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Research Summary

New South Wales Barrens

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This summary is part of a series that aims to clearly summarise current research on topical issues relevant to NSW DPI Fisheries, stakeholders, and community members.

Key points

- Longspined Sea Urchins (*Centrostephanus rodgersii*) are an important component of the rocky reef ecosystems in NSW.
- They have been commercially fished for over 50 years and form an important harvest of approximately 90 tonnes per year in the NSW Sea Urchin and Turban Shell (SUTS) Fishery.
- This species is currently classified as sustainable in the national Status of Australian Fish Stocks report, as the total harvest is only a small fraction of total biomass.
- *C. rodgersii* are the most dominant urchin species in barrens. While this habitat is often considered undesirable, in NSW they are a natural part of the rocky reef habitat and so have no specific current management.
- Barrens occur across most of the NSW coastline, but they tend to be larger and more numerous on rocky reefs along the south coast.
- NSW DPI have been characterising and monitoring shallow subtidal reef habitats, including barrens, since the 1980s and have found that barrens and *C. rodgersii* are a dominant yet stable feature of NSW shallow subtidal ecosystems.
- In NSW, there is no evidence of reductions in barrens areas or urchin numbers in Marine Park Sanctuary Zones despite significant and widespread increases in the abundance of urchin predators.

Barrens habitat with *Centrostephanus rodgersii* from Bare Island NSW. Image: Tim Glasby

The Longspined sea urchin (*Centrostephanus rodgersii*) and its associated barrens are increasingly perceived as undesirable due to the range extension of this species into Tasmania and its subsequent reduction of giant kelp forests. In NSW, however, this species is a natural part of the ecosystem and forms a valuable, sustainable fishery. See further details about *C. rodgersii* on p. 7.

What are barrens?

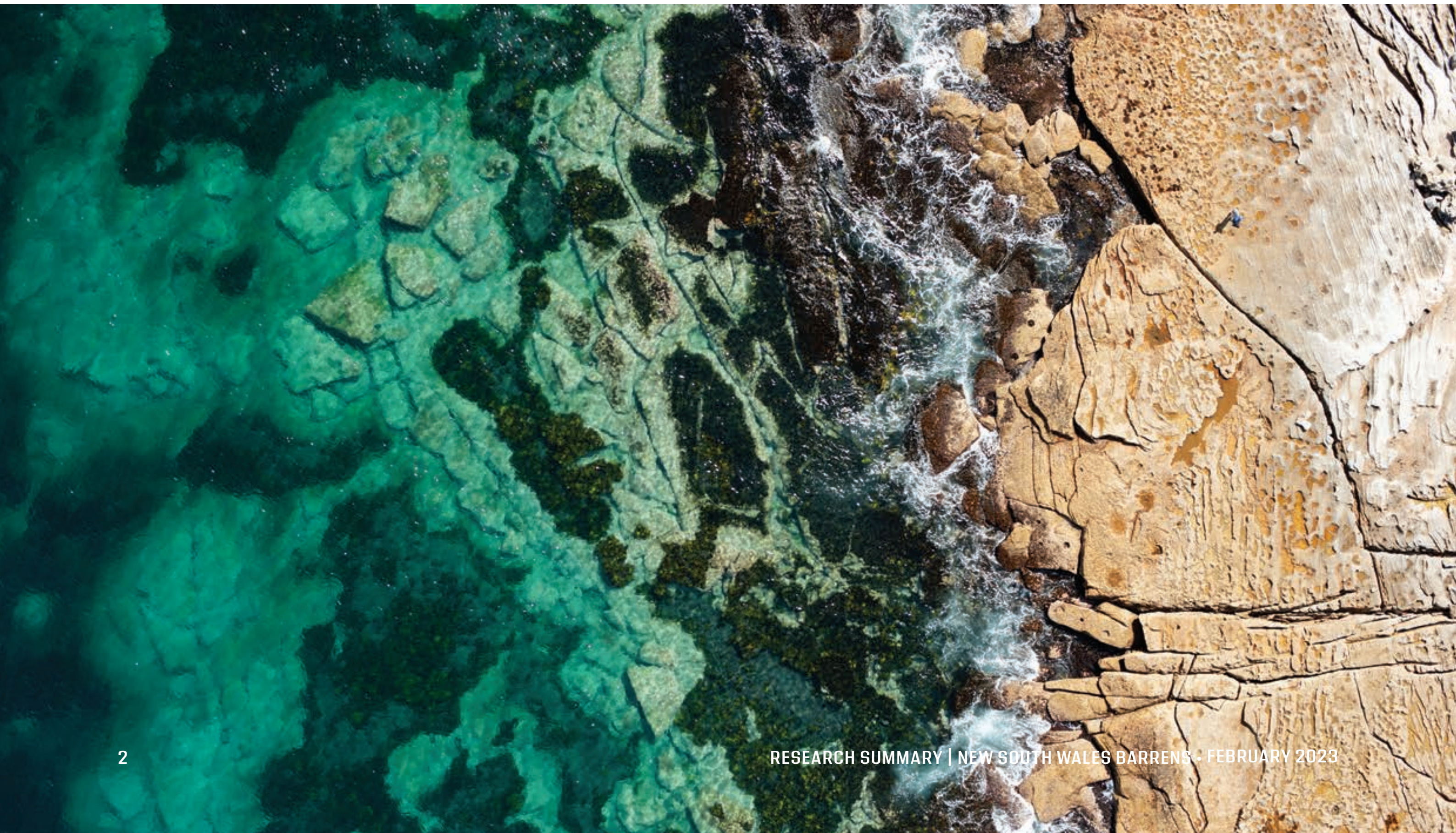
Barrens are rocky reef areas covered by crustose coralline algae that support distinct fauna (sponges, ascidians, urchins, limpets, fishes) [1] and are recognised as a typical and distinctive habitat of NSW rocky reef ecosystems [2, 3].

