IMPACTS OF RECREATIONAL BOATING ACTIVITIES ON THE SEAGRASS *POSIDONIA* IN SE AUSTRALIA.

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ABSTRACT

In SE Australia, the seagrass *Posidonia australis* is mostly restricted to isolated populations in estuaries and bays, and meadows in Sydney metropolitan estuaries have recently been listed by the NSW Government as threatened with extinction. While large developments impacting on seagrasses are now mostly controlled by environmental legislation, small-scale impacts remain and can lead to fragmentation across large areas. Here, damage to *Posidonia* meadows caused by boat moorings, propeller scouring and related recreational boating activities has been investigated using easily accessed aerial photography. While individual impacts were often small, in some locations large areas were affected and significant fragmentation of the seagrass landscape was observed and suggests urgent management action is required. The widespread availability of remote sensed data through tools such as Google Earth (©) should lead to greater community awareness of local changes in seagrassses meadows and could be used to improve the management of these smaller scale impacts.

INTRODUCTION

There is very little mention of the biology or ecology of the seagrass *Posidonia australis* Hook. f. (hereafter *Posidonia*; see Figure 1) along the east coast of Australia prior to the 1950s, which is surprising given the distribution and dominance of this species in major waterways, including the large lakes and embayments around Sydney (e.g., Lake Macquarie, Brisbane Waters, Pittwater, Sydney Harbour, Botany Bay and Port Hacking). When E.J.F. Wood (Ferguson-Wood 1959) presented a review of the biology of the seagrasses in eastern Australia in the late 1950s, his treatment was restricted to a description of *Posidonia* meadows at selected locations (Port Stephens, Botany Bay, Port Hacking, St Georges Basin and Merimbula Lake) and the seasonal occurrence of various species of epiphytes.

Figure 1: The seagrass *Posidonia australis*, showing the fruit.

Interestingly, he considered that the species was faster growing and more robust than the seagrass *Zostera* (used here to include *Zostera capricorni* Asch., *Zostera muelleri* Irmisch ex Asch. and

Heterozostera tasmanica (G.Martens ex Asch.)), and more able to withstand anthropogenic impacts. It is now known that *Posidonia* inhabits protected waters across southern Australia, between Wallis Lake (NSW) on the east coast and Shark Bay (WA) on the west coast, and occupies very large areas (>1000 ha) in Western Australia and South Australia (Larkum and McComb, 1989). In NSW, *Posidonia* is mostly restricted to relatively shallow waters (<10m) in enclosed bays and marine-dominated coastal lakes and rivers (West *et al.,* 1989).

Ferguson-Wood's original assessment of the resilience of *Posidonia* has not proven to be correct, and large-scale declines in distribution of the species were recorded at many locations around Australia in the 1970s and 80s due to anthropogenic impacts, such as eutrophication and physical damage (e.g., see Shepherd *et al.*, 1989). While the plant appears robust and is highly productive in terms of leaf growth (Kirkman and Reid 1979; West and Larkum 1979), like its Mediterranean cousin *Posidonia oceanica* (L.) Delile (Marba *et al.*, 1996), the Australian species has a long life history (i.e., from seed to mature plant) and the establishment of large meadows appears to depend primarily on division and spreading of rhizomes (West and Larkum, 1983). The life history of *Posidonia* has been difficult to study because seedlings and patches of newly established plants are rare (Larkum, 1976) and grow slowly (Kirkman, 1998). Based on evidence from one location in SE Australia, Meehan and West (2004) estimated that *Posidonia australis* seedlings developed the first orthotropic (vertical) shoot after approximately 3 years, and the first plagiotropic (horizontal) shoot after about 4-5 years. These seedlings and young plants have narrower leaves than mature plants (e.g., >10 years old), and should be easily identified in the field. However, in SE Australia, they appear to be very rare and restricted to a few marine coastal lakes, with micro-tidal conditions. As a result, the maintenance of the existing large meadows of *Posidonia* in SE Australia is thought to depend greatly on the spreading of rhizomes in established meadows (West and Larkum, 1979; 1983), with little or no exchange of genetic material between estuaries and bays. Existing meadows of *Posidonia* in eastern Australia appear to be established and maintained over centuries through slow rhizome growth and are possibly a remnant of past geomorphological conditions along this coastline. Currently, the long-term sustainability of *Posidonia* populations within particular estuaries is viewed with concern and has led to the NSW Government listing the populations in a number of Sydney metropolitan estuaries as threatened with extinction (NSW Gov., 2010).

