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NOTE

ABSENCE OF A LARGE BROWN MACROALGA ON URBANIZED ROCKY REEFS AROUND SYDNEY, AUSTRALIA, AND EVIDENCE FOR HISTORICAL DECLINE[1]

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Loss of habitat-forming algae is increasingly prevalent in temperate marine ecosystems. Here, we document absence of an important habitat-forming macroalga, *Phyllospora comosa* (Labill.) C. Agardh, along an urbanized coast in New South Wales (NSW), Australia. Dense *Phyllospora* canopies were common on shallow sublittoral reefs north and south of Sydney. In contrast, we did not find a single individual along ~70 km of rocky coastline in the Sydney metropolitan region, despite historical evidence to suggest that it was very common half a century ago. Recolonization of this important habitat-forming alga has not occurred on Sydney reefs despite improved water quality, protection of its habitat, and frequent long-distance dispersal of *Phyllospora* wrack. While there are obvious limitations, historical information can be useful for identifying potential shifts in community structure to increase our understanding of contemporary ecological patterns.

Key index words: **habitat-forming; loss; macroalga; *Phyllospora comosa;* urbanization**

Abbreviation: **NSW, New South Wales**

Loss and degradation of habitat-forming algae are becoming increasingly prevalent in temperate marine ecosystems (Steneck et al. 2002). Anthropogenic stressors, such as climate change, eutrophication, and urbanization, as well as episodic events, such as grazing, storms, and disease, can have dramatic effects on the health and persistence of large habitat-forming macroalgae (Dayton et al. 1998, Steneck et al. 2002, Thibaut et al. 2005, Airoldi and Beck 2007). Loss of habitat-forming macroalgae has major effects on the diversity and abundance of associated fauna, influencing a variety of trophic levels via changes in the amount and source of detrital inputs into marine food webs (Duggins et al. 1989, Bradley and Bradley 1993, Graham 2004) and influencing the diversity and abundance of fauna that directly or indirectly use the structure provided by macroalgae as a habitat on which to live (Graham 2004).

P. comosa is a monotypic, perennial fucoid alga common on the shallow subtidal reefs of temperate southeastern Australia (Womersley 1987, Millar and Kraft 1994). This species forms dense canopies (~20 kg · m^{-2} and up to 3 m in height) that support diverse assemblages of fish and invertebrates (up to 50 species of amphipods per plant, G. Wilson and A. J. Millar, unpublished data). Moreover, on the shores where it is abundant, dislodged *Phyllospora* represents an important food supply for abalone (C. Blount, personal communication) and a dominant source of material for detrital food webs (B. P. Kelaher, personal observation). Although *Phyllospora* has been documented historically to occur on moderately exposed to exposed coasts throughout southeastern Australia, it is now conspicuously absent from the shallow subtidal reefs around Sydney (Fletcher 1984, Underwood et al. 1991, Coleman 2002). When it has been located, it is often as isolated plants (Andrew and O'Neill 2000) or simply as drift. The last published record

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of *Phyllospora* on Sydney coasts was in 1952 where it is described as being ''very prominent from Newcastle to Victoria'' (Dakin 1952, p. 104). At around this time, there were also extensive populations on the northern shores of Sydney (see map in Pope 1943; Fig. 2, this study). Here, we used field sampling, historical herbarium collections, and anecdotal evidence to show that this important habitat-forming alga has since gone missing along ~70 km of urbanized rocky coastline around Sydney.

Shallow, subtidal reefs were surveyed along the NSW coast in 2007. We used a hierarchical design to sample three locations in each of the north, south, and Sydney regions (Fig. 1). Within each location, we sampled shallow (0 to 3 m below low tide) subtidal rocky reef in each of two sites (km apart). At each site, the percentage canopy cover of algae in 20 randomly placed 1×1 m^2 quadrats was recorded. An additional 39 reefs (including shores where *Phyllospora* was historically abundant and randomly chosen reefs) around Sydney were further examined to determine the exact location of the putative gap in the distribution of *Phyllospora* (Fig. 1). We utilized a variety of sources of qualitative historical data to show that *Phyllospora* was common in Sydney half a century ago. Although such data cannot provide information on abundances and are temporally sparse, they represent the only available data on subtidal communities prior to the 1960s. The complete holdings of *Phyllospora* from the National Herbarium of NSW were searched, in addition to herbaria from around Australia via the Electronic Flora of South Australia (Australia's Virtual Herbarium; http://www.flora.sa.gov.au). Herbarium abbreviations follow Holmgren et al. (1990). Further, anecdotal evidence was obtained from marine scientists who were actively researching on the intertidal shores and subtidal reefs of Sydney from the 1940s to the 1990s to ascertain when *Phyllospora* may have disappeared.