Sea urchins are conspicuous herbivores in barrens and include the Shortspined (*Heliocidaris erythrogramma*) and Longspined urchins (*Centrostephanus rodgersii*, see inset), as well as *Heliocidaris tuberculata*, *Pseudoboletia indiana* and *Phyllacanthus parvispinus*. *C. rodgersii* is the most dominant urchin species in barrens [1] and the main species responsible for grazing kelp, thus creating and maintaining this habitat [4, 5]. The NSW coastline is the centre of the natural distribution of this urchin [6].

New South Wales subtidal rocky reefs are characterised by mosaics of barrens and macroalgae beds [2], and urchin density is positively correlated with area of barrens [7]. Outside NSW, barrens have been associated with low macro-biodiversity, low primary productivity [8], and loss of blue carbon [9]. In these areas, they are often considered an undesired alternate state of kelp ecosystems [10–12] (see inset). However, studies in NSW reveal higher fish biodiversity in barrens [13] or comparable microscopic biodiversity in both systems [14].

Where do barrens occur in NSW?

Barrens occur across most of the NSW coastline, but they are larger [1, 15, 16] and more numerous [2, 7] on rocky reefs along the south coast. Barrens do not often occur on rocky reefs that are affected by sand movement, such as the narrow sloped reefs in northern NSW (north of Port Stephens) and in the far south of the state (south of Womboyn) [15,16]. NSW barrens are relatively stable in size, but their persistence varies among locations [16]. There are six published NSW statewide or large-scale assessments of barrens or associated urchin densities, all from NSW DPI Fisheries: three used aerial imagery informed by ground truthing [15–17], and three used underwater imagery [7, 18, 19] (Table 1). In addition, Reef Life Survey maintains an extensive database on urchin density, extending along the entire NSW coast (reeflifesurvey.com/explorer/map).



Aerial image of Cape Banks NSW showing mosaic of macroalgae and barrens to 5 m depth. Image: Tim Glasby

How are barrens and fisheries related?

Compared to kelp beds and other rocky reef habitat, it has been suggested that barrens support lower biodiversity, including that of commercially important species. However, except for abalone, this has not been quantitatively assessed. Indeed, barrens around Terrigal and Sydney supported a greater number of fish species than kelp beds and a similar number of species to sponge habitat [13]. Densities of *C. rodgersii* can be negatively correlated to abalone densities on the NSW south coast [20], thereby decreasing local productivity [15]. A study from Tasmania suggests that *C. rodgersii* may also increase likelihood of abalone seeking shelter in microhabitats, potentially making them more difficult to harvest [21].

Urchin densities and barrens have been linked to the quantity and quality of commercial urchin roe. The reproductive output of *C. rodgersii* in barrens is lower than those living on the fringe of macroalgal beds, and urchins from barrens do not warrant harvesting [22]. However, significant improvements in both roe colour and yield occurred after urchin density was reduced by 70% over three months, with greater improvement after two years [23]. There have also been some successful efforts to condition *H. erythrogramma* gonads to improve commercial harvest in Victoria [24]. Urchins transplanted to habitat with an abundance of macro-algae showed significant improvements in colour and yield of roe after six weeks, although the magnitude of change depended on density and season [23].

Has the area of barrens been increasing in NSW?

There is concern from the public that the area of barrens habitat along the NSW south coast has recently increased while kelp cover has decreased, similar to changes observed in Victoria and Tasmania. NSW DPI have been characterising and monitoring shallow subtidal reef habitats, including barren habitats, since the 1980s using various sampling techniques including aerial photography, underwater visual census, and underwater imagery [1, 15, 16]. In general, results from data over a 50–year time period found that barrens and *C. rodgersii* are a dominant yet stable feature of NSW shallow subtidal ecosystems [25, 26], particularly in southern NSW [16].

