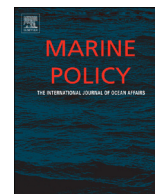




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Revealing complex social-ecological interactions through participatory modeling to support ecosystem-based management in Hawai'i



Rebecca J. Ingram^{a,c,*}, Kirsten L.L. Oleson^b, Jamison M. Gove^c

^a Joint Institute for Marine and Atmospheric Research, University of Hawai'i at Mānoa, 1000 Pope Road, Marine Sciences Building 312, Honolulu, HI 96822, USA

^b Department of Natural Resources and Environmental Management, University of Hawai'i at Mānoa, 1910 East-West Road, Sherman Laboratory 101, Honolulu, HI 96822, USA

^c Ecosystem Sciences Division, Pacific Islands Fisheries Science Center, 1845 Wasp Boulevard, Building 176, Honolulu, HI 96816, USA

ABSTRACT

The Hawaiian Islands are home to a complex and dynamic marine ecosystem that serves as a backbone to the state's economy and society's well-being. The marine ecosystem currently faces numerous threats that undermine ecosystem integrity and compromise socially valuable ecosystem services. The socio-economic and ecological complexity of the region invokes a clear need for ecosystem-based management (EBM) strategies. To support EBM development, participatory methods were used to gather expert and place-based knowledge from resource managers, scientists, and community members. Methods elicited local values, fostered diverse relationships, and increased community engagement in resource management. Using information collected, Conceptual ecosystem models were developed guided by the Driver-Pressure-State-Impact-Response framework that identify and quantify the strength of socio-economic and ecological interactions. The resulting models illustrate the complexity of system dynamics, highlighting connectivity between pressures and the ecosystem, with direct implications for ecosystem services. Importantly, many identified pressures occur at the local scale, presenting an opportunity for local resource management to directly affect ecosystem status. This study also found that many of the strongly impacted ecosystem services were cultural ecosystem services, which are critical to human well-being but lack integration into resource management. These models support an Integrated Ecosystem Assessment of the region by informing ecosystem-based strategies, facilitating the selection of ecosystem monitoring indicators, and emphasizing human dimensions.

1. Introduction

Society is inseparable from marine ecosystems [1], relying on numerous ecosystem services and benefits generated through complex social-ecological system interactions [2,3]. Despite this reliance, human activities such as overfishing, land-based pollution, and greenhouse gas emissions have degraded marine ecosystems globally [4–7], threatening food security, human health, and livelihoods.

Marine ecosystems in Hawai'i contribute substantially to the economy and to society's well-being [8–10]. In 2015 alone, commercial and recreational fisheries grossed \$933 million in sales (including direct sales of fish and sales related to fishing activity) [11]. In Hawai'i, tourism is the largest industry, generating \$15 billion dollars annually, and a significant portion of visitor activity is marine-based [12]. In addition to the marine ecosystem's contribution to the market economy, residents and tourists alike depend heavily on coral reefs in Hawai'i for coastline protection, medicinal properties, and research and educational opportunities [10].

Marine ecosystems in Hawai'i also play a significant role in sustaining culture, tradition, and social practices that are critical to human well-being [13]. While many definitions of human well-being exist, the Millennium Ecosystem Assessment defines human well-being as having access to necessary basic materials (e.g., food and water), human health, social relationships, a safe and secure environment, and freedom. This definition was also used to examine human well-being within marine social-ecological systems [8].

The societal dependence on the marine ecosystem in Hawai'i makes recent declines in ecosystem status all the more alarming. The condition of coral reefs and fish populations in Hawai'i has deteriorated over the past two decades [10,14]. Impacts of global climate change, including sea surface temperature rise, have led to back-to-back coral reef bleaching events in recent years [15]. Exacerbating these global stressors, a rapidly growing population is increasing coastal development, runoff, marine debris, and damaging forms of recreation (e.g., trampling of reefs) [10,16]. The societal importance of marine ecosystems in

* Corresponding author at: NOAA IRC NMFS/PIFSC/ESD 1845 Wasp Blvd, Building 176 Honolulu, HI 96818, USA.

E-mail addresses: ingram@hawaii.edu (R.J. Ingram), koleson@hawaii.edu (K.L.L. Oleson), jamison.gove@noaa.gov (J.M. Gove).

Hawai'i, combined with threats of further degradation, creates a clear need for effective management strategies.

Marine resource management has historically focused on individual species or sectors, rather than ecosystems as a whole [17,18]. While an important piece of the process, focusing solely on one species/sector ignores other potentially affected aspects of the ecosystem, which can lead to system collapses and non-ideal management outcomes [19]. By contrast, Ecosystem-Based Management (EBM) is a holistic strategy seeking to understand the temporally and contextually fluid connections within a social-ecological system [20]. Understanding and describing these connections is fundamental to resource management [17,21], yet most studies do an inadequate job [8].

Understanding how society benefits from and ultimately influences ecosystem services is central to EBM [1,22]. This study defines ecosystem services as the goods and benefits that people obtain from an ecosystem and the associated values and beliefs assigned by people to each service [23,24]. Ecosystem services are traditionally divided into categories: provisioning (i.e., materials provided by ecosystems), regulating (i.e., regulation of natural processes), supporting (i.e., supports production/maintenance of all other services), and cultural (i.e., non-material benefits or values) [3,25]. Services derived from ecosystems are numerous and complex, and a given good or service may cross categories and represent multiple values [26]. For example, in Hawai'i, fishing is not only a means for income and subsistence, but also holds immense socio-cultural value related to traditional practices and cultural heritage [8].