The growth of *Posidonia* rhizomes varies greatly, ranging from millimetres per year in orthotropic (vertical) rhizomes within well established, relatively stable meadows, up to about 25 cm per year for plagiotropic (horizontal) shoots in areas subject to instability, such as sand influx or the edges of meadows (West and Larkum, 1979; Larkum and West, 1983; West and Larkum, 1983; West, 1990). This, combined with evidence of slow natural recolonisation (Meehan and West, 2000; 2004) has led to the assumption that large (>1 km^2) meadows of *Posidonia* may take decades, and possibly centuries, to establish. Characterising the nature of the rhizomes in particular areas, such as the numbers of actively spreading (plagiotropic) shoots, was used to explain the dynamics of *Posidonia* meadows in Botany Bay (West and Larkum, 1979) and Jervis Bay (West, 1990). Likewise, the percentage of plagiotropic shoots has also been more recently recognised as an important descriptor of the condition of *Posidonia oceanica* beds in the Mediterranean (Fernandez-Torquemada *et*

al., 2008). This dependence on relatively slow-growing rhizomes reduces the ability of *Posidonia* to quickly recover after damage (Meehan and West, 2000) and also makes restoration a difficult, though not impossible, prospect (West *et al.*, 1990; Cambridge *et al.*, 2000; Meehan and West, 2002; Campbell and Paling, 2003; Paling *et al.*, 2003; Bastyan and Cambridge, 2008).

In NSW, management authorities have recognised the susceptibility of the seagrass *Posidonia* to anthropogenic impacts for several decades after a number of large-scale declines were documented in the 1970s and 1980s (Larkum, 1976; Shepherd *et al.*, 1989; Larkum and West, 1990). This, combined with the recognition of the important role of seagrasses (e.g., as a fish habitat), has led to policies that aimed to protecting all seagrass meadows, including areas of *Posidonia*. These improved management practices include the ability to provide funds for restoration, as part of a compensation package when there are expected losses at particular sites. Despite this increased awareness and a high level of regulatory protection at most locations, many small-scale impacts continue to cause fragmentation of the meadows and are eroding the long term viability of the existing *Posidonia* meadows. Fragmentation of seagrass areas, through the creation of a large number patches across the landscape, can result in sediments becoming mobile, deeper holes forming and leading to the entire meadow becoming unstable. This sequence of small losses in seagrass area, leading to fragmentation, substrate instability, increased erosion, and eventually resulting in large-scale losses was observed for *Posidonia* meadows in Botany Bay and described as an "auto-catalytic" process (Larkum, 1976).

Boating activities are among the smaller scale impacts that continue to cause patch formation and fragmentation of seagrass meadows sometimes across quite large areas. There have been a number of recent papers outlining the impact of small boats, moorings and marinas on *Posidonia oceanica* in Mediterranean waters (Francour *et al.*, 1999; Milazzo *et al.*, 2004; Lloret *et al.*, 2008; Montefalcone *et al.*, 2004; 2008). This damage usually only involves the physical removal of the seagrass leaves, plants or small patches within meadows, but when *Posidonia* species are involved, the losses can be considered as long-term damage (i.e., taking decades to recover) or even permanent. As described above, these small-scale losses can also have more widespread consequences. To date, there has been very little documentation of damage to *Posidonia* meadows caused by boating activities (but see Hastings *et al.*, 1995), although it is generally accepted as an impact. In the present communication, a brief description of the impacts on *Posidonia* meadows from boating, boat moorings and marina construction in NSW (SE Australia) has been provided in an effort to increase the awareness of the problem and improve management practices.

STUDY SITES AND METHOD

There are several seagrass species found in SE Australia, including *Posidonia*, *Zostera*, *Halophila ovalis* (R.Br.) Hook. f., *H. decipiens* Ostenf. and *Halodule uninervis* (Forssk.) Asch. Most of the seagrass meadows are within the sheltered waters of estuaries and bays, although there are some small patches located along the open coastline and in the lee of offshore islands. The earliest inventory of estuarine wetlands, mapped approximately 155 km^2 of seagrasses in 111 estuaries (West *et al.* 1985). Since that time, seagrass areas in NSW have been mapped by number of authors, at a range of scales and using a variety of improved methods, making an assessment of change difficult

(Meehan *et al.*, 2005). None of these studies provided details of fragmentation within the meadows, as they relied on producing shape files for large (>25m^2) meadows.