There is evidence of natural variation (increases and decreases) in the area of barrens at large spatial scales (>1–10s kms) over the last 30 years, with most sites between Newcastle and Eden fluctuating by ±10% area. The greatest increase in area of barrens has occurred in the Sydney region [16]. Small increases in area of barrens of 10–15% occurred at Shellharbour and Bawley Point and ~20% at Bermagui, while others areas showed less than 5% decreases in barrens [16]. On reefs where the area of barrens has increased, it has done so at a rate of 0.2 % per year [16].

Monitoring in the Batemans Marine Park on the south coast indicates that barrens have remained stable or even decreased in their coverage [27]. Examples of longer-term persistence of extensive barrens are relatively rare because underwater surveys only began in about the 1980s, but there are some large barrens in NSW that have persisted for over 30 years and, in one case where longer-term data was available, up to 68 years [16]. Whether the abundances of urchins and extent of barrens areas have been increasing over long temporal scales (>50 years) remains unknown.

Climate change should be considered when considering local fluctuations in the extent of barrens. High rainfall can cause periodic mass mortality of *C. rodgersii* such as that observed in Botany Bay (Andrew 1991) and in response to East coast lows where low salinity can inundate *C. rodgersii* habitat and storm events dislodge thousands of individuals weakened by low salinity [6]. These events are also deleterious for kelp, but the kelp may recover more quickly [28]. These observations stress the importance of considering the impacts of changing climate and associated multiple stressors on the dynamics of NSW barrens and kelp habitats.

Are barrens different elsewhere in the world?

In many locations around the world, barrens are thought to be the result of disturbances to rocky reef ecosystems. In the USA and Mediterranean, reductions in urchin predators through commercial harvest have enabled urchins to reach high densities, and they have overgrazed foliose algae on rocky reefs and substantially altered the rocky reef biodiversity. Importantly, the cyclical changes from kelp forests to barrens and the return to kelp forests on both sides of the North American continent are also driven by sea urchin disease, periodic warming and mass mortality of predator species that are not commercially harvested [29–32].

Large changes to ecosystems such as these have not been observed in Australia, and the drivers of barrens appear to differ from elsewhere in the world.

Within Australia, we have seen unexplained short-term population booms of urchins along with associated increases in barren, for example *Heliocidaris erythrogramma* in NSW [33] and Victoria [34] and *Tripneustes* sp. at Lord Howe Island [35]. The range extension of *C. rodgersii* to Tasmania due to the strengthening of the Eastern Australian Current has threatened kelp (Ling *et al*. 2009) and is predicted to continue increasing the extent of barrens [36]. In this region, low harvests of *C. rodgersii* can positively impact abalone habitat [37, 38]. Recent estimates from 5–40 m depth range from 0.018% barren cover in southern Tasmania to 2.10% barren cover in northern Tasmania [39]. Barrens occur in significantly deeper waters in Tasmania (16–58 m) compared to NSW (7–27 m) [40].

Mass mortalities of *C. rodgersii* and other urchins along Fairlight Beach in July 2022 after severe storms related to an East coast low. Image: Claire Reymond

How can barrens be managed?

Many local community groups are concerned by the presence of extensive barrens and large numbers of urchins on NSW rocky reefs, and there is growing interest in the idea of transforming barrens to kelp forests by harvesting or culling urchins [41]. The removal of all visible *C. rodgersii* causes an ecosystem shift from barrens to habitats dominated by foliose algae if the abundance of urchins is kept very low for an extended period of time [5, 42]. Partial removal even up to 66% of *C. rodgersii* in NSW barrens does not allow kelp and other foliose algae to successfully colonise [25, 43]. Although ineffective at transforming barrens, removal of some urchins can improve the quality of commercial product (roe) in the remaining animals [23]. A global review found that "sea urchin removal does not address the underlying cause of elevated sea urchin populations and is unlikely to provide a long-term solution to restore kelp forests and full ecosystem function on its own" [44].

There has been research in Tasmania on urchin removal and kelp recovery [45–47], but it is challenging to compare results from NSW and Tasmania studies due to different measurements (i.e. NSW surveys presented as percentage of original population reduction, while Tasmania surveys presented as urchin density) and ecosystems (i.e. *C. rodgersii* is native to NSW). Moreover the range extension of *C. rodgersii* in Tasmania is driven by larval dispersal through the strengthening of the EAC [48], a different ecological construct to the situation in NSW.

