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# Spatial vulnerability assessment of anchor damage within the Great Barrier Reef World Heritage Area, Australia

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ABSTRACT

The coral reefs and seagrass habitats in the Great Barrier Reef World Heritage Area (GBRWHA) are vulnerable to physical disturbances, including the anchoring of vessels. Both the anchor being deployed and retrieved, as well as the movement of the attaching rode, can cause damage to corals and seagrasses. Understanding the contributing processes that influence the deployment of anchors can assist with managing anchor damage in the GBRWHA, particularly in the context of climate change. Providing a spatial description of the vulnerability, rather than just a list of factors, requires the incorporation of social, geophysical and ecological factors. An integrated GIS-Bayesian Belief Network was utilised to combine 19 spatial datasets, 6 spatial models and expert opinion. The base scale was set to match the 250 m lattice interval of the Great Barrier Reef digital elevation model. With approximately 5 million data points the model was able to spatially describe the likelihood of damage from anchor deployment across the GBRWHA. While only 19% of the GBRWHA is considered susceptible to anchor damage, the assessment indicates that coral reefs and seagrass meadows adjacent to population centres and in particular close to islands are highly vulnerable. Comparisons with coral reef health surveys (Eye on the Reef Program) and detailed anchorage records from a scientific research vessel indicate the model is robust despite extensive use of disparate spatial data and expert opinion. The effect of each node in the Bayesian Belief Network on the anchor vulnerability beliefs was measured by standard variance reduction and this found that anchor site familiarity and accessibility were the dominant influences aside from the presence of sensitive habitat. Visualisation of the model outputs, including the intermediate stages, provided additional qualitative evaluation. Enhancing the vulnerability assessment to describe every location in the GBRWHA will contribute to the development of policy and governance mechanisms whilst supporting focused monitoring of sites vulnerable to anchor damage.



## 1. Introduction

Australia's Great Barrier Reef (GBR) Region is defined in the *Great Barrier Reef Marine Park Act 1975*, and covers an area of approximately 346 000 $km^2$. This huge expanse of ocean and reefs stretches some 2 300 km along the eastern Australian coast, from the tip of Cape York in the north to past Lady Elliot Island in the south (Day and Dobbs, 2013). The Great Barrier Reef World Heritage Area (GBRWHA) is an iconic symbol of marine biodiversity and includes over 2 900 coral reefs with an area of approximately 20 000 $km^2$ and an estimated 1 741 $km^2$ of seagrass meadows (Johnson and Marshall, 2007). The Great Barrier Reef Marine Park is a multiple-use marine park in which zoning provides one of the key management tools. The multiple-use zoning approach, implemented by Great Barrier Reef Marine Park Authority (GBRMPA), provides for the separation of conflicting uses while allowing a wide range of commercial and recreational activities. In 1981, the Great Barrier Reef was listed as a UNESCO World Heritage Area, with the Commonwealth Marine Park covering 99% of the World Heritage Area and the remaining area is under State jurisdiction.

The GBRWHA is vulnerable to a range of environmental and anthropogenic pressures (Vella et al., 2012; Wakeford et al., 2007). Climate change alone is forecast to increase the average intensity of tropical cyclones over the rest of this century (De'ath et al., 2012) and change the acidity of the oceans (Veron, 2008). Increasingly full recovery from disturbance is taking longer as destructive events increase in intensity and frequency (Graham et al., 2011; Roff and Mumby, 2012).

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Consequently the GBRWHA is showing signs of reduced health through measures such as coral cover decline (De'ath et al., 2012, 2009) and loss of seagrass meadows (Coles et al., 2012). Additionally, repeated small scale disturbances, such as anchoring, can alter resilience to perturbations for a localised area (Walker et al., 2004), especially if recovery is limited (Beeden et al., 2014; Ceccherelli et al., 2007; Jaap, 2000; Stachowitsch, 2006). Stressors like poor water quality and physical damage due to anchoring and/or divers and snorkelers (McManus et al., 1997) also have the potential to increase the competitive advantage of macroalgae and hence reduce recovery rates.

Widely reported damage from anchoring raised concern about the impact of tourism in the Great Barrier Reef in the 1990s (GBRMPA, 2009). Anchoring of both tourist and recreational boats can be a significant local issue in heavily visited sites (Brodie and Waterhouse, 2012). Pathogen virulence and coral disease susceptibility can also increase as a consequence of the disturbance (Heron et al., 2012). For example, physical damage to corals may allow ciliates to become established, which could lead to skeletal eroding band lesions (Page and Willis, 2007).