In the current study, the impact of boating has been assessed qualitatively using Google Earth (©). Where the imagery allows, *Posidonia* seagrass meadows in each of the NSW estuaries have been located and an initial assessment of the scale of the impact on *Posidonia* from boating and related activities has been carried out. It should be noted that the aerial photos used by Google Earth (©) vary between locations in terms of both quality and in the date of capture, and have been used to provide an initial overview of damage.

RESULTS AND DISCUSSION

It is very likely that large-scale losses in seagrass areas occurred in NSW estuaries, particularly in the Sydney metropolitan waterways (Sydney Harbour, Botany Bay and Port Hacking), during the 19th century, as many major dredging and reclamation projects were carried out to modify entrances, deepen channels and establish ship and ferry facilities. While these early losses in seagrasses, including *Posidonia* meadows, are likely to remain undocumented, more recent changes in NSW seagrasses can often be investigated using historical aerial photography, which is available for about the last 50 years for most locations, and even earlier for some Sydney waterways (e.g., Larkum and West, 1990). As a result, losses in the area covered by *Posidonia* meadows over the past approximately 50 years have been investigated at several locations within NSW, particularly in the estuaries around the Sydney metropolitan area, such as Botany Bay (Larkum, 1976; Larkum and West, 1990) and Port Hacking (Meehan, 2001). The majority of these changes were attributed to dredging and reclamation associated with large-scale developments which generally required government approval. An increased awareness about such impacts and about the importance of seagrasses to the near-shore environments, has led to a higher level of government protection and improved assessment and management of large-scale development projects. However, significant damage to *Posidonia* meadows is still occurring through smaller-scale activities, such as recreational boating. Of particular concern here are impacts from moorings, boat propellers and jetty construction.

Boat Moorings

Traditional boat moorings, comprised of a large weight (concrete or steel), length of chain and float, can cause significant damage when placed in seagrass meadows, scouring out the seagrass and leaving a circular bare patch. Impacts on seagrass meadows from boat moorings have been reported from many parts of the world (e.g., Hastings *et al.*, 1995; Francour *et al.*, 1999), but have not been well documented for eastern Australia. Damage to *Posidonia* meadows from boat moorings is of particular concern as natural restoration of these sites is likely to be slow and any attempt at rehabilitation will be expensive and involve some risk of failure. During the current study, significant damage to *Posidonia* meadows from boat moorings was found at a number of sites (e.g., see Table 1 and Figure 2). Measurements taken from a selection of sites indicate that the average diameter of the damaged area under single moorings is approximately 15m, meaning that about 55 moorings can cause an area of approximately 1ha of seagrass to be removed. In many NSW estuaries and bays, such as Port Stephens (Figure 2A), Lake Macquarie (Figure 2B & 2D), Pittwater and Sydney Harbour (Figure 2C), there are hundreds of moorings located in seagrass meadows and

Table 1: Estuaries in SE Australia (listed north to south) containing *Posidonia*. Estimated areas of *Posidonia australis* (based on West *et al.*, 1985; Creese *et al.* 2009) and brief descriptions of meadows and observed impacts are included.