With the commencement of marine parks in NSW, one of the initial predictions was that the protection of urchin predators in no-take sanctuary zones may lead to a reduction in urchin numbers and associated barrens areas [49, 50]. This prediction was based on findings from overseas in which the restoration of predators within marine protected areas led to a shift from barrens to seaweed forests [51–53]. This is a field of research that is quickly developing with improved understanding of predator prey dynamics [54, 55] and the multi-decadal analysis of barrens and kelp habitat-mosaic in NSW [16, 56].

In NSW, there is no evidence of reductions in barrens areas or urchin numbers in Marine Park Sanctuary Zones [16] despite significant and widespread increases in the abundance of the predators, *C. auratus* (Snapper), *Achoerodus viridis* (Eastern Blue Groper), and *Sagmariasus verreauxi* (Eastern Rock Lobster) in sanctuary zones [57, 58]. Barrens are even more abundant inside of the sanctuary zones for Jervis Bay Marine Park than outside [59]. Research suggests that the control of *C. rodgersii* by lobsters has been overestimated. Although *S. verreauxi* (Eastern Rock Lobster) can eat up to three urchins per day when starved in aquaria [60], gut contents analysis of this species suggests that urchins may not be a key food item, with *C. rodgersii* detected in only 1% of lobsters collected over a wide latitudinal range [54]. This was corroborated by feeding trials in which *H. erythrogramma* was eaten more regularly than *C. rodgersii* by *S. verreauxi* in NSW [54] and *Jasus edwardsii* (Southern Rock Lobster) in Tasmania [55].

What do we still need to know?

Driver(s) of ecosystem shifts in NSW.
We have yet to understand the drivers of barren distribution and ecosystem shifts in NSW, particularly over long timescales (100s years). Because barrens are a stable state that have been around in NSW for a long time, and subtidal scientific surveys only began in the 1970s, we do not have historic data on barrens extent in NSW and, therefore, little evidence for their increase or the reasons behind any changes. Addressing this knowledge gap will help inform whether and how urchin barrens are managed in NSW.

Best practice monitoring for NSW populations.
There is currently no consensus on the most suitable methods required to monitor urchin barrens and *C. rodgersii* populations in NSW, and it is likely these are dependent on the monitoring purpose and scale of interest. Detecting change in *C. rodgersii* abundance and barrens cover requires scientifically designed surveys to detect change at the spatial scale of interest. Most research quantifies urchin populations using underwater visual census or imagery, while barrens can also be quantified using aerial imagery.

Role of predators on NSW urchin densities. Although elsewhere in the world evidence shows that predators control urchin barrens, in NSW the natural predators of *C. rodgersii* are unclear. It is assumed that it is large Eastern Rock Lobsters and fish such as Snapper and Eastern Blue Groper, and Port Jackson Shark, but their feeding rate and preference (size and species) for urchins remains largely unknown. Gut analysis, feeding trials, and stable isotope analysis may help establish the role of predation in structuring barrens, as would investigating the historical abundance of predators in relation to barren extent in NSW.

Integration of Traditional Ecological Knowledge in research projects. Urchins and kelp are important for many Aboriginal communities along south-eastern Australia. The local knowledge and oral histories held by these communities will prove invaluable in establishing long-term patterns and implementing suitable management actions.

Cumulative or multiple threats to kelp. Decreases in kelp cover are likely to be influenced by concurrent or cumulative stressors in addition to urchin herbivory, such as those related to climate change and associated extreme flooding events [28], heavy metals [61], or disease [62]. In addition, more severe disturbance regimes associated with climate change are likely to drive shifts between kelp and barrens ecosystems [63] and affect the success of kelp restoration efforts [64].

Efficacy of marine parks in maintaining barrens and kelp forests. In other parts of the world, marine parks have been shown to decrease barrens by providing refuge for predators that feed on urchins, but there has been no evidence of this in studies of the NSW sanctuary zones. The reasons for this are unknown, and future research can help determined if NSW barrens are naturally persistent, size of sanctuary zones precludes effects, habitat complexity is too high so small urchins can hide, or time scale too short to detect change.

Feasibility of culling and harvesting to eco-engineer barrens to kelp. In NSW, we have yet to fully understand the logistics, efficacy, and potential impacts of removing urchins and how this may vary among stakeholder groups (Traditional Owners, commercial fishers, community groups). It remains uncertain whether urchin population reduction should or could be maintained over large scales by culling, in what part of the barrens the culling would have to occur, and whether other concurrent measures would need to be undertaken (e.g. seeding reefs with kelp via green gravel [91]).

