THE HON TANYA PLIBERSEK MP
MINISTER FOR THE ENVIRONMENT AND WATER

April 2023

Invitation: Seeking ambitious and innovative ideas to halt and reverse decline in our biodiversity

Globally, we have seen a significant decline in biodiversity. In the last 200 years, Australia has lost 34 mammals to extinction, more than the rest of the world combined. And since the national environmental law was introduced in 1999, the list of threatened species and ecological communities has grown by more than a third.

On 19 December 2022, Parties to the United Nations Convention on Biological Diversity adopted the *Kunming-Montreal Global Biodiversity Framework*. Australia played a positive role in negotiating a strong framework that will drive global action on biodiversity conservation for the next decade. Now we must shift our focus to being a global leader in implementing the framework, including its 2030 mission to halt and reverse biodiversity loss and put nature on a path to recovery.

To halt further species loss and reverse this decline, together we need to take action on three key challenges: climate change; habitat loss; and invasive species.

The Government has committed to:

- **climate change** - reduce our emissions by 43% by 2030, on a path to net zero by 2050.
- **habitat loss -** protect and conserve 30% of our land by 2030, which will see us add 60 million hectares of our landmass to the protected and conserved area estate over this decade. This will contribute to the Government commitment to accelerate national efforts towards a target of zero new extinctions.
- **invasive species** - reduce the impact of feral cats, foxes, Gamba Grass, Myrtle Rust and new environmental invasives on priority species and places in the *Threatened Species Action Plan 2022-32*.

In December 2022 the Government released its response to the Samuel Review of our national environmental laws, the *Nature Positive Plan: better for the environment, better for business*. The response is the most comprehensive reform of Australia's national environmental laws in over two decades. Alongside these law reforms, we need more on-ground action to protect and restore nature. Ambitious, collective action will be key to success.

To that end, I am seeking ambitious and innovative ideas to achieve better, longer lasting improvements for our biodiversity from governments, the private sector, First Nations peoples, NGOs, and philanthropic organisations. Specifically, I invite you to pitch innovative ideas on how we can work together to:

- expand public land conservation, including through growing national parks
- expand private land conservation, including in ways that increase productivity, promote resilience to climate change and improve outcomes for nature

- expand areas of land and sea Country managed by Indigenous groups as protected or conserved areas for biodiversity conservation and in accordance with Traditional Owners' aspirations
- establish land and water packages that deliver water and environment outcomes and meet the aspirations of First Nations people
- deliver solutions to environmental challenges, such as controlling feral species and using of technology to track the health of our environment.

Ideas may include opportunities to build partnerships that leverage government, private sector, and philanthropic investment in biodiversity conservation, or identify high priority areas of importance for biodiversity conservation.

Ideas gathered through this process will inform Australia's efforts to halt and reverse biodiversity loss and put our environment back on a path of recovery. I plan to hold a roundtable later in 2023 to discuss the ideas with the greatest potential.

Please submit your ideas by 31 May 2023 to NRS.environment@dcceew.gov.au.

If you wish to discuss your idea(s) in the interim, please feel free to reach out to the Department of Climate Change, Energy, the Environment and Water Deputy Secretary, Mr Dean Knudson (0477 322 093).

I look forward to discussing your innovative and ambitious ideas to halt and reverse the decline in our biodiversity.

Tanya Plibersek

TANYA PLIBERSEK

References

Nature Positive Plan: better for the environment, better for business

Australia’s Strategy for Nature 2019-2030

National Reserve System

Threatened Species Action Plan 2022-2032

National Landcare Program

Reef 2050 Plan

Murray-Darling Basin Plan

Response to call for ideas to halt or reverse biodiversity decline

30 May 2023

Professor Hugh Possingham – Biodiversity Council Chief Councillor

The Biodiversity Council brings together leading experts including Indigenous knowledge holders to promote evidence-based solutions to Australia's biodiversity crisis. The Council was founded by 11 universities with the support of Australian philanthropists.

Threatened Plant Action Groups: the low hanging fruit of a zero extinction strategy

The most cost-effective way to slow the rate of extinctions in Australia is for the Federal Government, with state and local government support, to invest in a national network of threatened plant action groups.

Context

- Most of Australia's threatened species list are plants: more than two-thirds of the almost 2000 species.
- Australia has many more plant species than mammals.
- Plants contain more useful genetic diversity than vertebrates.
- Almost all plants can be easily secured by local community groups with technical guidance from natural resource management bodies and state governments.

Proposal

- A tiny investment in 10 *community-led* Threatened Plant Action Groups ($1 million a year each) would secure several hundred plant species.
- Similar groups - like the South Australian Threatened Plant Action Group - already exist, demonstrating a proven model of delivery. (See page 3 of this document).
- At least three groups would need to be in Western Australia.
- The return on investment from securing plant species is often 10 to 100 times bigger, per species, than vertebrates (which require a much bigger investment).

For more information contact:

Ilsa Colson
Executive Director
Biodiversity Council
Ilsa.colson@unimelb.edu.au

[On the following page please find an example of what a small South Australian community-led Threatened Plant Action Group can do with almost no funding. Imagine what they could do with one million dollars a year.]

Biodiversity Council

Response to call for ideas to halt or reverse biodiversity decline

30 May 2023

Professor Gretta Pecl – Institute of Marine and Antarctic Studies, University of Tasmania; and the Centre for Marine Socioecology, University of Tasmania

The Biodiversity Council brings together leading experts including Indigenous knowledge holders to promote evidence-based solutions to Australia's biodiversity crisis. The Council was founded by 11 universities with the support of Australian philanthropists.

Context

See attached submission to the Senate Inquiry into Climate-Related Invasive Species – (Keane, Ling et al 2022)

- Australia's temperate reef system stretches across 71,000 square kilometres, supports thousands of species, and contributes more than $10 billion annually to Australia's economy through fisheries and tourism (Bennett et al 2016).
- Climate change is leading to the redistribution of life on earth – species at the cooler edge of their distribution extending into new areas that are now warm enough, but contracting at the warmer range edge where conditions have become too warm. The result is local losses and gains of species at an unprecedented rate. IPCC (2022) estimates 50% of species globally have already shifted.
- Australia's temperate reefs have among the highest rates of climate-driven species redistribution documented globally (Gervais, Champion and Pecl 2021).
- Much is yet to be learnt about the impacts, threats and opportunities of climate-driven marine species redistribution. As these impacts are complex, multi-sector and cross-jurisdictional, a national approach is required.

- Whilst some redistributions may present opportunities (ie new fisheries species, which would also require specific research and management), some redistributing species represent considerable threats. One such example is the climate-driven spread of the Longspined Sea Urchin in eastern Tasmania:
    - Populations have exploded from a few individuals in 1978 to an estimated 20 million 40 years later.
    - Due to overgrazing, the species represents one of the biggest marine environmental threats to south-eastern Australian kelp forests and their ecosystems.
    - Its spread has resulted in the local loss of more than 150 species that live in Tasmanian kelp beds.
    - It also threatens local fisheries such as Blacklip Abalone (annual value approximately $80 million) and Southern Rock Lobster (annual value approximately $100 million).

Recommendation to Halt or Reverse Biodiversity Decline:

- **Establish a Centre for Research into Climate-Driven Marine Species Shifts** – to grow knowledge and understanding of threats and opportunities related to marine species redistributions caused by the changing climate; develop strategies for managing risks; and advise on adaptation solutions.
- **Implement a Giant Kelp Forest Recovery Plan and Reforestation Strategy** – to respond to the climate-driven loss of some 95 per cent of this ecological community across eastern Tasmania, prompting its endangered listing under the EPBC Act in 2012.
- **Inject funds into a Longspined Sea Urchin Management Plan** – to investigate, develop and implement potential solutions to its impacts.

For more information contact:

Ilsa Colson
Executive Director
Biodiversity Council
Ilsa.colson@unimelb.edu.au

Senate Inquiry into Climate-Related Marine Invasive Species

October 2022

20 October 2022

Committee Secretary
Senate Standing Committees on Environment and Communications
PO Box 6100
Parliament House
Canberra ACT 2600

Climate-related marine invasive species

On the 5 September 2022, the Senate referred an inquiry into the spread of "*Climate-Related Marine Invasive Species"* (scientifically referred to as range-extending or range-shifting species) to the Environment and Communications References Committee. The key focus of the inquiry is the dramatic impact of the Longspined Sea Urchin (*Centrostephanus rodgersii*) which has undergone range-extension from New South Wales to Tasmania. The Institute for Marine and Antarctic Studies (IMAS) at the University of Tasmania welcomes this inquiry, having researched the species ecology, its impacts and control options for the past two decades.