Surveys of historical herbarium collections revealed that the last collection of *Phyllospora* from the Sydney region was in 1945 (Collaroy NSW291968). Earlier (1898–1901) collections from numerous sites along the southern (Bondi: NSW750240,

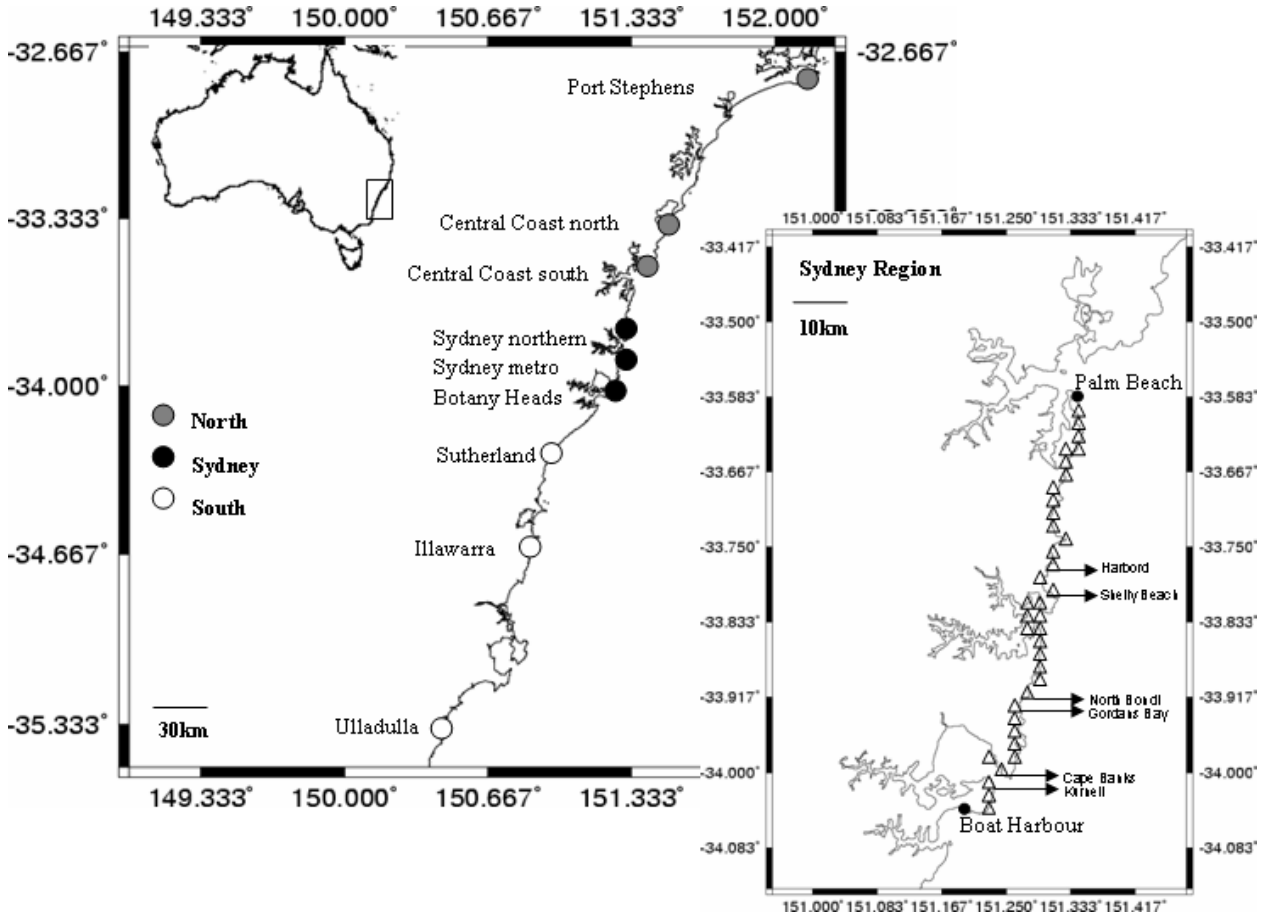

FIG. 1. Map of central New South Wales showing locations (three) that were sampled in the north (gray circles), south (white circles), and Sydney (black circles) regions. Included is a detailed map of the Sydney region showing the northern (Palm Beach) and southern (Boat Harbour) boundaries of the gap in *Phyllospora* distribution. Additional places that we surveyed for the presence of *Phyllospora* are shown (white triangles).