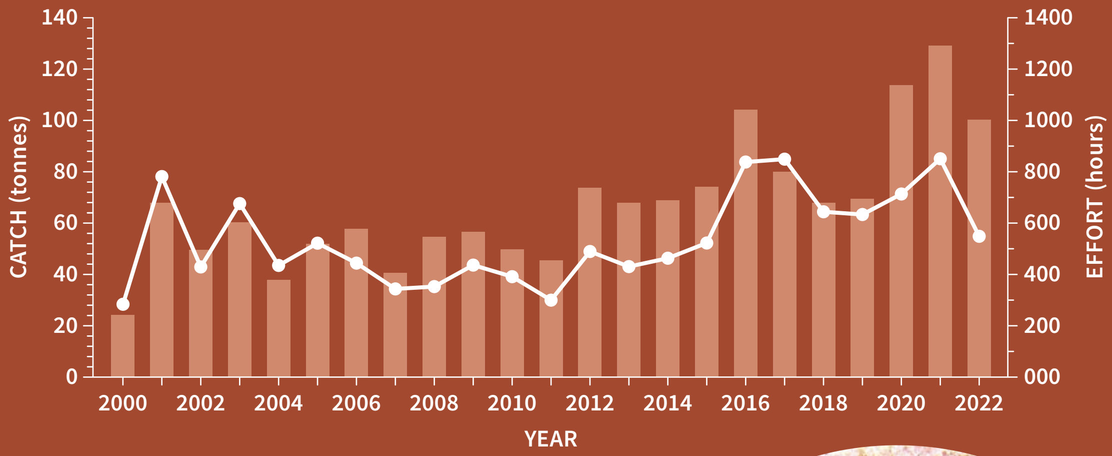
Centrostephanus rodgersii

Centrostephanus rodgersii is a native species of southeastern Australia and New Zealand [65]. It is abundant along the NSW coast, with its typical latitudinal distribution extending from Byron Bay to Wilson Promontory [1, 4, 6]. In recent decades the species has extended its range into Tasmania due to ocean warming [8] and its wide larval thermal tolerance range [66], causing loss of giant kelp ecosystems there [48]. During the day, the urchins show strong homing to crevices [4, 67], coming out at night to feed. *C. rodgersii* seems unable to directionally sense its macroalgal food and instead forages in a generalised pattern around its nocturnal home crevices [67].

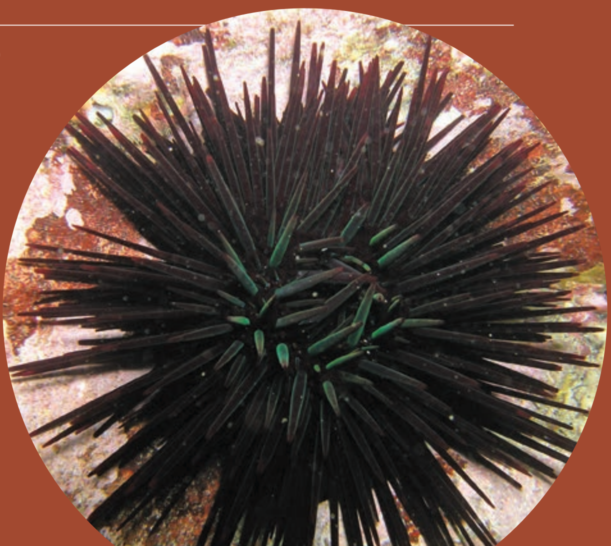
Spawning is highly synchronous and occurs in winter [68], with southern populations having a longer spawning period than northern populations [22]. The distribution and abundance of *C. rodgersii* in NSW does not have consistent spatial patterns among localities [20]. Although booms and busts in populations are consistently recorded [69], NSW populations are often relatively stable over years [1, 16]. Size frequencies among sites are similarly variable [15], and genetic diversity among populations is associated with sea surface temperature (SST) and geography rather than spatial proximity [70], likely reflecting the long larval duration (1–4 months depending on temperature) and high dispersal potential of this species [71, 72].

The main predators of *C. rodgersii* in NSW are uncertain, but may include the Eastern Rock Lobster [54], a generalist which can eat up to 3 urchins per day in captivity [60], and larger fish species such as Snapper and Eastern Blue Groper [73]. It has been suggested that a small increase in urchin abundance may be explained by removal of the larger predators through fishing [74]. Other stressors that impact urchins include ocean acidification which could result in smaller larvae [75]. The larvae of *C. rodgersii* are broadly thermotolerant and may be comparatively resilient to concurrent warming and acidification due to the presence of tolerant genotypes [66, 75].

Centrostephanus rodgersii is the main species of urchin harvested in NSW, with annual catches varying from 24 to 103 tonne per year [76], effective March to early May [22]. It is managed through the NSW Sea Urchin and Turban Shell (SUTS) restricted fishery. The greatest yield of high quality roe comes during summer and autumn from moderately-sized urchins living in vegetated habitat adjacent to barrens; roe harvested from larger urchins, within barrens, or during the spawning season was generally of a poor quality [42, 77].