In eastern Tasmania, the Longspined Sea Urchin has undergone a population explosion from first records of two positively identified individuals in 1978, to 11 million in 2002, to an estimated ~20 million in 2018. During this period, grazing of kelp bed habitats and formation of barrens by this urchin has rapidly expanded to constitute 15% of reefs along Tasmania's east coast. The urchin represents the single largest and most immediate marine environmental threat to kelp-dominated reef ecosystems in south-eastern Australia. Extensive barrens threaten reef ecosystems from ~2-40m depth with local loss of hundreds of kelp-associated species, including lucrative fishery species such as abalone and lobster, plus the iconic weedy seadragon, as well as downgrading social, economic and cultural values.

IMAS is a national leader in researching the threat of sea urchin grazing, identifying control options and associated opportunities. As such we consider our submission, which includes the contributions of 18 researchers, to provide a key evidence-base for this inquiry towards effective solutions to control the urchin while dually capitalising on the opportunities they present.

IMAS recommends:

1. Development and execution of a regional Longspined Sea Urchin management plan, encompassing the varied ecological/social/cultural/economic values across the urchin's endemic and extended ranges.
2. Funding of $50 million to support scalable solutions to:
   i. increasing resilience of kelp beds through urchin harvesting and predator stock rebuilding.
   ii. restore kelp where it has been lost to urchin overgrazing causing extensive barrens.
   iii. enhance urchin fisheries nationally, including product, by-product and export market development.
3. Activation of a Giant Kelp Forest Recovery Plan and $6 million funding for a Giant Kelp Forest Reforestation Strategy for this endangered ecological community.
4. Establishment of a *Centre for Research into Climate-Driven Marine Species Shifts* to address climate-related impacts on marine species distributions, ecosystems and industries focussed on developing adaptation solutions and risk mitigation within and beyond Australia.

Lead authors: John Keane (10-years topic expertise – fisheries), Scott Ling (22-years topic expertise - ecology).

Other contributors: Katie Cresswell, Craig Johnson, Elisabeth Strain, Cayne Layton, Scott Bennett, Jeffrey Wright, Jemina Stuart-Smith, Jawahar Patil, Gretta Pecl, Jennifer Smith, Harriet Walker, Neville Barrett, Caleb Gardner, Sean Tracey, Vanessa Lucieer, Catriona MacLeod.

Inquiry into climate-related marine invasive species

Terms of Reference

The spread of climate-related marine invasive species, particularly long spined sea urchins (*Centrostephanus rodgersii*) along the Great Southern Reef, with particular reference to:

(a) the existing body of research and knowledge on the risks for and damage to marine biodiversity, habitat and fisheries caused by the proliferation and range shifting of non-endemic long spined sea urchins;

(b) management options, challenges and opportunities to better mitigate or adapt to these threats, and governance measures that are inclusive of First Nations communities;

(c) funding requirements, responsibility, and pathways to better manage and co-ordinate stopping the spread of climate-related marine invasive species;

(d) the importance of tackling the spread of invasive urchin 'barrens' to help facilitate marine ecosystem restoration efforts (such as for Tasmanian Giant Kelp *Macrocystis pyrifera*); and

(e) any other related matters.

Introduction

The Institute for Marine and Antarctic Studies (IMAS) is a teaching and research institute of the University of Tasmania in Hobart, Tasmania. IMAS was established in 2010, building upon The University's partnership with CSIRO Oceans and Atmosphere and the Australian Antarctic Division. The Institute aims to improve the understanding of temperate marine, Southern Ocean, and Antarctic environments, their resources, and their roles in the global climate system through research, education, and outreach. IMAS was established with core research and education capabilities, through expertise in the three following foundational themes:

- *Fisheries & Aquaculture* – supporting long-term sustainable harvest of marine resources
- *Ecology & Biodiversity* – determining structure and functioning of marine ecosystems
- *Oceans & Cryosphere* – observational oceanography, modelling, cryospheric research

IMAS regards the range extension of the Longspined Sea Urchin, *Centrostephanus rodgersii*, as a matter of national significance and a priority for our marine environment, requiring coordinated effort across the marine regions of impact - Tasmania, Victoria, and New South Wales. IMAS researchers have been studying the species ecology, its impacts, and control measures for over 20-years (see bibliography). As such IMAS is well-placed to contribute in a valuable way to the senate inquiry, to lead research, monitoring and evaluation, as well as work with key stakeholders to execute mitigation efforts and/ or develop focussed fisheries. IMAS also leads several large regional, national and international initiatives at the forefront of understanding, modelling and adapting to the broader issue of climate-driven species re-distribution in marine systems, including leading the most cited research in this area globally.

Australia's temperate reefs

Australia's temperate reef system covers an area of 71,000 square kilometres. It supports thousands of marine species, and contributes more than ten billion dollars annually to Australia's economy through fisheries and tourism (Bennett et al. 2016). IMAS researchers play a lead role in tracking the extension and displacement of climate affected marine species in Australia and globally, which was catalysed in Tasmania by the discovery of the dramatic range-extension, population explosion and kelp bed overgrazing by the Longspined Sea Urchin. Discovery of this phenomenon across eastern Tasmania and its' destruction of reef habitat, including endangered Giant Kelp Forest communities which support thousands of species, and upon which important recreational and commercial fisheries depend, was the result of research spanning the three foundational themes at IMAS. This required the integration of biology, subtidal ecology, fisheries, biogeography, benthic and water column habitat mapping, oceanography, remote sensing, mathematical modelling, statistics, and management.

Since the initial discovery of this large-scale environmental problem, much research effort has been placed on understanding the ecological mechanisms underpinning the sea urchins' arrival and impact in Tasmania and searching for opportunities to minimise the risk of its destruction on reef flora and fauna. The population exploded in Tasmania from very few individuals in 1978, to 11 million in 2002, and then reached a staggering ~20+ million by 2018 (Ling & Keane 2018). Longspined sea urchin barrens have rapidly expanded along Tasmania's east coast, increasing from a total cover of 3% to 15% during this period (Ling & Keane 2018). Ultimately the urchin's destructive grazing creates extensive barren grounds (1 - 100's of hectares) devoid of kelp habitats resulting in loss of fisheries production and biodiversity which threatens the commercial and recreational viability of temperate reef ecosystems.

More broadly, the loss of diverse kelp systems downgrades social, economic, and cultural values and reduces overall socio-ecosystem resilience. **Modelled projections of observed rates of population increase and overgrazing indicate that unless there is meaningful response to this threat, half of all reefs in eastern Tasmania are likely to become urchin barren grounds by mid-2030s.** IPCC (2022) assessed with 'high confidence' kelp loss in south east Australia from urchin overgrazing as one of several "**Key risks that have potential to be severe but can be reduced substantially by rapid, large-scale and effective mitigation and adaptation**". In recent years, the Tasmanian Government with research support from IMAS has supported the development of a Longspined Sea Urchin fishery, now the largest reef fishery by weight annually in eastern Tasmania (~500 tonne per year; Appendix I), which has provided an important opportunity to mitigate the risk of overgrazing.

Scalable solutions

IMAS researchers are guiding efforts to combat urchin overgrazing over broad scales, while pioneering scalable techniques to aid the recovery of endangered Giant Kelp Forests through innovative partnerships with industries and non-government organisations. The Tasmanian State Government is actively undertaking Ecosystem Based Reef Fisheries Management, where the links between reef ecosystem components (humans, finfish, lobsters, abalone, urchins, and kelp) require holistic management. These linkages are complex, and the evidence-based management of the Tasmanian Government relies heavily on IMAS research. IMAS is also leading several reef restoration initiatives with increasing focus on seaweed solutions for people and the environment, plus has a threatened marine species research team.

Demonstrating the track-record of IMAS in leading cross-institutional projects in temperate reef research, it was recently awarded funding from the philanthropic *Ian Potter Foundation* for the project entitled "*Safeguarding natural values of the Great Southern Reef*" which spans government agencies and researchers from all temperate state of Australia. Other cross institutional projects include those with *Sea Forest Foundation* – "*Upscaling the restoration of endangered Giant Kelp Forests in Tasmania*"; and *The Nature Conservancy – "Kelp forest restoration in Tasmania: opportunities to restore kelp forest ecosystems for the benefit of people and nature".*

Local, regional and global understanding

IMAS researchers are currently extending their research portfolio on reef ecosystem collapse and recovery across temperate, sub-tropical and tropical systems, including focus on the Longspined Sea Urchin across its entire distribution spanning south-eastern Australasia, including mainland and offshore islands of NSW, eastern Victoria, Tasmania, and northern New Zealand.