Despite their importance to human well-being, ecosystem services are not widely accounted for in management strategies [27], partially due to limited understanding of the social-ecological relationships that both produce and limit them [23]. This omission is especially true for cultural ecosystem services, likely due to a combination of factors, including their intangible nature, the propensity for individuals to ascribe values differently, and the difficulty or appropriateness in assigning monetary value [26,28]. Perhaps due to their recognized significance, cultural services are a stated management responsibility in Hawai'i [29], yet there are few existing management policies in place to conserve or protect them [30].

Although a wide acknowledgement of the need for EBM exists, transitioning from theory to practice has been slow [20]. Many challenges restrict implementation of EBM, including limited data availability, conflicting governing agencies, and timeline or financial restraints [31]. While limited, successful examples of EBM begin by employing participatory methods to build a consensus of complex social and ecological system structure and function [19,31–33].

EBM has not been widely adopted in Hawai'i; however, coastal resource managers across the state of Hawai'i recently identified whole ecosystems (as opposed to individual species or habitats) and culturally important resources as their primary management responsibilities [29]. Nevertheless, few federal, state, or local EBM policies exist that support this more holistic management approach [34]. This study responded to the need for EBM in Hawai'i with a participatory process that identified social-ecological connections along the west coast of Hawai'i Island. Through an investigation of how human activities are affecting the nearshore marine ecosystem and how society benefits from that region, participants identified key pressures that influence both the ecosystem state and ecosystem services.

1.1. Using conceptual ecosystem models within an Integrated Ecosystem Assessment

The National Oceanic and Atmospheric Administration developed the Integrated Ecosystem Assessment (IEA) Program to inform and facilitate EBM [22]. IEAs commonly use conceptual ecosystem models (CEMs), a method of diagramming social-ecological system elements, to discover, integrate, and communicate relationships that exist amongst

habitats, species, and social aspects of a system [18,35]. CEMs identify knowledge gaps, inform research needs, and represent a hypothesis of system structure and processes [36,37].

CEMs benefit from participatory methods, such as collaborative workshops with scientists, resource managers, and community members [21]. Participatory methods have multiple advantages: they capture place-based knowledge, incorporate regionally specific needs, build community trust in management programs, and build social cohesion [37–39]. Participatory methods also render the decision-making process more democratic [39].

CEMs are frequently structured using the Driver-Pressure-State-Impact-Response (DPSIR) framework [18,21,33,40–42]. DPSIR is valuable in identifying cause-and-effect relationships between society and the ecosystem [43,44], and joining scientific and place-based knowledge [45]. DPSIR can also integrate information regarding intensities of identified relationships [18,46,47]. Many variations of the framework exist. In this study, *Drivers* are natural or societal events that create *Pressures* on the ecosystem's *State*, leading to *Impacts* in ecosystem service delivery that may generate a *Response* from society or management [18,40].

2. Methods

2.1. Study Site: West Hawai'i Island

The west coast of Hawai'i Island, commonly referred to as West Hawai'i (Fig. 1), is home to an ecologically dynamic nearshore marine ecosystem with a diverse assemblage of species [48]. The productivity of the region provides socio-economic value to residents through numerous ecosystem services, such as commercial, recreational, and subsistence fishing, as well as intangible services, such as cultural and traditional practices [13]. However, coral and fish communities across the region have suffered recent declines [10,49,50] suggesting deteriorating underlying ecosystem functions and processes [48]. A rapidly growing population, coastal development, marine-based tourism, and land-based pollution are partially to blame for the recent changes in marine ecosystem status [51–54]. Adding to these local impacts are the effects of global climate change. For example, elevated ocean temperatures in 2014 and 2015 led to the most destructive coral reef bleaching event ever recorded in this region [55,56]. Ultimately, these threats compromise the ability of the marine ecosystem to provide the numerous goods, services, and benefits that society depends upon for its well-being [13].

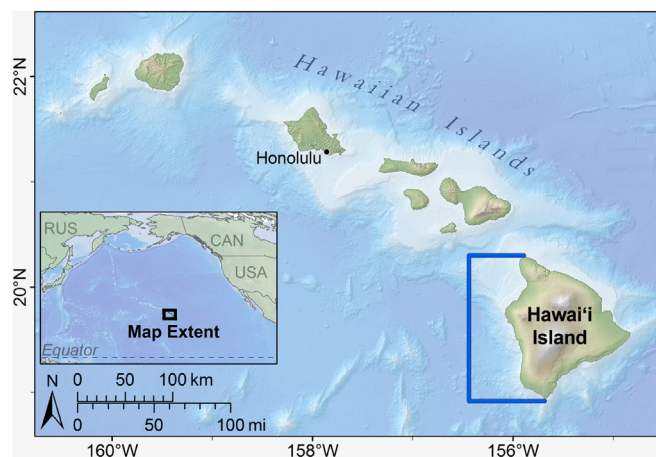


Fig. 1. Map of Hawai'i Island within the Main Hawaiian Islands. The geographic boundary of the West Hawai'i IEA are demarcated in blue.

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