Commercial catch (vertical bars) and effort (white lines) of *C. rodgersii* from the SUTS fishery.



Longspined sea urchin (*Centrostephanus rodgersii*) from Port Stephens NSW at 5 m depth.
Image: Tom Davis

NSW kelp

The dominant species of kelp along the NSW coastline is the golden or common kelp (*Ecklonia radiata*), extending from mid-latitudes (Brisbane, Geraldton) to southern Tasmania [78]. Other dominant macroalgae include *Phyllospora comosa*, extending from Port Macquarie to Robe and Tasmania [79]) and bull kelp *(Durvillaea potatorum*), extending from Tathra to southern Tasmania. The presence of *E. radiata* is correlated with depth, nutrients and herbivory, including that from urchins [19, 80, 81].

Mass mortalities and range contractions of *Ecklonia radiata* have been attributed to marine heat waves [82], storms [83], disease [84], water quality [85] and flooding [28]. Similarly, poor water quality [86] and warming and disease [84] have caused declines in *Phyllospora comosa*. While loss of kelp forests can occur quickly, natural recovery can take decades depending on the scale and previous history of the ecosystem. Herbivorous fish can also increase mortality and hinder recovery of kelp in both barrens and vegetated habitats [87] and herbivory is increasing in low latitudes where warmer waters are increasing herbivorous fish abundance [88]. Importantly, the temporal dynamics of a potential ecosystem shift to kelp forest will also be influenced by climate-driven habitat warming because of the thermal sensitivity of kelp [60] and influence of storms [28]. Compared to urchins, kelp are a recent evolutionary arrival (3 MYA) to Australia [89].

The kelp *Ecklonia radiata* at Brunswick Heads NSW (15 m depth). Image: Tom Davis

Table 1: Datasets related to Barrens in NSW.

Date	Locality[1]	Species or habitat	Metric	Reference	Key Findings
1950–2016	NSW central – south coast (21 sites, sampling duration varies among sites)	Rocky reef	Habitat types (aerial imagery)	[16]	Averaged across all sites, barrens area increased at a rate of 19.9 ± 8.4 m^2 per year per hectare of reef from 1980s–2010s. 55% of sites had stable or fluctuating (± 10% cover) barrens over this period, rather than displaying continual increases. Although the extent of shallow barrens increases with latitude, the temporal dynamics of barrens did not differ among three latitudinal regions where barrens are the most extensive. Associations between variability in barrens cover and environmental variables indicated that reef topography might pay a role in influencing barrens. Examples of long-term persistence of extensive barrens are relatively rare in other parts of the world and potential reasons for this and possible future changes are discussed.
1982–1984	Botany Bay (2 sites)	*C. rodgersii* Algae Molluscan herbivores	Cover (algae Abundance (herbivores, urchins)	[5]	Where both limpets and urchins had been removed, the cover of foliose algae continued to increase quickly and was ≈80–100% after 12 months. In areas where only urchins were removed, the increase in the cover of algae was slower, and only approached 100% after 18–24 months. Invertebrate grazers, especially *C. rodgersii* appeared to be necessary for the maintenance of the areas of crustose algae. *C. rodgersii* were found to be necessary for the continued presence of the limpets within these areas.
1983–1984	Central – south coast (4 sites)	Microscopic organisms	Abundance, richness, assemblages	[14]	The diversity of microscopic taxa in barrens rivals that of kelp forests but is composed of diminutive and less “desirable” taxa such as ephemeral algae. Recruitment of kelp and foliose brown algae was extremely low in both habitats highlighting the role of episodic recruitment as well as physical and biological processes in structuring differences in assemblages between habitats. Barrens are not biologically depauperate and the ephemeral taxa they support play an extant and emerging role in temperate reef ecology.
1986–1988	Botany Bay (5 sites)	*C. rodgersii* Algae Molluscan herbivores	Density, size (urchins only)	[69]	Following the disappearance of *C. rodgersii*, filamentous and foliose algae increased while coralline crustose algae declined, and there was a short-lived increase in limpets.

[1] Sites refer to the largest spatial category in the given study, noting that terminology varies across studies (e.g. sites could be 100s m within a single bay or 10s km along the entire NSW coast).