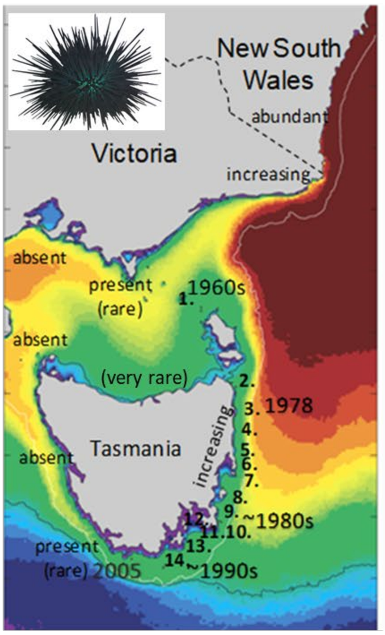
Below we collectively address each of the Senate Inquiry Terms of Reference (ToR) (a) through (e).

(a) The existing body of research and knowledge on the risks for and damage to marine biodiversity, habitat and fisheries caused by the proliferation and range shifting of non-endemic long spined sea urchins;

Overgrazing impacts

Of the approximately 77 marine range-extending species recently documented to have undergone climate-driven extension across Australia (e.g. http://www.redmap.org.au/), the Longspined Sea Urchin is the most ecologically important (see timeline, **Fig. 1a**) due to its ability to overgraze kelp habitats and maintain an alternative and hyper-stable barren grounds (Hill et al. 2003; Ling 2008, 2013; Ling et al. 2009a; *reviewed by* Ling et al. 2015; Byrne & Andrew 2020). Across Australia's temperate reefs, no other benthic herbivore has as large an effect on shallow reef communities as the Longspined Sea Urchin (e.g., Fletcher 1987; Andrew 1991; Andrew & Underwood 1992; Ling 2008; Ling et al. 2015; see **Fig. 1b**).

The flow-on impacts of kelp bed overgrazing by this urchin are dramatic, with local loss of over 150 species that live amongst Tasmanian kelp beds (Ling 2008), which threatens parts of the lucrative fisheries for Blacklip Abalone (*Haliotis rubra*; total annual gross value of production ~$80 million) and Southern Rock Lobster (*Jasus edwardsii*; total annual gross value of production ~$100 million) (Johnson et al. 2005; Strain & Johnson 2009; Johnson et al. 2011). Thus, when population increases in Tasmania became evident in the early 2000s, this urchin was rightly considered the single biggest threat to the structure and function of rocky reefs ranging to 40m (Johnson et al. 2005, 2011; Ling & Keane 2018).

a.


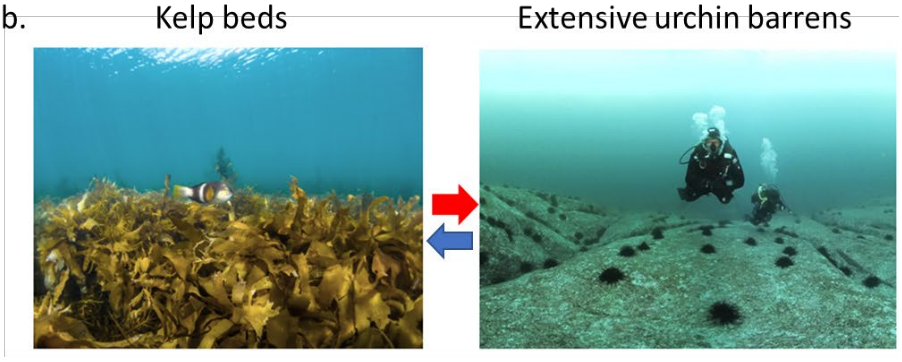
b.


Figure 1 (a.) Map of south-eastern Australia showing the dominant influence of the warm East Australian Current flowing south from NSW to eastern Tasmania, overlaid is the year of first discovery of the Longspined Sea Urchin along the coast and the 14 long-term Tasmanian monitoring sites. The relative abundance and absence of the urchin across SE Australia is also overlayed. **(b.)** The dramatic overgrazing transition from kelp beds (left) to extensive barrens (right) as is progressively occurring in eastern Tasmania, recovery of kelp can occur within 18-24 months providing urchin densities are sufficiently reduced to reverse this shift (Ling 2008). (Photocredits: kelp bed - Scott Ling; barren - John Keane).

Dynamics of overgrazing

In the 15-years since the first baseline survey of the sea urchin population across eastern Tasmania in 2001 (Johnson et al. 2005, 2011), the threat of kelp bed overgrazing became increasingly apparent, with the expansion of barrens compounding at a rate of 10.5% per annum (Ling & Keane 2018). Projecting this rate of expansion indicated that up to 50% of reef habitat in eastern Tasmania could be impacted by barrens by 2030 (Ling & Keane 2018), which would reflect the extent of urchin dominated reefs along the central NSW coastline (Andrew & O'Neill, 2000; Glasby and Gibson 2020). Importantly, the presence of Longspined Sea Urchins in low abundance and/or the presence of small barrens patches (1-10s square metres) within kelp beds is not problematic for fisheries production or biodiversity more generally. It is only problematic when the sea urchin's abundance builds towards the tipping-point of overgrazing (approx. 2.0 urchins per m^2), across hectares to hundreds of hectares of the reef, that collapse to extensive barrens occurs (Fig 1b; Ling et al. 2015; Ling & Keane 2018).

Once sea urchins consume all the macroalgal stands they switch diet to feed on attached micro-, filamentous- and encrusting-algae (*reviewed by* Ling et al. 2015). Importantly, only relatively few urchins are required to maintain barrens once they form, meaning that almost all urchins need to be removed for kelp to recover (recovery tipping-point is approx. <0.2 urchins m^{-2}), thus extensive barrens can be hyper-stable in the long-term as witnessed across much of NSW (Ling et al. 2015; Glasby & Gibson 2020) and as is now apparent in some eastern Tasmanian locations (Ling & Keane 2018, 2021). From the Tasmanian experience, first signs of grazing by the Longspined Sea Urchin occur as small "incipient barrens" (1-10s m^2 in size) within otherwise healthy kelp beds (Johnson et al. 2005, 2011; Flukes et al., 2012). These patches can then coalesce with neighbouring patches to form larger scale features and **the rapidly accelerating prevalence of incipient barrens across the east coast of Tasmania is a major cause for alarm** (Ling & Keane 2018, 2021).

The key to managing the problem of urchin overgrazing is to recognise there are different collapse and recovery pathways (Fig. 2), that is, "*an ounce of prevention is worth a ton of cure*" when it comes to finding solutions. The "*ounce of prevention*" required to maintain urchins below the overgrazing tipping-point can be assisted by having high abundances of sea urchin predators (Ling et al. 2009; Ling & Keane 2021). Harvesting urchins along with maximising predator abundance further enhances the resilience of kelp beds. Once kelp has been overgrazed, options for kelp recovery are limited and require "*a ton of cure*" given large numbers of urchins need to be removed to reach the point of kelp recovery (blue pathway, **Fig. 2**). Rebuilding naturally abundant predators on extensive barrens over 12-yrs did not control urchins to the point of kelp recovery (Ling & Keane 2021), with prior modelling indicating much more than 50-years is required before predators may be able to exert sufficient predation pressure to achieve kelp recovery (Johnson et al. 2013). Additionally, fully parameterised models of the interactions between urchins, kelp and lobsters also indicate that, without intervention to rebuild kelp bed resilience, 50-60% of eastern Tasmania reefs are likely to transition to extensive barrens within 20-30 years (Johnson et al. 2013; Marzloff et al. 2016).