Name	**Location (Lat; Long)**	**Approx. Area (km^2)**	**Description**
Wallis Lake	32°10'28.61"S; 152°30'35.04"E	2.429	*Posidonia* is found in shallow waters in channels and around the edge of the main lake, which is micro-tidal. Currently, very little obvious impact from any boating activities.
Port Stephens	32°42'31.40"S; 152°11'26.74"E	4.097	*Posidonia* occurs around much of the waterway in relatively deep water. Observable impacts from moorings and marina construction along southern shoreline. Refer Fig. 1A, 1D, & 3A.
Lake Macquarie	33° 5'17.41"S; 151°39'33.82"E	0.886	Largest areas of *Posidonia* are along the eastern edge of the lake on sandy substrates. Significant impacts from propeller damage, moorings and marina construction have occurred. Refer Fig. 1B & 3B.
Brisbane Waters	33°31'55.46"S; 151°20'4.58"E	0.957	*Posidonia* occurs in small meadows around southern edges of waterway. Impacts from propeller damage can be found in several areas. Refer Fig. 2A.
Pittwater	33°34'55.36"S; 151°18'57.28"E	1.247	*Posidonia* is found on eastern and western shoreline. Impacts from boating have occurred but are difficult to assess in current imagery. Refer Fig. 3C.
Hawkesbury River	33°34'43.73"S; 151°15'26.73"E	0.008	Mainly small, deep areas of *Posidonia* (e.g., in entrance to Cowan Creek) with little effect of boating.
Port Jackson (Sydney Harbour)	33°49'44.63"S; 151°16'53.47"E	0.104	*Posidonia* meadows currently occur in several bays throughout Sydney Harbour, usually in small meadows. Long-term losses to *Posidonia* are undocumented but, given the history of the waterway, likely to be significant. Currently small-scale impacts from boating and marina construction can be observed. Fig. 1C.
Botany Bay	34° 0'5.05"S; 151°13'48.72"E	2.739	*Posidonia* now restricted to southern shoreline, but previously reported along northern shore (Larkum, 1976). Long-term losses from Port construction reported by Larkum and West (1990). Currently, small-scale damage from propellers can be observed at Bonna Point. Refer Fig 2B.
Port Hacking	34° 4'41.29"S;	0.633	*Posidonia* occurs from Jibbon Headland upstream to SW Arm. There have been significant impacts from dredging and reclamation, particularly from the mining of shell grit (Meehan, 2001; Meehan and West, 2004). Currently several areas are impacted from moorings and propeller damage. Refer Fig. 2C & 2D.
Jervis Bay	35° 6'13.41"S; 150°46'33.64"E	5.131	Largest area of *Posidonia* in NSW, found in deep waters around Bay. Regrowth after damage from seismic testing investigated by Meehan and West (2000).
St Georges	35°11'1.16"S; 150°35'36.24"E	1.401	Areas of *Posidonia* (and *Zostera capricorni*) lining entrance channel, lake delta and surrounding main lake. Some scouring from boat propellers visible.

Batemans Bay	35°43'35.55"S; 150°13'23.32"E	0.095	Small area of *Posidonia* in protected bay waters away from river mouth. No obvious impacts.
Wagonga Inlet	36°12'38.96"S; 150° 7'58.16"E	0.605	*Posidonia* is found on the marine delta and in parts of main lake. Only minor impacts observed. Meehan (2001) reported some expansion of *Posidonia* areas after entrance works.
Bermagui River	36°25'24.35"S; 150° 4'22.67"E	0.199	*Posidonia* found along main channels and marine delta. No damage observed.
Merimbula Lake	36°53'39.40"S; 149°55'17.87"E	1.157	*Posidonia* found along main channels and marine delta. No small-scale damage from boat movement and mooring can be found. Other impacts on seagrasses include oyster farming. Refer Fig. 3D.
Pambula Lake	36°56'55.58"S; 149°54'57.76"E	0.523	Meadows of *Posidonia* are found in the entrance channel, marine delta and around the lake away from the freshwater river. No damage from boating recorded.
Twofold Bay	37° 5'29.54"S; 149°54'30.24"E	0.001	Small isolated patches of *Posidonia* are present but unaffected by boating.

