Science of the Total Environment 534 (2015) 97–109

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Unravelling complexity in seagrass systems for management: Australia as a microcosm

Kieryn Kilminster [a,*], Kathryn McMahon [b], Michelle Waycott [c,d], Gary A. Kendrick [e], Peter Scanes [f], Len McKenzie [g], Katherine R. O'Brien [h], Mitchell Lyons [i], Angus Ferguson [f], Paul Maxwell [h,j], Tim Glasby [k], James Udy [j]

[a] WA Department of Water, PO Box K822, Perth, WA 6842, Australia
[b] School of Natural Sciences and Centre for Marine Ecosystems Research, Edith Cowan University, WA 6027, Australia
[c] University of Adelaide, Adelaide SA 5005, Australia
[d] Plant Biodiversity Centre, Department of Environment and Natural Resources, Adelaide, SA, Australia
[e] The Oceans Institute (M470) and School of Plant Biology, The University of Western Australia, 35 Stirling Highway Crawley, WA 6009, Australia
[f] NSW Office of Environment and Heritage, PO Box A290, Sydney South, NSW 1232, Australia
[g] Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER), James Cook University, Cairns, QLD 4870, Australia
[h] School of Chemical Engineering, University of Queensland, St Lucia, QLD 4072, Australia
[i] Centre for Ecosystem Science, School of Biological, Earth and Environmental Sciences, University of New South Wales, NSW, Australia
[j] Healthy Waterways, PO Box 13086 George St, Brisbane QLD 4003, Australia
[k] NSW Department of Primary Industries, Fisheries NSW, Locked Bag 1, Nelson Bay, NSW, 2315, Australia

HIGHLIGHTS

- Management requires understanding of seagrass life history, habitat and meadow form.
- These three attributes assist our understanding of seagrass response to disturbance.
- A new classification of transitory or enduring meadows informs monitoring and policy.
- Past management has historically focused on enduring seagrass meadows.
- This transdisciplinary synthesis supports monitoring, management and policy.

ARTICLE INFO

Article history:
Received 30 September 2014
Received in revised form 15 April 2015
Accepted 15 April 2015
Available online 25 April 2015

Keywords:
Life-history
Transitory
Monitoring
Decision-making
Environmental management
Policy
Seagrasses

ABSTRACT

Environmental decision-making applies transdisciplinary knowledge to deliver optimal outcomes. Here we synthesise various aspects of seagrass ecology to aid environmental decision-making, management and policy. Managers often mediate conflicting values and opinions held by different stakeholders. Critical to this role is understanding the drivers for change, effects of management actions and societal benefits. We use the diversity of seagrass habitats in Australia to demonstrate that knowledge from numerous fields is required to understand seagrass condition and resilience. Managers are often time poor and need access to synthesised assessments, commonly referred to as narratives. However, there is no single narrative for management of seagrass habitats in Australia, due to the diversity of seagrass meadows and dominant pressures. To assist the manager, we developed a classification structure based on attributes of seagrass life history, habitat and meadow form. Seagrass communities are formed from species whose life history strategies can be described as colonising, opportunistic or persistent. They occupy habitats defined by the range and variability of their abiotic environment. This results in seagrass meadows that are either transitory or enduring. Transitory meadows may come and go and able to re-establish from complete loss through sexual reproduction. Enduring meadows may fluctuate in biomass but maintain a presence by resisting pressures across multiple scales. This contrast reflects the interaction between the spatial and temporal aspects of species life history and habitat variability. Most management and monitoring strategies in place today favour enduring seagrasses. We adopt a functional classification of seagrass habitats based on modes of resilience to inform management for all seagrass communities. These concepts have world-wide relevance as the Australian case-studies have many analogues throughout the world. Additionally, the approach used to classify primary scientific knowledge into synthesised categories to aid management has value for many other disciplines interfacing with environmental decision-making.

* Corresponding author.
E-mail address: kieryn.kilminster@water.wa.gov.au (K. Kilminster).

http://dx.doi.org/10.1016/j.scitotenv.2015.04.061

1. Introduction

Informed environmental decision-making requires the decision maker to combine scientific understanding with cultural and societal values to prioritise actions which may deliver the desired outcome. For scientific knowledge to be an influential component of environmental decision-making it needs to be communicated in a useable context that provides relevant knowledge on biophysical processes and likely effects on community values (Dietz, 2013). Decisions are made every day and often on very short timelines. An additional challenge is that the time frame in which managers and politicians make decisions is often much faster than the rate at which identified knowledge gaps can be filled, so decisions are frequently made with incomplete information. Full integration of current scientific understanding into the decision-making process is also hampered by people's capacity to absorb, comprehend and then apply large quantities of new information during the process (Lupia, 2013).

To assist environmental decision-making, there is an urgent need to synthesise current knowledge of environmental processes and effects of past management actions across multiple disciplines, into an easily accessible and understandable format that can be applied during decision-making processes (de Bruin and Bostrom, 2013). Information should address the three main components of decision-making: (i) understanding the science, (ii) addressing community values, and (iii) understanding the effect that various decisions will have on the ecosystem and its ability to meet community values in the future (Dietz, 2013). Each of these components has inherent variability and uncertainty that cross multiple disciplines. Good decisions require a multi- and trans-disciplinary approach to provide coherent synthesis both within and across these components.