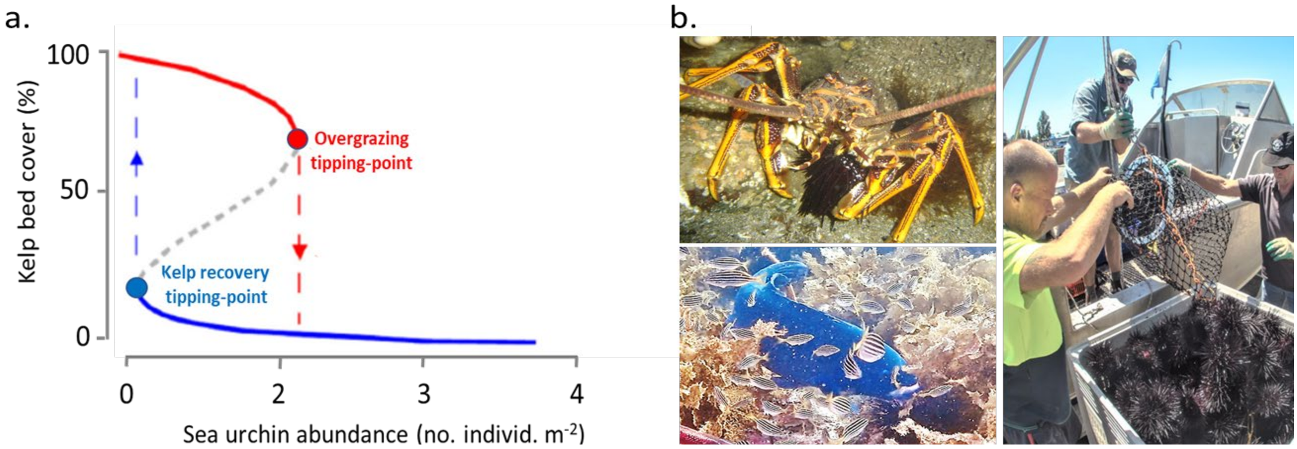


Figure 2. (a.) Dynamics of Longspined Sea Urchin overgrazing. Starting with high kelp cover, urchin abundance can build within kelp beds and cause overgrazing when urchin abundance exceeds approx. 2 individuals/m^2 (red pathway). Once overgrazing has collapsed kelp beds to extensive barrens, recovery of kelp does not simply occur by reducing urchin abundance to below 2 individuals/m^2, instead urchin abundance must be driven down to less than 0.2 individuals/m^2 for kelp recovery to occur (blue pathway) the difference between these tipping-points is referred to as the 'magnitude of hysteresis' and it is why extensive barrens are hyper-stable. **(b.) Kelp bed resilience.** The risk of Longspined Sea Urchin abundance reaching the overgrazing tipping-point can be minimised by rebuilding naturally high abundances of urchin predators including large rock lobsters (top left; *after* Ling et al. 2009; Ling & Keane 2021) and spatially targeted harvest of urchins within kelp beds (right); bottom left is an Eastern Blue Groper (*Achoerodus viridis*), a specialist urchin predator, preying on a Longspined Sea Urchin within a south coast NSW kelp bed (photocredit: Scott Ling).

ToR (a) Key points and recommendations

1. Longspined Sea Urchins are undergoing range-extension and sustained population increases, causing dramatic overgrazing in southeast Australia.
2. Productivity of commercial reef-based fisheries and kelp associated biodiversity collapses once extensive barrens are formed.
3. There is a need to rebuild kelp bed resilience to reduce the risk of extensive barrens formation 'before it is too late'.
4. Extensive barrens are hyper-stable and very difficult to rehabilitate (due to 'hysteresis'), requiring much more drastic intervention to achieve kelp recovery at meaningful scales.

(b) Management options, challenges and opportunities to better mitigate or adapt to these threats, and governance measures that are inclusive of First Nations communities;

Management challenges – distribution and values

Management of the Longspined Sea Urchin across both its extended and endemic range presents a challenge given spatially varying ecological/social/cultural/economic values of the reefs contained within. For example, management objectives for a reef system in northern NSW, within the urchin's native range, will be different to a historical Giant Kelp dominated reef system in southern Tasmania undergoing restoration, or an ecologically diverse hotspot supporting recreational (dive) activities. **A national management plan needs to be developed with Target Reference Points in urchin abundance and barren extent within reef systems at appropriate scales**. This process will be aided by the development of marine spatial planning tools (e.g., Tasmanian Marine Atlas; https://www.frdc.com.au/project/2019-111) encompassing all ecological and stakeholder values.

Recruitment of urchins into its extended range has been driven initially by larval flows from urchin stocks within the endemic northern range. Thus, eradication of the urchin from its extended range is not feasible. However, **limiting the impact of the urchin within this region is possible and should be prioritised with long-term management strategies**. Managing the urchin threat must centre around two key components: 1) prevention of extensive barren formation (rebuilding kelp bed resilience), and 2) restoration of extensive barrens where kelp habitat has been lost. **Stakeholders need to be acutely aware that there are more effective and affordable options to prevent overgrazing in the first place, while rehabilitating extensive, hyper-stable, extensive barren grounds once formed is more problematic and will inevitably involve substantial effort.**

Management options

Despite potential varied management objectives across jurisdictions/reefs, the suite of tools available to manage the Longspined Sea Urchin, as well capitalise on opportunities, are universal. Towards developing and delivering on a regional Longspined Sea Urchin strategy, **IMAS has been researching management options for Longspined Sea Urchin control for two decades (Table 1). Options that can both be rapidly implemented and have timely large-scale impact on urchin populations and associated barrens are currently limited to diver control mechanisms**. These vary from an unrestricted and/or subsidised harvests (Appendix I), through to paid 'take-all' harvests (all size classes removed) and culling activities (killing underwater). Each variant has been trialled in Tasmania and can be applied to individual reef systems to meet management objectives (Target Reference Points). Beyond diver control, additional mechanisms are available to increase reef resilience and reduce risk over the longer term, such as stock enhancement of predators (e.g., Rock Lobster, large predatory fish). The *Tasmanian East Coast Rock Lobster Stock Rebuilding Strategy* was implemented in 2013 to both rebuild lobster stocks for fisheries production and enhance reef resilience against urchins. Further urchin control mechanisms have been proposed but require additional R&D and/or are untried, including aquaculture ranching, quickliming, robotics and futuristic genetic methods (Table 1).

Opportunity in the threat

While the Longspined Sea Urchin threatens reef ecosystems, dependent lucrative fisheries, cultural and social values in some regions, it also provides **significant opportunities, across all jurisdictions, given that urchin roe can have economic value**. This opportunity should be capitalised on whether the purpose be mitigating threats or maximising resource utilisation. In Tasmania the commercial Longspined Sea Urchin fishery has grown to ~500 tonnes pa (2,500 t total since 2009), stimulating regional employment and economic activity while offsetting urchin control costs. Fundamental to the development of the large-scale fishery in Tasmania have been harvest subsidies. The subsidies were introduced in 2016 to stimulate and accelerate the processing sector but have subsequently been spatially manipulated to direct harvest to meet management objectives (Appendix I; Creswell et al. 2019, 2022); currently ~40% of the Tasmanian harvest is free of subsidy. The latest Tasmanian surveys and data modelling show the impact of the fishery on the urchin population, significantly reducing the rate of population expansion. Kelp recovery is now evident in some heavily fished sites (Appendix I).

Nationally, the largest opportunity resides in NSW where the total biomass of Longspined Sea Urchin was conservatively estimated at 52,000 t, with about 22,000 t in fringe habitat and about 30,000 t in barrens

(Worthington and Blount 2003). Here it is feasible for a sustainable fishery with harvests up to 1,000 t pa to be developed (Worthington and Blount 2003). Longspined Sea Urchin fisheries would significantly benefit from industry investment and support (Campus 2021). Knowledge and expertise gained developing the fishery in Tasmania could be drawn upon to sustainably develop the fishery within its native range. Opportunities also exist to restore lost kelp reefs to support productive fisheries for lucrative Abalone and Rock Lobster; urchin impact is one stressor influencing cuts to the Total Allowable Catch for these fisheries across southeast Australia in recent decades. Translocation of Abalone and Rock lobster into recovered kelp ecosystems may be a strategy to expedite their stock rebuild.

Limitations and resolution

While intense urchin harvesting has been demonstrated to facilitate kelp recovery, it has some limitations relating to spatial coverage, urchin density, size selectivity, roe quality and depth (Table 1; Appendix II). When unmanaged, harvest is naturally concentrated in regions that return maximum financial reward to divers. However, a suite of methods utilising harvest subsidies and diver payments can overcome most of these challenges and spatially redirect and/or concentrate harvest in targeted areas to reach management objectives (Appendix I), while simultaneously returning social, cultural, economic, and ecological benefits. **Long term harvest-based solutions need to increase product value (e.g., Campus 2021) and/or develop a sustained subsidy funding source.** To inform management, IMAS has developed modelling capability to examine the population effects of different rates of urchin removal (Appendix I). A further key challenge for a large-scale urchin processing sector is urchin processing waste, which is totalling 100's of tonnes pa. IMAS, in partnership with industry, are developing methods for waste processing. Semi-commercial field trials of an organic soil conditioner/ fertiliser are highly promising but would benefit from further investment (Appendix III).

One key limitation of diver control methods is the depth at which they can operate, the deeper the dive the less time available given decompression limitations (Table 1). Use of Nitrox (oxygen enriched air) has increased harvest depths from ~18 m to ~25 m. However, substantial extensive barrens exist below this depth. In Tasmania ~40% of barrens are within the 25-40 m depth range (Ling & Keane 2018). At these depths controls are currently limited; there is known localised recreational culling at these depths at a few recreationally important dive sites, and rebuilding of predators (lobsters) is underway, but may take decades before becoming ecologically meaningful (Table 1). Tackling the problem at these depths, will require intensive and expensive technological intervention. Two candidates to kill urchins at these depths are quicklime (Keane 2021) and autonomous (i.e., untethered) underwater vehicles able to identify and kill urchins *in situ* (Appendix IV). Both require substantial R&D&E to become feasible and will require ongoing funding to operate (Table 1).