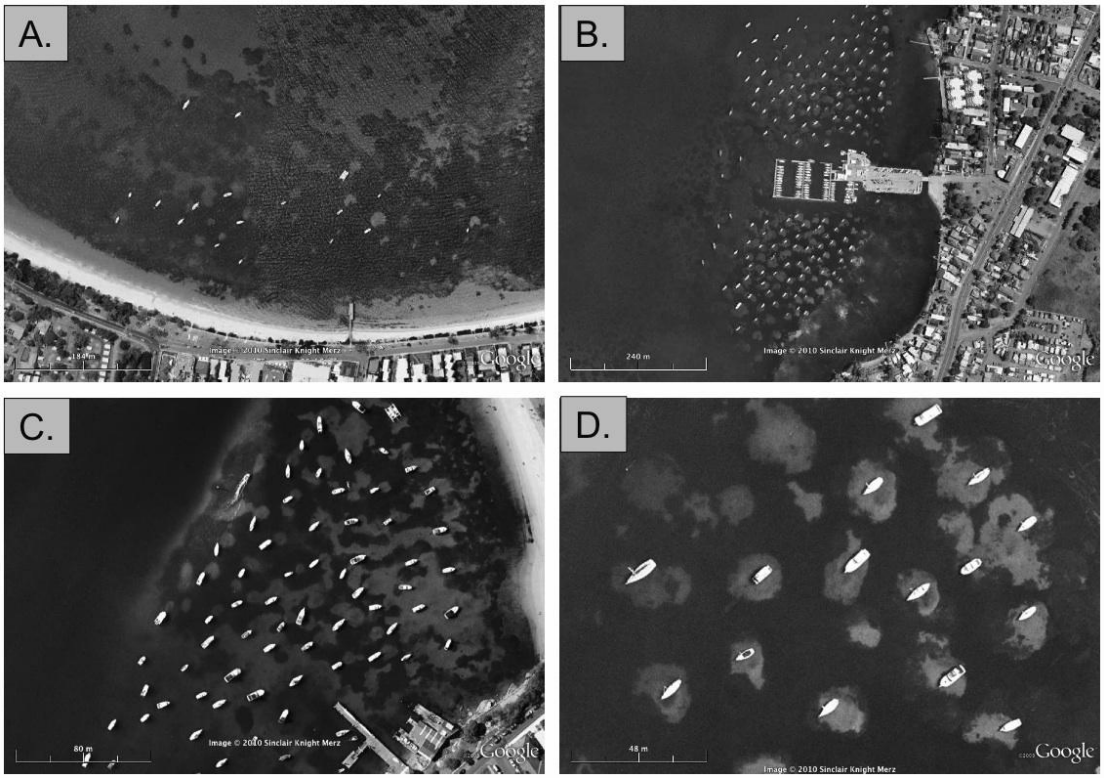

Figure 2: Examples of mooring damage to *Posidonia australis* meadows at a number of locations in NSW (Australia): A. Shoal Bay, Port Stephens (32°43'3.46"S, 152°10'34.41"E), B. Belmont, Lake Macquarie (33° 2'19.41"S, 151°39'12.89"E), C. Manly Cove, Sydney Harbour (33°48'8.26"S, 151°17'3.76"E), D. Close-up of the damage in Lake Macquarie, showing holes formed from swinging-chain moorings. Note: Sites can be viewed in Google Earth (©) using co-ordinates supplied. Aerial photographs reprinted courtesy of Google Earth (©), incorporating images from Sinclair Knight Mertz Pty. Ltd. (Australia) and DigitalGlobe.

at some sites the damage to *Posidonia* beds is very significant, and the swinging moorings are likely to also impact associated benthic communities (e.g., see Herbert *et al.*, 2009). Often, in the process of cleaning these moorings, they are re-positioned, which further increases the area of impact. At some sites, such as in Lake Macquarie, moorings are so closely spaced that the holes in the seagrass meadows combine to form large continuous bare patches (e.g., see Figure 2C).

Along with the direct removal of seagrass, there is the added issue of fragmentation and increased potential for erosion. Considering the slow rate of natural expansion of *Posidonia*, these damaged areas are likely to take many decades to be restored. At some sites, it is likely that restoration of the *Posidonia* meadow will never be achieved and the species will be replaced by faster growing and more widespread seagrasses, such as *Zostera capricorni* or *Halophila* spp. This investigation is only a first attempt to document the extent and nature of the impact of boat moorings on *Posidonia* meadows. A more thorough inventory of damaged sites and the development of a management strategy to resolve the problem, such as the use of seagrass friendly moorings, are urgently required.