The goal of our analysis is to synthesise existing understanding of seagrass ecosystems into a framework which managers can apply during common decision-making scenarios relating to monitoring and policy development. Despite the recognised ecological and economic role of seagrasses as a critical coastal habitat providing many ecosystem services to support health and wellbeing of coastal communities (Barbier et al., 2011; Costanza et al., 1997), seagrass meadows are continuing to decline at an accelerating rate internationally (Short et al., 2011; Waycott et al., 2009). This points to: (i) a failure of scientists to effectively engage with government and/or the community leading to other activities being prioritised higher than the protection and preservation of seagrass habitat, (ii) an inability of managers to act at the appropriate spatial or temporal scale, or (iii) that decision makers do not understand the consequences of their cumulative actions on seagrass. These issues of competing pressures in complex systems are not unique to seagrass ecosystems; rather they are common, or even close to ubiquitous, across environmental decision-making.

Environmental management should seek to characterize the aspects of a system that contribute to the resilience of that system (Benson and Garmestani, 2011). We aim to aid the decision makers' understanding of seagrass resilience allowing for appropriate monitoring and management to be undertaken (note, we define ecological resilience as the capacity of a system to maintain function in the face of disturbance, which includes the ability to resist and recover (Bernhardt and Leslie, 2013; Folke et al., 2004)). In doing so, we address the first component of decision-making ‘understanding the science’. In the context of seagrasses, it is necessary to draw on knowledge from multiple biophysical sciences to explain the interaction of hydrology, pollution and disturbance processes and the influence these have on seagrass life cycles, including reproductive strategies and physiological tolerance. Individual research projects are often designed to focus on one or two of these aspects, but rarely encapsulate information across all disciplines that is required to understand causal relationships. For this paper, scientists and environmental managers (with different experience and discipline expertise) created a conceptual classification of seagrass ecology, identifying three critical attributes which contribute to seagrass functional resilience. The value of this classification for management is explored as it relates to monitoring and policy in Australia. The classification of knowledge in this way aims to bridge the gap between scientists who desire to understand the system better and managers who need to make informed decisions.

2. Functional classification based on mode of resilience

Classification of seagrass knowledge, which is considered important for the development of appropriate management strategies and to inform policy, exemplifies a transdisciplinary approach. ‘Seagrasses’ are a ‘biological group’ rather than a single evolutionary lineage or natural group (cf. Arber, 1920; den Hartog, 1970; Les et al., 1997; Sculthorpe, 1967). Debate still occurs as to which species qualify for inclusion as seagrasses, however for the purposes of this paper we take a pragmatic approach including both *Ruppia* and *Lepilaena* (as they are common in Australian estuaries). The 72 species of seagrass currently recognised (Short et al., 2011) belong to four independent evolutionary lineages (Les et al., 1997). The origins of these lineages are ancient, estimated to be more than 65 million years old and among the oldest divergence times within the aquatic monocotyledon order Alismatales (Janssen and Bremer, 2004). The ancient evolutionary origins give rise to variability in a range of traits across lineages (e.g. Kendrick et al., 2012; Waycott et al., 2006), however a lack of species diversity across lineages, despite their ancient origins, reflects the extremity of adaptation required to survive the marine environment (Les et al., 1997).

The ecological breadth among living seagrass groups is evident given the extraordinary evolutionary success of these plants, surviving across the globe in virtually every habitat they might occupy. As such, seagrasses employ different modes of resilience to resist or recover from environmental or stochastic pressures, which means that management of this diverse group requires more than a single approach. We propose that there are three critical attributes that affect the resilience of seagrasses: (i) seagrass life history, (ii) meadow form, and (iii) physical habitat. Further, the combination of these attributes will inform the monitoring and policy required for effective management.

2.1. Attribute 1: seagrass life history

Life-history traits of seagrasses enable a functional classification at the individual species level, which varies substantially among species. This variability has been grouped previously in a number of ways (e.g. Carruthers et al., 2002, 2007; Collier and Waycott, 2009; Walker et al., 1999; Waycott et al., 2011), and here we adopt a form-function model for seagrasses that explicitly seeks to group species by their response to disturbances (Fig. 1). Broadly, we categorise species as having either persistent or colonising traits based on their ability to resist or recover, and species with a mixture of those traits are categorised as opportunistic. In general, we suggest seagrass species have a high level of concordance in growth form and reproduction within genera as presented by Walker et al. (1999). There is also much in common with these models and the traditional r–K model of species life-history traits sensu MacArthur and Wilson (1967) or the C–S–R model adapted for plants of Grime (1979). The r–K model categorises species into two groups primarily based on size of organism, life expectancy and reproductive characteristics, whereas the C–S–R model categorises into three groups primarily based on the interaction of resources and disturbance.

Our model uses three categories based on consideration of growth forms and reproductive strategies that may contribute to resilience. Seagrasses are monocotyledons that grow following a simple modular pattern (den Hartog, 1970; Duarte et al., 1994; Tomlinson, 1974). Individual plants expand their occupancy of space by the extension of rhizomes, with shoots arising from meristems on the rhizome and roots anchoring the plants (Duarte et al., 1994). This modularity enables growth units (rhizome, shoot and root i.e. the ramets) to become independent from each other, thus forming clonal entities (Arnaud-Haond