Lobster predation has been shown to build reef resilience and stem barren formation in healthy reefs (Ling & Keane 2021), but may be less effective in habitats where preferred prey (e.g., Blacklip Abalone and Shortspined Sea Urchin) is abundant (Smith et al. 2022; Table 1)). The rate of predator rebuilding is limited by recreational and commercial take, and while increasing catch restrictions will increase rebuilding rates, it is not without social, cultural and/ or economic sacrifice (Table 1). In contrast, there is no evidence from large-scale field experiments (Ling & Keane 2021), or modelling (Johnson et al. 2013; Marzloff et al. 2016), that rebuilding lobster populations alone can be effective at rehabilitating extensive barrens, even in the longer-term.

ToR (b) Key points and recommendations

1. Develop a national Longspined Sea Urchin management plan, including Target Reference Points for urchin abundances and acceptable extent of barrens habitat at appropriate spatial scales, encompassing the varied ecological/social/cultural/economic values across the urchin's endemic and extended ranges.
2. Prioritise harvesting as the central urchin management control option within dive-able depths and invest in product, by-product and export market development.
3. Employ harvest subsidies nationally to enhance fisheries and/or spatially target problematic urchin populations.
4. Employ targeted urchin removals/culls for habitat protection and restoration of reefs with ecological/social cultural/economic value.
5. Rebuild predator stocks to increase kelp bed resilience.
6. Support R&D for urchin control in deeper water.

Table 1. Summary of available and potentially novel Longspined Sea Urchin control options for building resilience of kelp beds (prevention) and recovering extensive barrens (restoration). Green cells indicate effective solutions; orange indicates local effectiveness given current technologies and/ or there is considerable uncertainty in effectiveness; red cells indicate ineffective solutions. Success of control over the long-term will require monitoring and evaluation, as well as the integration of multiple control options within specific areas (e.g., the harvesting of urchins combined with rebuilding lobsters (nocturnal urchin predators) and fishes (typically diurnal urchin predators) within kelp beds) and/ or transitioning between control options as contexts change within an adaptive management framework. Note that urchin/ kelp ecosystems are highly complex and there will be variance around the specific application and effectiveness of controls within kelp beds and on extensive barrens in relation to reef substrate type, urchin/ kelp recruitment and growth, as well as the frequency and intensity of control efforts.

Type	Management option	Prevention (Kelp bed resilience)	Restoration (Recovery of extensive barrens)	Effective Depth Range	Timeframe to effective set-up & control [a]	Relative cost	Opportunities/Benefits	Comments / limitations	Ref
Diver Based	Urchin harvesting; Unrestricted	Yes, within limitations	Long term, extension (deepening) of kelp edge	0-25m[b]	Short (prevention) to Long (restoration)	Minimal - Industry driven	Low-cost; employment; large scale application (dependent on profitability). Extensive barens may be eventually rebuilt by the gradual extension of the kelp edge over an extended time period.	Limited spatially by areas of economic value, depth and minimum densities; Size and quality selective; Exploitation rates need to be high enough to significantly deplete stock;	1-8, R
	Urchin harvesting; Subsidised	Yes	Long term, extension (deepening) of kelp edge	0-25m[b]	Short (prevention) to Long (restoration)	Low-Medium	Spatially directs harvests; facilitates harvest at lower densities increasing resilience; incentivises processing sector; enhanced employment and economic activity.	Size and quality selective; limited by depth, Extensive barens may be eventually rebuilt by the gradual extension of the kelp edge over an extended time period.	5-9, R
	Urchin harvesting; Paid removals, all size classes	Yes	Yes	0-25m[b]	Immediate	Medium-High	Removes small urchins, more effective recovery, employment and economic activity; ideal for areas where no urchin barrens are desired.	Repeat visits may be required; could be costly.	10-13, R
	Urchin Culling - contracted	Yes	Yes	0-25m[b]	Immediate	High	Employment; preferred option if urchins have no economic value, i.e. in extensive barrens where roe quality is generally poor	Repeat visits may be required; could be costly.	14-18
	Urchin culling - Recreational	Yes	Limited by scale and coordination	0-25m[b]	Short	Low	Clearing urchins from recreational dive sites is a meaningful scale for recreational divers/tourist operators; Community engagement; Recreational culling campaigns 'derbies' can be a way of creating awareness and obtaining high participation.	Conflict with commercial sector; Misidentification: other urchin species may be culled; spatial limitations. Reporting of recreational culling activities would require additional effort and would need coordination among individuals/ groups such that effort/ efficacy could be gauged.	19
	Urchin culling – Deep water	Yes	Limited by diver decompression schedules	0-40m	Immediate	Med-High	Protection of recreational dive sites, areas of high biodiversity and/or ecological importance, social values. Recreational culling of urchins to 40 m using advanced dive technology (rebreathers) has been occurring in Tasmania for ca. 5 years.	Costly; likely limited to tactical operation at local scales; diver decompression schedules limits time available at depth.	PC
	Urchin culling – during other commercial diving (fishing) activities	Yes	No	0-20m	Immediate	Low	Opportunistic, low cost.	Other fishing activities (e.g. abalone) only operate in healthy / incipient reef – limited by success of fishing activity. If fishing is good little time is spent culling. Furthermore, large barrens are avoided (swum around) and not culled given the time and effort taken to achieve a meaningful cull, but small patches with only several urchins can be culled efficiently.	20

Type	Management option	Prevention (Kelp bed resilience)	Restoration (Recovery of extensive barrens)	Effective Depth Range	Timeframe to effective set-up & control [a]	Relative cost	Opportunities/Benefits	Comments / limitations	Ref
Predator Rebuilding	Rock lobsters	Yes	No	0-40m+	Medium to long	Variable	Ecosystem benefit. Large lobsters are capable of consuming all sizes-classes of Longspined Sea Urchin. Rebuilding large and abundant populations of lobsters rebuilds kelp bed resilience to overgrazing. Lobsters will also readily prey upon Shortspined Sea Urchins *Heliocidaris erythrogramma*, which also overgrazes kelp beds along sheltered coasts. Rebuilding lobster populations also improves catch-rates for fisheries.	Short to medium term economic/social costs (due to cuts to recreational/commercial fishing); rebuilding large biomass of large lobsters requires med/long-term; some localised barrens may persist and/or form but at reduced frequency and spatial extent; lobsters are generalist predators and will first drive-down stocks of more preferred prey items including mussels, gastropods (including Blacklip Abalone), and Shortspined Sea Urchins. High predator biomass must be sustained long-term.	21-26
	Large fish (e.g. Eastern Blue Groper, other wrasses, Heterodontid sharks)	Yes, likely	Uncertain	0-40m+	Medium to long	Variable	Ecosystem benefits. Decline of large Eastern Blue Groper due to fishing has been associated with 3–4 fold increase in Longspined Sea Urchin abundance, historically predators in NSW likely played a greater role in regulating sea urchin populations. EB Groper is now fully protected in Tasmania and building groper stocks would increase overall predation on urchins.	Short to medium economic/social costs if cuts to recreational/ commercial fishing or full protection of Eastern Blue Grouper (the emblematic State fish of NSW), which is a specialist predator of Longspined Sea Urchins; some localised barrens may persist and/or form but at reduced frequency and spatial extent; potential declines of other macroinvertebrates. High predator biomass must be sustained long-term.	PO, 21, 27-30
R&D Limited	Urchin Ranching	No	Limited by scalability	0-25m[b]	Short	Industry driven	Concept is to ranch urchins from barrens in aquaculture facilities; value adding; employment.	Size selective removals, untried commercially, scalability and economic viability uncertain for Longspined Sea Urchin.	4
	Chemical control: Quickliming	No	Yes; limitations	0-40m+	Short	Moderate to high	Largescale application on extensive barrens.	Uncertainty of social acceptance/ license; Potential impact on other invertebrate species; application at depth untested and will need R&D; Potentially expensive; Nocturnal operation for effective application on nocturnally emergent urchins.	31
Novel/Untired	Autonomous Robotic culling	Unknown; Unlikely to be effective beneath kelp canopy	Plausible	0-40m+	Uncertain	High/ Unknown	Potential application at depth on extensive barren grounds. Elimination of diving risks which increase with depth. Prototypes under development by Hullbot (https://hullbot.com/) in consultation with IMAS researchers (see Appendix IV).	Technology currently limited with cost and effectiveness of culling urchins at meaningful scales unknown. Potential conflict with commercial sector in harvestable depths; autonomous vehicles have demonstrated limited navigational capability within kelp beds, but more feasibly navigate on open barrens grounds. Will need to ensure sufficient urchins are culled to allow kelp & sessile invertebrate recovery in deeper water. Nocturnal operation for effective application.	Appen-dix IV
	Genetic control	Possible	Implied	0-40m+	Uncertain	High initial cost, with low long term operating costs	Species specific, environmentally safe and can reach populations and individuals with greater efficiency than any other. IMAS research focused on a non-GMO approach known as Trojan Chromosome ('Trojan C' for short) using a model and nationally widespread pest fish species, Gambusia, is on the cusp of field trials.	Trojan C has been already filed trialled for controlling pest populations of Brook trout in USA and holds promise. Its advancement for applications into complex marine systems requires significant R&D investments.	
	Bio-tech control (triggering disease)	Uncertain	Uncertain	0-40 m+	Uncertain	Unknown	Disease has been known to cause major population decline of tropical species of Longspined Urchins.	Non-target species potentially impacted.	32