Propeller Scouring

Physical removal of seagrass leaves and rhizomes caused by boat propellers is well documented for some species and locations (e.g., Dawes *et al.*, 1997; Burfeind and Stuntz, 2004; Martin *et al.*, 2008) and can impact on the structure of the seagrass community as a whole (Uhrin and Holmquist, 2003). The most obvious signs of propeller damage are long narrow ruts cut through the seagrass meadows, often just a few metres wide. The extent of such damage is difficult to accurately estimate and only high-resolution aerial photography or digital mapping can provide an insight into the overall level of impact across the seagrass landscape (Martin *et al.*, 2008). Despite having a very robust rhizome, which is often buried by several centimetres of sediment, there are many examples of propeller damage to *Posidonia* at sites throughout eastern Australian waters, but very few, if any, of these examples have previously been documented. In the current investigation, a number of sites where *Posidonia* meadows had been damaged by propeller scouring were identified along the NSW coast. Examples of these sites were located in Brisbane Waters (Figure 3A), Botany Bay (Figure 3B), Port Hacking (Figure 3C & 3D), but many of the other estuaries and bays listed in Table 1 were also affected to some extent. Propeller damage to seagrass meadows can be a result of wayward navigation due to poor channel marking, although at some locations poorly located boat ramps, jetties and moorings can only be accessed across shallow waters In many circumstances, the damage is accidental, as it usually results in considerable damage to the boat propeller and engine. Propeller damage is generally restricted to narrow widths, perhaps up to 50 cm, but can be many hundreds of metres in length. Improved public information about seagrass damage from propeller scouring may assist in reducing this problem.

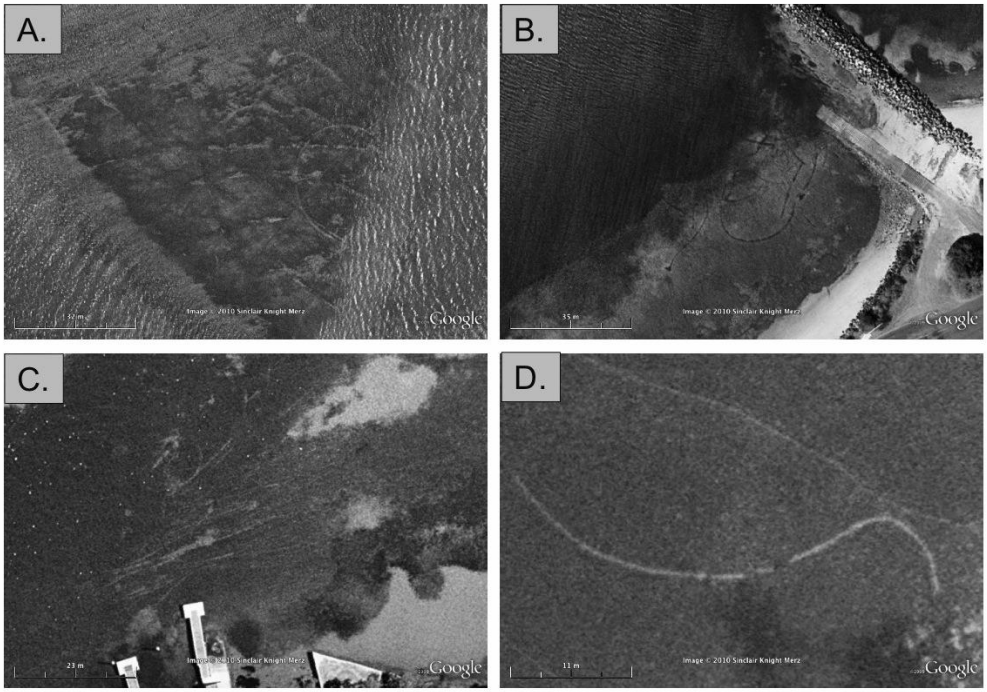

Figure 3: Examples of damage to *Posidonia australis* meadows from boat propellers at a number of locations in NSW (Australia): A. Brisbane Waters (33°30'13.77"S, 151°20'24.77"E), B. Bonna Point, Botany Bay (34° 0'24.45"S, 151°11'30.16"E), C. Burraneer Bay, Port Hacking (34° 4'5.38"S, 151° 8'3.31"E), D. Close-up of the damage in SW Arm, Port Hacking (34° 4'37.08"S, 151° 6'39.88"E), showing lines formed from scouring by boat propellers. Note: Sites can be viewed in Google Earth (©) using co-ordinates supplied. Aerial photographs reprinted courtesy of Google Earth (©), incorporating images from Sinclair Knight Mertz Pty. Ltd. (Australia) and DigitalGlobe..