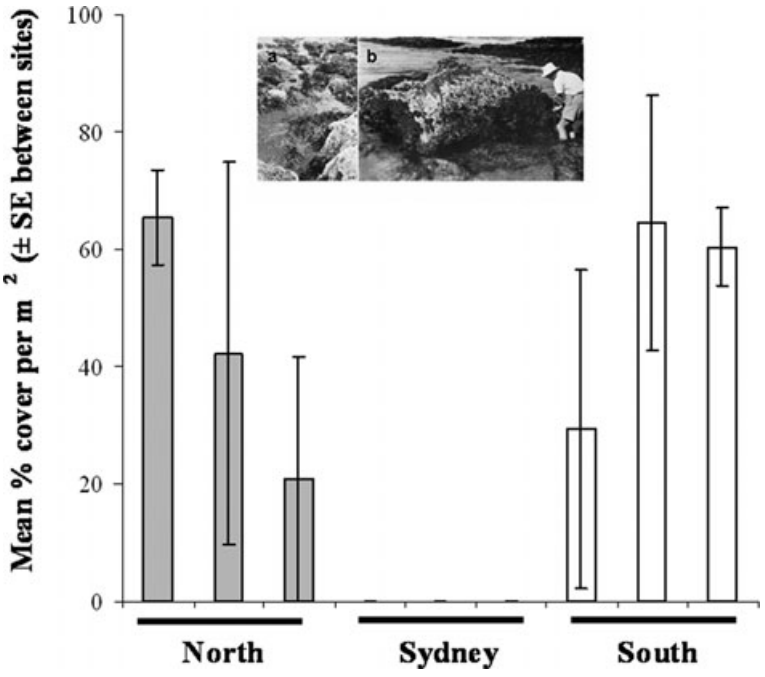

FIG. 2. Mean percentage cover of *Phyllospora* in locations to the north (gray bars), south (white bars), and within the Sydney region (*Phyllospora* absent). Means and standard errors are between the two replicate sites within each location. $n = 20$ replicate quadrats per site. Photographs show abundant *Phyllospora* from shallow areas at Long Reef in (a) 1943 (Pope 1943) and (b) 1948 (Dakin 1952). Photographs reproduced with permission from the Linnean Society of New South Wales and CSIRO Publishing, Victoria, Australia.

NSW750255, NSW750257 to NSW750260; Long Bay: NSW750233; and Bronte: NSW750254, NSW750251) and northern (Collaroy: ADA50054; Long Reef: ADA10187; and Newport Beach: ADA13049) metropolitan coasts suggest that *Phyllospora* was most likely common on the shallow subtidal reefs of Sydney prior to the 1940s (see photograph in Fig. 2). Indeed, one researcher described *Phyllospora* as ''common'' in Sydney in 1944 (Dr. Isobel Bennett field notebook, MS9348 National Library of Australia).

According to anecdotal evidence of marine scientists who worked extensively on the coast of Sydney before the 1970s (I. Bennett, E. Sakker), in the 1970s (A. J. Underwood, R. Creese), in the 1980s (A. Millar, S. Kennelly, R. Fletcher, M. Lincon-Smith), and in the 1990s (P. Steinberg, P. Scanes, M. Kingsford, and N. Andrew), only Underwood, Scanes, Bennett, and Sakker could reliably attest to *Phyllospora* being present on two rocky reefs between Boat Harbour and Palm Beach (Cape Banks and Harbord). Moreover, these sightings were all before the 1970s (Bennett and Sakker) or in the 1980s (Underwood and Scanes).