a - Short-term within 5-yrs; Medium-term 10-yrs +; Long-term 20-yrs+; b -25 m is the dive depth that divers utilising Nitrox 40% are harvesting too in Tasmania. The Code of Conduct enables them to harvest to 30m; R – Ongoing and/or current research. PC – Personal communication. PO – Personal observation. References in short (for fully referenced list see page 15): 1. Keane et al. 2019; 2. Cresswell et al., 2021; 3. Baulch 2018; 4. Campus 2021; 5. Cresswell & Hartmann et al. 2019; 6. Cresswell et al. 2020; 7. Cresswell et al 2022; 8. Keane and Ling 2022; 9. Cresswell & Keane et al. 2019 10. Larby 2020; 11. Charlton 2021; 12. Larby 2021 13. Keane 2022; 14. Tracey and Baulch et al., 2015; 15 Tracey & Mundy et al., 2015; 16. Huddlestone 2019; 17. Huddlestone 2020; 18. VFA 2019; 19. NRM South, 2022; 20. Sanderson et al. 2016; 21. Ling et al. 2009; 22. Ling & Johnson 2012; 23. Johnson et al. 2013; 24. Ling & Keane 2021; 25. Smith et al. 2022; 26. Day et al. 2021; 27. Gillanders 1995; 28. Young et al. 2014; 29. Byrne & Andrew 2020; 30. Bax et al. 2013; 31. Keane 2021; 32. Rodríguez-Barreras et al. 2018.

(c) Funding requirements, responsibility, and pathways to better manage and co-ordinate stopping the spread of climate-related marine invasive species;

Collaborative approach to fund and coordinate Longspined Sea Urchin management

IMAS works in collaboration with the Tasmanian Government, and is aware of, and is supportive of, the *Department of Natural Resources and Environment* call for $50M of national funding for a regional approach to Longspined Sea Urchin management. Explicit funding is required to both mitigate threats in its extending southern range, plus capitalise on opportunities in its northern endemic range. IMAS has the knowledge, experience and capacity to be a key collaborator in a regional management program, having expertise in urchin ecology, control methodology, fisheries development, marine spatial planning and socioecology. Furthermore, IMAS has established links with stakeholders across jurisdictions and the capacity to leverage large grant schemes, including Australian Research Council Discovery, Linkage and Cooperative Research Centre schemes, linking strongly with CSIRO, universities, research institutes and industries across Tasmania, Victoria, and NSW.

In Tasmania, only ~$5M has been committed to address the Longspined Sea Urchin since recognition of this problem by IMAS scientists 21-years ago (**Fig. 3**). Funding was initiated by the Fisheries Research and Development Corporation (FRDC) who have been highly supportive of baseline surveys and ecological research into this problem. Most recently urchin control has been funded by the Tasmanian State Government's $1 million per annum Abalone Industry Redevelopment Fund (AIRF). This has supported management, research, monitoring and industry development, and by the time of termination of the fund in 2023 it will have overseen a total urchin harvest approaching 2,000 tonnes. Current research surveys across eastern Tasmania (2016-2021) are shown increasing urchin populations despite some 1,650 t removed. **While local impacts and resilience from harvesting is being detected (Appendix I), the state-wide population increase highlights the need for further upscaling of solution focussed action.** Further development of the urchin fishery and expansion of export markets are critical given commercial harvesting is central to urchin management. As such regional strategies are essential as harvests in one state may adversely affect another, as seen following the implementation of subsidies in Tasmania.

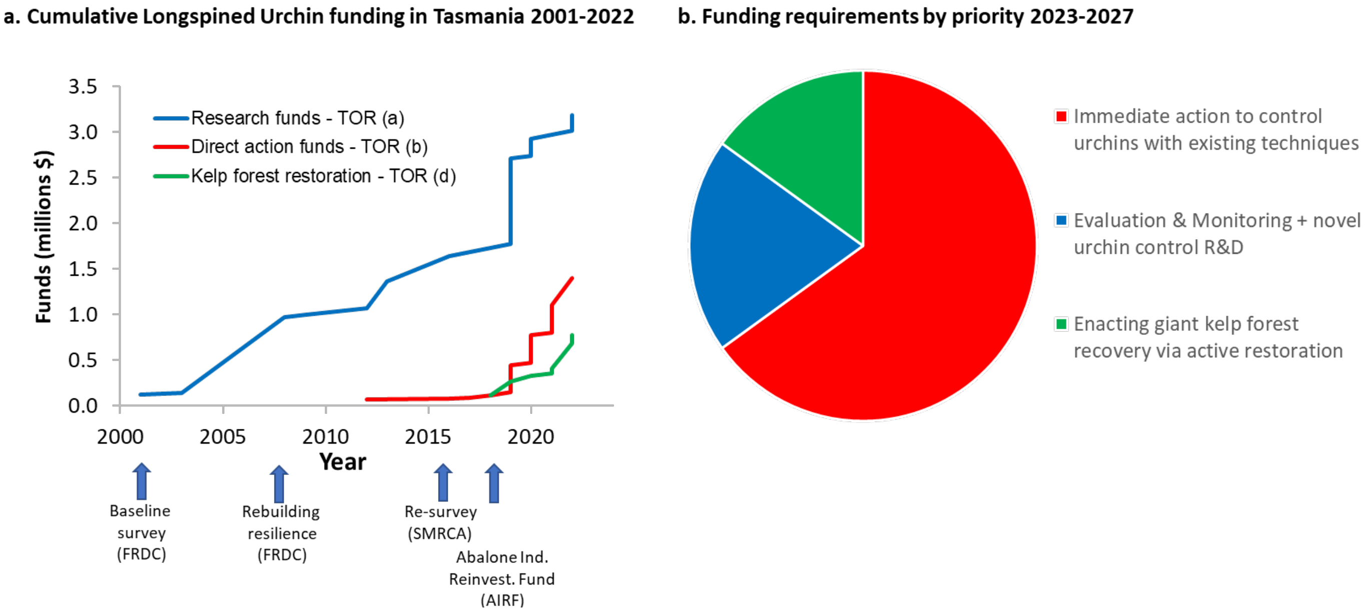


Figure 3. (a) Cumulative funding to date for projects addressing the impact of Longspined Sea Urchins in Tasmania by Terms of Reference. Upward arrows indicate key points in time from the pioneering *Fisheries Research & Development Corporation* (FRDC) funding in 2001 which identified the threat of urchin overgrazing, followed by FRDC funds to understand management options in 2008, and the *Sustainable Marine Research Collaboration Agreement* (SMRCA) funds enabling the re-survey of eastern Tasmania in 2017 - which in 2018 led to the immediate establishment of the 5-year *Abalone Industry Re-investment Fund* (AIRF) focussed on direct urchin control measures. **(b)** Funding required by priority for the next 5-years to ramp-up urchin control and kelp forest recovery. Two-thirds of future funding is required for direct control of the growing urchin problem which must be enacted immediately before urchins exceed the tipping-point of overgrazing; one-fifth of funds are required to evaluate & monitor the effectiveness of control inclusive of further R&D of novel control methods for deep water; one-sixth of future funds are required to enact the recovery plan for the threatened Giant Kelp Forest community via active restoration.

A call for $50 million is less than one-third of the $162 million recently announced for Crown-of-Thorns-Starfish (CoTS) control on the Great Barrier Reef over the next 8-years. Notably, a CoTS outbreak is triggered at a density of 15 starfish per hectare (GBRMPA 2017). Longspined urchins overgrazing kelp beds in eastern Tasmania are locally exceeding 20,000 urchins per hectare and there has been an increase of ~1,500 per hectare on average over the past 15-years (Ling & Keane 2018), this increase alone is 100 times greater than the density of CoTS triggering strong and immediate management action by GBRMPA. Similar to the scale required for CoTS control, the spatial extent of Longspined Sea Urchin ranges from northern NSW to southern Tasmania, approx. 2,000 km of coastline, which is of similar extent to the Great Barrier Reef, at.