Date	Locality[1]	Species or habitat	Metric	Reference	Key Findings
1985–1988	NSW central coast (4 sites)	*C. rodgersii* Algae Molluscan herbivores	Density, size (urchins only)	[1]	The abundance of *C. rodgersii* changed very little during 3 years at 3 out of 4 locations. The densities of limpets, turbinids, crustose and filamentous algae similarly varied little during this period. Size frequency distributions were unimodal at two sites, but showed evidence of recruitment at the other two sites.
1985–1988	Botany Bay	*E. radiata*	Survival	[87]	There were no significant differences in survival of planted kelp between barrens and ungrazed habitats, suggesting that *C. rodgersii* has little impact on the abundance of *Ecklonia* outside sharply defined boundaries.
1985–1987	Botany Bay	*E. radiata* Molluscan herbivores	Abundance	[43]	Removal of all *C. rodgersii* caused the loss of barrens habitat and the development of foliose algae assemblages. Foliose algae did not colonise treatments in which only some (33% or 66%) of urchins were removed.
1986–1988	Botany Bay	*C. rodgersii* Benthic invertebrates Algae	Abundance, foraging behaviour (urchins only)	[4]	The density of foliose algae was reduced on boulders moved from kelp forest to barrens. The availability of shelter was sufficient for the creation of areas of barrens habitat, thus making their local distribution and that of the barrens habitat more predictable than in other temperate regions.
1988	NSW central – south coast (5 sites)	Algae Small invertebrates Rocky reef	Abundance, habitat types	[2]	Distribution of barrens habitat is not related to depth. Barrens are dominated by invertebrate herbivores, particularly sea urchins. Barrens habitat more common at southern sites.
1989	NSW south coast (5 sites)	*C. rodgersii* *Haliotis rubra*	Density, abundance	[20]	There was considerable variation in *C. rodgersii* abundance within each site, but no patterns among sites. At 20% of sampling locations, abalone and urchin densities were negatively associated .

Date	Locality [1]	Species or habitat	Metric	Reference	Key Findings
1993–1997	NSW central – south coast	*C. rodgersii* *Haliotis rubra* Rocky reef	Abundance (urchin, abalone) Habitat types (rocky reef)	[42]	The relative abundance of small (<60 mm) and medium (<115 mm) abalone in NSW increased between 1994 and 1997. There was no evidence suggesting that the abundance of sea urchins increased in the four years of the study. Very few abalone were found in Barrens habitats, and abalone were most abundant in vegetated habitats adjacent to barrens. Manipulative experiments demonstrated that by removing *C. rodgersii*, barrens habitat can be modified such that the recruitment, survival and growth of abalone is increased. The greatest yield of high quality roe was obtained from small urchins (60–80 mm) in the Fringe habitat during summer and autumn. Roe harvested from larger urchins, from the Barrens habitat, or during the spawning season, was generally of a poor quality.
1994–1995 (central-south coast) 1996–1997 (north coast)	NSW north – south coast	*C. rodgersii*	Gonad condition	[22]	Reproduction was synchronous at all locations (Coffs, Sydney, Ulladulla, Eden), consistent with response to exogenous factors (short days, lunar conditions). The major difference in reproduction among locations was in the duration of spawning. In the southern parts of its range breeding occurred over a 5 to 6 mo period, whereas at the Solitary Islands it lasted ‘1 mo. The lower reproductive output of urchins observed in the barrens habitat was attributed to the food-poor conditions typical of this habitat.
1994–1995	NSW central – south coast (3 sites)	*C. rodgersii*	Roe colour, texture, granularity	[77]	There were significant relationships among the measures of roe quality and among the covariates (test size, roe weight, total weight).
1996–1997	NSW central – south coast (12 sites)	Rocky reef	Habitat types (aerial imagery)	[15]	Barrens habitat covered an estimated 50% of nearshore reefs between Port Stephens and Disaster Bay. There was no significant correlation between latitude and representation of the Barrens habitat. There was considerable variability in turfing algae among sites within localities. There was no north–south trend in mean density of *C. rodgersii* among localities, nor was there a significant correlation between latitude and the mean density. The mean representation of *Ecklonia* forest at localities declined with increasing latitude.