We did not find *Phyllospora* at any of the Sydney sites that had historically been known to harbor the species (e.g., Long Reef), nor at any of the 39 reefs that we surveyed in the Sydney region (Fig. 2). Although it remains possible that small populations of *Phyllospora* or individual plants exist in areas we did not sample, it appears that there is a gap of ~70 km (40 km linear distance) in the distribution of *Phyllospora* between Palm Beach at the southern tip of Broken Bay and Boat Harbour on the Kurnell Peninsula (Fig. 1). *Phyllospora* was, however, abundant along the northern and southern NSW coasts (Fig. 2), and there were no differences in its percentage cover between these regions (analysis of variance [ANOVA] on north and south data only: 1, 6, df; $F = 0.26$; $P = 0.639$) or among locations within regions (ANOVA: 4, 6, df; $F = 0.93$; $P = 0.507$). There was, however, always variation in the percentage cover of *Phyllospora* between sites within locations (ANOVA on north and south data only: 6, 228, df; $F = 31.75$; $P < 0.0001$). There were no significant differences in the percentage cover of other common canopy-forming species (e.g., *Ecklonia radiata* and *Sargassum* spp. among regions [ANOVA: 2, 6, df; $F = 0.209$ and 0.059 for *E. radiata* and *Sargassum* spp., respectively; $P < 0.05$]) or locations (ANOVA: 6, 9, df; $F = 0.454$ and 0.144 for *E. radiata* and *Sargassum* spp., respectively; $P < 0.05$), but the percentage cover of *Sargassum* spp. was positively correlated with the absence of *Phyllospora* (Pearson's $r = -0.96$, $P < 0.001$, $n = 9$ locations).

While it is too late to empirically determine the exact cause of *Phyllospora's* historical decline, its absence corresponds closely with the location of Sydney's ocean outfalls, which, from the early 1900s until the 1990s, each discharged up to ~465 $ML \cdot d^{-1}$ of primary treated sewage, stormwater, and

urban runoff into the shallow subtidal reefs in and around Sydney. These outfalls caused significant decreases in brown algal diversity in intertidal areas (Borowitzka 1972). Indeed, *Phyllospora* may be particularly sensitive to sewage, as germination of *Phyllospora* zygotes subjected to sewage effluents is particularly poor relative to other species of algae (Burridge et al. 1996) and could contribute to recruitment failure and contemporary absence from Sydney reefs.

Alternatively, increased turbidity and sedimentation associated with coastal development around Sydney's urbanized coastline may be responsible for *Phyllospora*'s absence from these areas (see review by Airoldi 2003). We find this possibility unlikely, however, since both north and south of Sydney, *Phyllospora* can be found at the mouth of estuaries where water turbidity is high (e.g., Pearl Beach). Indirect effects via trophic cascades (e.g., grazing) or episodic events, such as disease, may also have played a role in the loss of *Phyllospora* from Sydney, but it is unclear why such events might be restricted to this specific section of coastline.

Irrespective of the exact cause of the disappearance of *Phyllospora* from Sydney, its contemporary absence appears to be not easily reversible, particularly given that Sydney reefs are protected by legislation, and because water quality has improved since the installation of deep water outfalls in the 1990s. As with other habitat-forming macroalgae (Dayton et al. 1984, Kennelly 1987, Graham 1997, Airoldi 1998), we suggest that preemptive competition, particularly with algal turfs or *Sargassum* spp., may inhibit recruitment of *Phyllospora*. Indeed, experimental clearances of *Phyllospora* in Tasmania demonstrated that recolonization did not occur once other species became established (Valentine and Johnson 2003). Alternatively, limited dispersal may be preventing recolonization of *Phyllospora* to reefs in Sydney. We do not think that this is likely, however, since dislodged *Phyllospora* individuals are extremely buoyant and capable of long-distance dispersal (hundreds of km, Millar and Kraft 1994, Millar 1999), including transport via currents to Sydney shores (M. A. Coleman, personal observation). Certainly, the failure of *Phyllospora* to exist on Sydney reefs warrants further investigation.

The absence of the habitat-forming *Phyllospora* is likely to have had a substantial influence on the ecology of shallow subtidal reefs around Sydney, potentially biasing our view of how these systems function. Ecological knowledge based on systems that are altered from their ''natural'' state may be limited in its applicability and relevance when not considered in a larger spatial and temporal context. Despite obvious limitations, the use of historical records and herbarium specimens (Millar 2003, Coleman and Brawley 2005), as well as large-scale observations, is invaluable for identifying such shifts in community structure and is a useful step in building a knowledge base with which to effectively manage and conserve our marine environments.

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