Restoration of Giant Kelp Forests

A Giant Kelp Forestation Restoration Strategy has been developed and costed at $6 million (see Term of Reference d); Appendix VI).

Climate-driven redistribution of marine species

The impacts, threats and opportunities of climate-driven species redistribution are real, cross-jurisdictional and requires a coordinated national approach. While the Longspined Sea Urchin is the poster child of marine climate change, the research community, including citizen science programs Redmap and Reef Life Survey, have collectively documented 198 marine species that have undertaken climate-driven redistribution in Australian waters; most extensions are occurring at the cooler poleward end of their range, while some contractions are occurring at the warmer equatorward end of their distribution (Gervais et al. 2021; Appendix V). Critically, the potential ecological consequences, as well as opportunities, for most of this growing list of marine range-shifters remains unknown. Furthermore, IPCC (2022) estimates that globally approximately half of all life on earth has already undertaken climate-driven changes in distribution, thus it would be prudent to consider a national management plan for climate-driven redistribution of marine species more generally.

To deliver fundamental research needs, the establishment of a proactive national research centre, e.g., a **Centre for Research into Climate-Related Marine Species Shifts** is appropriate, with pathways for funding via ARC Cooperative Research Centre (CRC) or Centres of Excellence (CoE) schemes possible. The centre would undertake innovative and potentially transformational research in the management of climate-driven redistribution of marine species, linking research organisations across the nation. It would rapidly build capacity to manage the world's most rapidly changing ecosystems.

ToR (c) Key points and recommendations

1. National funding for Longspined Sea Urchin management in the order of $50 million as proposed by the Tasmanian State Government (and supported by fishery sectors, scientists and conservationists), to enable urchin control and fisheries enhancement.
2. Giant Kelp Forest Restoration Strategy funding to the value of $6 million, as described in Term of Reference d).
3. Support for citizen science programs to continue broad-scale monitoring of marine species distributions.
4. Development of a national management plan for climate-driven redistribution of marine species.
5. Establishment of a *Centre for Research into Climate-driven Marine Species Shifts* to provide a platform for research and solutions addressing climate-related impacts on marine species distributions, ecosystems

(d) The importance of tackling the spread of invasive urchin 'barrens' to help facilitate marine ecosystem restoration efforts (such as for Tasmanian Giant Kelp, Macrocystis pyrifera);

Loss of Giant Kelp Forests

Establishment of the Longspined Sea Urchin in eastern Tasmania has resulted in extensive urchin barren formation on reefs where Giant Kelp Forests once flourished (**Fig. 4**). While the presence of overgrazing urchins has a direct impact on macroalgal communities, including Giant Kelp Forests, the loss of >95% of the iconic Giant Kelp Forests formed by *Macrocystis pyrifera* has occurred across eastern Tasmania including areas where urchin populations have yet to establish (Johnson et al. 2011; Steneck & Johnson 2014; Butler et al. 2020). Coincident with warming waters, dramatic loss of Giant Kelp Forests has occurred across Tasmania and Victoria, which prompted an endangered listing for this ecological community under the EPBC Act in 2012. However, 10-years later a recovery plan is still yet to be developed.

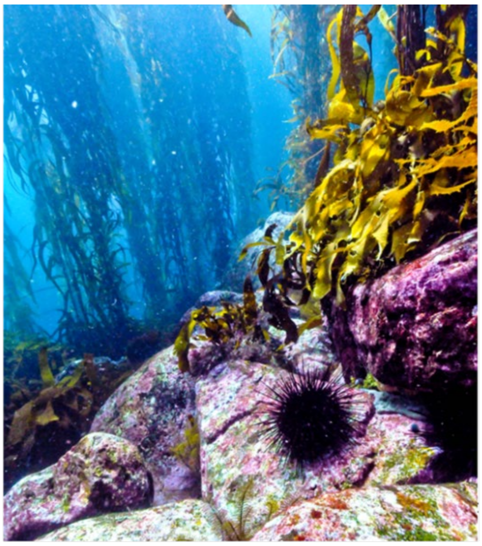


Figure 4. Longspined urchin barrens forming within giant kelp forest, Schouten Island Tasmania, 2011. Photocredit: Scott Ling.

While Giant Kelp as a species is still found as isolated individuals around Tasmania, there has been a general range-retraction of these Giant Kelp Forests to the Bruny Bioregion in the far south. While much focus has been placed on climate-related shifts of reef species from NSW south to Tasmania, there is great concern that such range retractions are squeezing many species into the last remaining southern reefs given no temperate land masses occur further south.

Sea urchin removal and seaweed habitat restoration will facilitate the safeguarding of our threatened and vulnerable reef species along the highly sensitive reefs of south-east and southern Tasmania.

Assisted restoration of Giant Kelp Forests

In Tasmania, the removal of sea urchins to below the kelp recovery tipping-point rapidly leads to the local re-establishment of the common kelp bed species given local propagule supply from nearby shallow waters (<6m depth) immune from overgrazing due to wave action. However, Giant Kelp densities are now too low around most of the coast to enable direct re-establishment following urchin removals, thus assisted reseeding of propagules is required for Giant Kelp Forest restoration. Recent interest in seaweed-based aquaculture solutions has resulted in large abundances of Giant Kelp propagules being generated in Tasmanian hatcheries. IMAS scientists have also identified thermally tolerant families of Giant Kelp, and ongoing research is using selective breeding and outcrossing of these lines to select for thermal tolerance. In addition to laboratory-based studies, important advances have been made towards re-establish Giant Kelp Forests at scale. **Recently IMAS scientists have developed a rapid technique for successfully seeding hatchery-reared Giant Kelp propagules to natural reefs at forest scales (Fig. 5)**. Other work is establishing patches of warm tolerant Giant Kelp on natural reefs to assess the efficacy of using 100 m^2 'seed patches' to expand kelp recruitment through local spore production. IMAS also leads a Blue Economy CRC project (~$3.25M across 8 organisations) to develop technologies for Giant Kelp mariculture offshore, with the use of farm modules to inoculate natural reefs to be trialled at scale.

Pilot upscaling research by IMAS funded by the *Sea Forest Foundation* and in collaboration with the local dive tourism operator *Eaglehawk Dive Centre* is currently underway, which is building on recent proofs-of-concept established via out-planting activities over the past 3-years **(Fig. 5)**. Many fundamental ecological lessons have been learned about how to seed the reef to enable Giant Kelp Forests to re-establish and to overcome the processes currently limiting recovery potential. IMAS researchers are also collaborating with *The Nature Conservancy* to apply their highly successful "*Reef Builder*" model used to successfully re-establish Australian shellfish reefs, to achieve national upscaling of restoration efforts. **Ultimately restoring Giant Kelp Forests is contingent on a whole-of-reef ecosystem strategy utilising hatchery-reared Giant Kelp propagules and removing the sea urchin threat.**

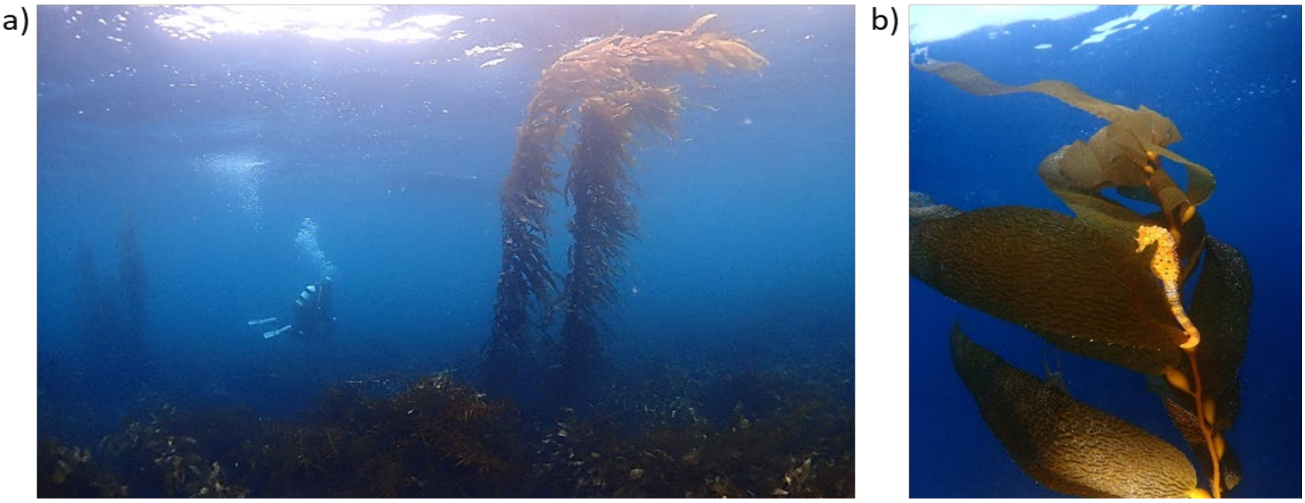


Figure 5. Re-establishment of Giant Kelp in south-eastern Tasmania by IMAS researchers achieved in collaboration with a local dive tourism operator and seaweed rearing by *Sea Forest*. (a) Giant Kelp reaching the surface after the removal of sea urchins and seeding microscopic Giant Kelp propagules to the reef 10-months prior. (b) Restored Giant Kelp surface canopy providing habitat for the big-belly seahorse (*Hippocampus abdominalis*) (photo-credit: Scott Ling).

