added complexity of integrating the two sets of processes. This was the five-stage implementation strategy shown in Figure 3. It begins with articulation of the problem, and steps through science, engagement, policy development and concludes with articulation of best practice methodology.

One important outcome of the application to the case study was to identify, for future use, the criteria for assessing whether habitat modification is a suitable method to minimise disservice while also sustaining or enhancing service in mangroves near human settlement, including:

- The mangrove system is providing ecosystem disservices, e.g., mosquitoes, odour
- The mangrove system is providing poor ecosystem services, e.g., sparse fish or other organisms, poor water quality (low pH; low DO)

- The reasons for the disservice and poor services have been established, e.g., legacy infrastructure associated with early rural or urban development; recent infrastructure associated with urban development; changes to hydrology related to development or sea level changes
- Modification is physically feasible and is legally permissible.

Future development of the concept would benefit from some objective quantification of the service/disservice to be managed in order to evaluate change and ultimately success or failure. Monitoring is essential to determine the level of success (or failure). In the conceptual models we defined the level of services and disservices qualitatively (low to high) but, when the models are applied, the appropriate measurements need to be adopted. For the example used here water quality is assessed using dissolved oxygen, pH and tidal connectivity, while mosquito production is assessed by standardized mosquito larval counts. For other service and disservice functions other measures would be needed.

7. Conclusion

We presented a conceptual model that integrates management of both service and disservice. The key objective was to improve services and to reduce disservices. The implementation strategy allows for recognition that the relative levels of service and disservice change. These should be monitored so that an objective assessment of success and failure is possible. It is critical that both service and disservice are considered in decision-making to achieve improved management. Application of the model in a mangrove forest known to produce mosquitoes demonstrated its benefits, resulting in improved service and reduced disservice

Implementing the approach outlined in the conceptual model can achieve important integrated policy outcomes by engaging scientists, practitioners and policy makers across all stages of the research. Inclusive engagement produced deep collaboration that fostered agreement and understanding for all in the team.

Finally, the conceptual model has provided best practice outcomes in the case study presented and this supports the recommendation that the approach would be appropriate and feasible to apply in other problem ecosystems.

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Conflict of interest

The authors declare there is no conflict of interest.

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