In this paper, the definition of anchoring is considered to be the short-term deployment of a physical device to hold fast to the substrate by a vessel. Any damage resulting from anchoring is regarded as being caused by both the anchor being deployed and retrieved as well as the movement of the attaching rode (Walker et al., 2012). Internationally, the significant impact of anchoring in high use zones has been reported (Backhurst and Cole, 2000; Davis, 1977; Diedrich et al., 2013; Hendriks et al., 2013; Rogers and Garrison, 2001; Walker et al., 2012). With inshore reefs and seagrass meadows in serious decline from land based pollutants, and climate change impacting on the general reef system (Hughes et al., 2003), the potential increase in boat-associated impacts is a cause for concern. Boat ownership is increasing along Queensland coastal communities. For example, in Townsville there was an increase in boat numbers (in the class of 4.5–18 m) from 1 953 in 2001 to 3 919 in 2010 (Queensland Department of Transport and Main Roads, 2011). During development of the draft Commonwealth Strategic Assessment of the Great Barrier Reef Region (GBRMPA, 2013), workshop participants raised the need for better understanding of the changing recreational sector, in particular the growing number of new recreational users as a result of the mining boom and suggested future management actions included more Reef Protection Markers (RPMs) and moorings, as well as increased education.

The 2009 Outlook Report (GBRMPA, 2009) assessed the general threat of anchoring on coral by small vessels as an 'almost certain' likelihood but a medium risk with a minor consequence. The likelihood of anchor damage across the entire GBRWHA has not been described previously and hence management actions have been based on a case-by-case basis in regions of high vessel use (Dinsdale and Harriott, 2004). GBRMPA and the Queensland Parks and Wildlife Service (QPWS) implemented a system of RPMs in combination with public moorings in the mid 1990's in high use areas in the marine park, i.e. in the Cairns, Whitsunday and Hinchinbrook areas (Great Barrier Reef Marine Park Authority, 2002) and GBRMPA have developed "Responsible Reef Practices for Anchoring" to support this program (http://www.gbrmpa.gov.au/visit-the-reef/responsible-reef-practices). A comprehensive approach to describing the likelihood of anchor damage for the whole of the GBRWHA can be utilised within the broader framework of managing for climate change resilience.

The GBRMPA has a range of projects in progress to operationalise resilience theory to support the future of the GBRWHA under a changing climate (GBRMPA, 2012; Johnson and Marshall, 2007). A vulnerability framework that considers the threatening processes, in the context of a sensitivity analysis, can assist the prioritisation of on-ground actions. While many threatening processes, such as cyclones, are difficult to mitigate, physical damage to coral reefs by human activities such as dredging, ship grounding and anchoring can be managed effectively (Schmahl, 2012; Walker et al., 2012).

Marine managers on the Great Barrier Reef (GBR) are required to develop strategies for reducing impacts on species and habitats. However, given the vast extent of the GBRWHA, assessing the spatial distribution of the vulnerability to anchor damage is inherently a difficult exercise due to the complexity of the marine environment, the intangible social components and the lack of robust empirical data. The GBRWHA has over 2 900 mapped reefs and a high likelihood of many deeper submerged reefs, each with considerable intricacy, shaped by localised and regional forces (Bridge and Guinotte, 2013; Johnson and Marshall, 2007). Attempting to accurately describe the physical structures at the scale of a boat anchoring, such as a coral bommie, is futile except for highly focused sites such as tourism dive locations. GBRWHA-wide assessments can only hope to present a range of probabilities for a given vulnerability for any specific location.

Vulnerability assessments that involve social and environmental factors are particularly complex (Ban et al., 2013; Measham and Preston, 2012). Targeted impact assessments of commercial activities such as trawling, tourist operations and fishing have been based on industry-supplied records often obtained through mandatory reporting requirements. For an anchor damage vulnerability assessment, which is based on the diverse array of social components linked closely to the environmental constraints, a more comprehensive approach is required. In particular, a modelling framework that can combine geophysical, ecological, and social components to produce anchor vulnerability likelihood for each location will be essential (Stelzenmüller et al., 2010).

The social component, of where and how private vessels may anchor, is a complex array of variables including site attractiveness, safety considerations, comfort concerns, familiarity and accessibility. The personal attitude of the skipper will determine the final location of any single anchor and the subsequent potential disturbance to the benthos. For instance, commercial shipping, outside of the General Use Zone and the Designated Shipping Areas, is subject to restrictions regarding where and how they may anchor by GBRMPA and Maritime Safety Queensland through a marine parks permit process. However, for the majority of the GBRWHA, the recreational skipper has the final say on the exact location of any anchorage if no other legislative considerations apply.

Basing the vulnerability assessment simply on observed instances of anchor damage is also problematic. The lack of a focused study on the anchoring habits and locality preferences of recreational and commercial vessels has prevented a historical assessment of any value (however see Dinsdale and Harriott, 2004). As a consequence, systematic evidence of anchor damage has required the use of spatial information that was not primarily collected for this purpose and hence remains limited in the quality of information able to be extracted. Examples include Reef Health Impact Surveys (RHIS) that have been, in general, too shallow and focused on the reef edge and yet, during 2009–2012, over 50 observations of coral colony damage from anchoring activity were reported (http://www.gbrmpa.gov.au/about-the-reef/how-the-reefs-managed/eye-on-the-reef). A lack of robust data on the motivational attitudes of skippers regarding anchorage selection further hinders the quality of assessment. This is exemplified in the Outlook Report 2009 (GBRMPA, 2009) which states 'Given the distribution of boat ownership and the size of vessels owned, any impacts are predicted to be principally in inshore areas close to major regional centres'. A desktop study indicated that the ship anchorages associated with the five major ports in the GBRWHA are generally located in open seabed systems and anchor drop or chain