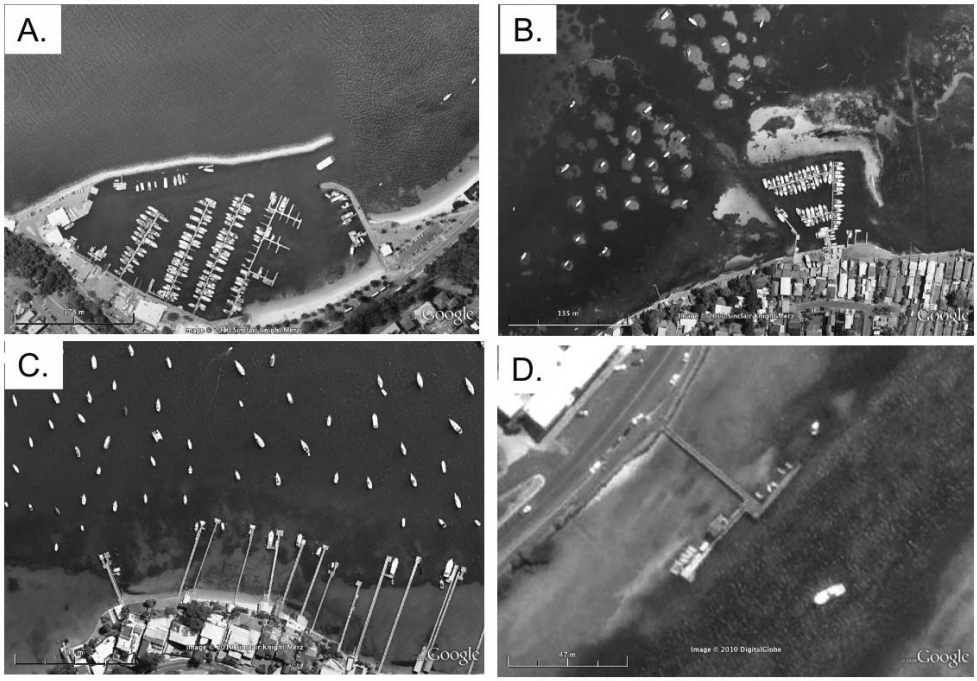

Figure 4: Examples of various impacts on *Posidonia australis* meadows at locations in NSW (Australia), described in the text: A. Marina, Port Stephens (32°43'4.87"S, 152° 8'45.64"E), B. Marina, Lake Macquarie (33° 3'7.52"S, 151°38'31.23"E), C. Private jetties, Pittwater (33°39'13.05"S, 151°17'35.65"E), D. Small jetty, Merimbula Lake (36°53'29.78"S, 149°54'39.77"E). Note: Sites can be viewed in Google Earth (©) using co-ordinates supplied. Aerial photographs reprinted courtesy of Google Earth (©), incorporating images from Sinclair Knight Mertz Pty. Ltd. (Australia) and DigitalGlobe.

Other recreational boating impacts

A number of other recreational boating activities have impacted on the NSW seagrass meadows, and more specifically on areas of *Posidonia*. For example, the construction and operation of some marinas in NSW, used primarily by recreational boats, has often resulted in dredging of seagrass meadows and reclamation of shallows. Some of these have been relatively large projects involving dredging and reclamation of significant areas of *Posidonia* (e.g., Fig. 4A), whereas others have been smaller-scale impacts (e.g., Fig. 4B). In NSW, these types of projects require government approval through an environmental impact assessment process, and it is now less likely that developments, where major impacts of seagrass meadows are expected, would be allowed. Smaller-scale activities, such as the construction of private jetties (e.g., see Fig. 4C) and small public jetties (e.g., see Fig. 4D) often require less detailed review of impacts, but can have dramatic impacts on the survival of seagrasses. Better planning and more careful control over these small-scale developments is now required to reduce further losses of seagrasses, in particular of *Posidonia* meadows.

CONCLUSION

Posidonia meadows occur in a number of estuaries and bays in SE Australia but these populations are isolated from one another, easily damaged and slow to recover. In the past, widespread declines in the area of *Posidonia* in NSW have occurred due to large-scale developments (e.g., dredging and reclamation), mainly in waterways in the Sydney region. At some locations in NSW, recreational boating and associated activities now represent a major threat to the long-term survival of the remaining large meadows of *Posidonia*. Improved management practices are needed to reduce the impact of boat moorings, propeller scouring and marina construction on the remaining threatened populations of *Posidonia*. Tools such as Google Earth (©) and NearMap (© see: http://www.nearmap.com) should provide local communities with the means to assess these smaller-scale impacts across wide spatial scales, and in future across temporal scales, and assist in improving the management of these impacts.

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