Date	Locality[1]	Species or habitat	Metric	Reference	Key Findings
1996–1998	Botany Bay	*H. erythrogramma* Algae	Abundance (urchin) Cover (Algae)	[33]	Of the 6 abundant foliose algae, 2 had relatively low survivorship, while 2 had relatively high survivorship when grazed by high densities of sea urchins. Grazing by different densities of *H. erythrogramma* resulted in differences in the foliose algal community composition and for the chemically-defended D. pulchra there appeared to be a threshold sea urchin density required before its removal.
2000–2002	NSW south coast	*C. rodgersii*	Roe yield and colour	[23]	Significant improvements in both colour and yield occurred after reductions in density (as low as 33% reduction) over short periods of time (i.e. 3 months), and greater improvement was observed after two years. Urchins transplanted to habitat with an abundance of macro-algae showed significant improvements in colour and yield of roe after six weeks, although the magnitude of change depended on density and season.
2001	Sydney (3 sites)	Foliose, filamentous and crustose algae	Cover	[25]	33% of original density of *C. rodgersii* maintained barrens habitat. Macroalgae-dominated areas were only cleared when *C. rodgersii* densities exceeded those in barrens. Non-linear relationship between grazing and densities suggest that both barrens and fringe habitats are stable and still persist unless there is >33% decrease in urchins in barrens or large population increase in fringe habitats. Results imply that reducing urchin densities in barrens habitats or translocating urchins from barrens to fringe habitats will not alter algal assemblages in the short term (3 months).
2002–2011	Solitary Island region (12 sites)	Fish Urchins	Richness, abundance	[88]	Over 10 years and 0.6 °C warming, herbivory increased as kelp gradually declined and then disappeared. Concurrently, fish communities from sites where kelp was originally abundant but subsequently disappeared became increasingly dominated by tropical herbivores. Results show that warming-mediated increases in fish herbivory pose a significant threat to kelp-dominated ecosystems in Australia and, potentially, globally.

Date	Locality[1]	Species or habitat	Metric	Reference	Key Findings
2004–2006	Global (NSW component drew on data from Neil Andrews)	*C. rodgersii* *E. radiata*	Abundance (urchin) Cover (algae)	[12]	Kelp cover and urchin abundance are negatively correlated in NSW.
2004, 2010	NSW statewide (15 sites)	*E. radiata* Urchins Substrate type	Presence/ absence, cover (algae)	[19]	The distribution and cover of *Ecklonia* was not related to sea surface temperature or latitude. Instead, depth and the presence of urchins best explained the presence of *Ecklonia* with the addition of nutrients and substrate in explaining percent cover of *Ecklonia*.
2005–2006	Southeastern Australia, Lord Howe Island, New Zealand	*C. rodgersii*	Genetic diversity (6 loci)	[70]	There was weak genetic differentiation and no isolation-by-distance over 1000s km among samples from eastern Australia and northern New Zealand. Along the SE Australian coast, fine-scale genetic structure was associated with sea surface temperature (SST) variability and geography. The optimal scale for fisheries management and reserve design should vary among localities in relation to regional oceanographic variability and coastal geography.
2006–2009	NSW statewide (15 sites)	Rocky reef	Habitat types (towed video)	[18]	Barrens usually occurs at depths greater than 2 metres. It is devoid of macroalgae but is often covered with encrusting coralline algae, small numbers of sessile invertebrates and numerous limpets and snails which graze on the algae. There is a strong correlation between the types and amount of algal cover and the abundance of the Longspined urchin, *C. rodgersii*.
2008–2012	Batemans Bay (9 sites)	Fish Macroinvertebrates Substrate type (including barrens)	Abundance	[27]	There was a greater abundance of sea urchins and barrens habitat outside relative to inside the marine park, but this was driven by a single site outside the park.
2009–2013	NSW statewide (~40 sites, sampling duration varies among sites)	Rocky reef	Habitat types (aerial imagery)	[17]	Barrens were more common in southern NSW and absent from northernmost sites. There was no positive correlation between the cover of subtidal urchin-grazed barrens and human population.

Date	Locality[1]	Species or habitat	Metric	Reference	Key Findings
2019	NSW statewide (6 sites)	Urchin Fish Habitats	Density, abundance (urchin, fish) Assemblages (fish, habitats) Percent cover (habitats)	[7]	Urchin density was found to increase with increasing latitude, although urchin densities in Sydney were lower than in Port Stephens. Latitude, average depth, cross-shelf distance, wave exposure and coastal aspect were the environmental variables that best explained habitat assemblages including urchin barrens. Coverage of the kelp *Ecklonia radiata*, densities of the urchin *C. rodgersii*, and coral cover were also confirmed as potential valuable biological indicators of climate-driven changes. Urchin density was positively correlated with cover of barrens habitat. Abundance of carnivores was generally higher at higher latitudes, which were dominated by barrens habitat, while invertivores, herbivores and planktivores were generally more abundant at lower latitudes, which were dominated by sponge habitat.
2020	NSW statewide (23 sites)	Urchin Kelp	Density (urchins) Percent cover (kelp)	[90]	Urchin densities all varied latitudinally with sea surface temperature and current strength. Coverage of the kelp *Ecklonia radiata*, densities of the urchin *C. rodgersii*, and coral cover were also confirmed as potential valuable biological indicators of climate-driven changes.
2019–2021	South coast (6 sites)	Kelp Abalone	Diver observations	[41]	8 hectares of barrens were culled of *C. rodgersii*. Barrens were subsequently transformed to macroalgal assemblages based largely on anecdotal observations. Roe quality of remaining urchin improved after culling, although confounded with seasonal variation in product quality.

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