ToR (d) Key points and recommendations

IMAS has proposed an ***'East Coast Giant Kelp Reforestation Strategy'*** (Appendix V) which combines the latest scientific advancements and management mechanisms to create a restoration economy for Tasmania's east-coast communities. **This strategy is focussed on creating better habitats for better biodiversity, enhanced tourism experiences and replenishment of fished stocks**. The $6 million strategy over next 3-years will provide a whole-of-ecosystem approach to reforestation of Giant Kelp to ensure resilient and thriving kelp dominated reefs into the future by:

1. Funding a high-production Giant Kelp hatchery for microsporophytes on the east coast ($0.75M).
2. Funding targeted urchin removals by commercial divers within Giant Kelp Reforestation Zones to pave-the-way for out-planting of Giant Kelp propagules ($1M).
3. Funding local commercial divers to re-seed Giant Kelp at multiple sites totalling 10 hectares ($2M).
4. Funding the recreational dive industry to establish a volunteer-tourism internship program to train and educate divers to establish and maintain iconic Giant Kelp Forests as local dive/ snorkel/ tour boat attractions ($0.25M).
5. Funding a ramp-up the *East Coast Rock Lobster Stock Rebuilding Strategy's* translocation of lobsters by commercial fishers from southern Tasmania to the east coast to help safeguard restored kelp forests against future sea urchin incursions ($0.5M).
6. Funding monitoring, evaluation, and optimisation of restoration of large self-sustaining Giant Kelp Forests to maximise gains in reef productivity for Tasmania's east coast ($1.5M).

Additional funding pathways in support of upscaling Giant Kelp Forest restoration:

- NESP Funding for climate-effective management for threatened species and protected places: https://www.dcceew.gov.au/science-research/nesp
- Australian Government threatened species action plan: https://www.dcceew.gov.au/environment/biodiversity/threatened/strategy/priority-places

(e) Other related matters.

Opportunities for coastal peoples and environments

IMAS welcomes the establishment of a regional approach to managing the Longspined Sea Urchin underpinned by ongoing commercial urchin fisheries investments and harvesting programs to ramp-up urchin control. This will facilitate much needed coordination across states and, in combination with the associated strategy for Giant Kelp restoration, will create wins for people and the environment in coastal areas as it will directly and indirectly support:

- **Commercial fishing industries** - explicit links to abalone and rock lobster fisheries respectively via the *Abalone Industry Reinvestment Fund* supporting urchin control measures, and the *East Coast Rock Lobster Stock Rebuilding Strategy*.

- **Emerging marine restoration industries** – increasing interest from private and public enterprises focussed on ecosystem restoration of coastal environments, significant potential for marine industry, encompassing kelp polyculture and offshore kelp mariculture.

- **Recreational fisheries** - A passionate and connected recreational fishing community who still can harvest wild abalone, rock lobster and finfish but who have witnessed the dramatic changes in their marine environment over recent decades.

- **Tourism** - Enrichment of a rapidly growing natural tourism sector (e.g., tourist divers visiting restored kelp forests & voluntourism by recreational divers being actively involved in local restoration, tour companies will benefit by diversification of their tour products).

- **Citizen Science –** Engagement by the general public in climate-related species range shifts has been enhanced via the citizen science project Redmap (e.g. Appendix V), which will grow as coastal jobs and awareness of temperate reef ecosystems ramps-up with the regional approach to Longspined Sea Urchin management. Similarly, the "Kelp Tracker App" is an IMAS initiative designed to track Giant Kelp through citizen science. The citizen science program Reef Life Survey, in partnership with IMAS, actively collects underwater visual census data across Australia and beyond including spanning the distributional range of Longspined Sea Urchins which can feed into the data available to evaluate management strategies. These citizen science initiatives address critical knowledge gaps and have thus far provided approximately 20% of all known data on range shifts in Australia waters (Gervais et al. 2021). Furthermore, several evaluations and social science studies have demonstrated the use of these programs in effectively engaging the general public on climate change (Redmap, Nursey-Bray et al. 2018) and improving communication and relationships amongst resource management and stakeholder groups (Redmap, Kelly et al. 2019) as climate-driven changes in distribution will involve 'wins' and 'losses' for different stakeholder groups, this is critical.

- **Science underpinning restoration of threatened species and communities** – Reforesting extensive urchin barrens will represent an important high-profile project and a key outcome will be to clearly position researchers, industries, and managers of Australia's temperate reefs as a world-leaders in marine ecosystem restoration within the UN Decade on Ecosystem Restoration. Further fostering cross-institutional linkages in temperate reef research, IMAS has recently been awarded funding via the *Ian Potter Foundation* for the project entitled "*Safeguarding natural values of the Great Southern Reef*" which spans government agencies and researchers from all temperate state of Australia.

- **Current and upcoming research projects informing Longspined Sea Urchin management**
  Beyond the materials referenced within this submission, IMAS has a range of current and upcoming projects addressing research questions that underpin the capacity to manage the Longspined Sea Urchin at large scale including this listed below.

Primary Investigator	Title	Funding Body
Cresswell, K.	Larval dispersal for Southern Rock Lobster and Longspined sea urchin to support management decisions	Fisheries Research and Development Corporation 2019-130 / AIRF
Keane, J.P.	Effects of urchin fishing on urchin populations and kelp recovery	Tasmanian Government (Abalone Industry Redevelopment Fund)
Keane, J.P.	Understanding *Centrostephanus*: Age, Growth and Size of Maturity	Tasmanian Government (Abalone Industry Redevelopment Fund)
Keane, J.P.	Commercial upscaling of urchin fertilizer	Tasmanian Government (Abalone Industry Redevelopment Fund)
Keane, J.P.	*Developing spatial based assessment methodologies and tools for small scale dive fisheries: Case study of the Tasmanian Commercial Dive Fishery*	*Fisheries Research and Development Corporation 2022-039 (Application in review)*
Lacharite, M.	Tasmania's Marine Atlas	Fisheries Research and Development Corporation 2019-111
Rust, S.	Social-economic analysis for the Tasmanian dive sector	Tasmanian Government (Abalone Industry Redevelopment Fund)
Smith, J.	Stable isotopes: a rapid method to determine lobsters diet and trace lobster origin?	Fisheries Research and Development Corporation 2021-020
Smith, J. (PhD Project)	Lose Home or Eat More: Prey choice of Southern Rock Lobsters on barren forming sea urchins and native prey.	Holsworth Wildlife Research Endowment / Tasmanian Government (Abalone Industry Redevelopment Fund)
Walker, H.	Assessing the benefits of sea urchin processing waste as an agricultural fertiliser and soil ameliorant	Fisheries Research and Development Corporation 2019-128
Ling, S.D.	Reef health tipping-points: triage for threatened/collapsed reef ecosystems	Australian Research Council, Future Fellowship
PhD Project commencing 2023	Meta-community modelling of the Great Southern Reef	CSIRO/ IMAS

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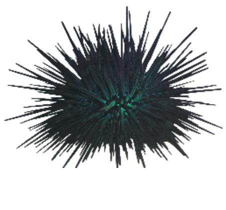


Appendix I. Impact of Commercial Fishing on the Longspined Sea Urchin in Tasmania (Dr. Katie Cresswell, Dr. John Keane, Associate Professor Scott Ling)

The Tasmanian Commercial Dive Fishery commenced harvesting Longspined Sea Urchins in 2009 and has expanded to become one of the state's largest wild fisheries. Over 2,500 tonnes have been removed since its inception, with an average catch ~500 tonnes (~1.3 million urchins) over the last 4 years (**Fig. 1**). A subsidy began in late 2016 at a flat rate down the east coast, but since 2019 it has been spatially structured to shift effort. Subsidy was removed from Region 2 in 2020, which had landed >95% of the harvest up to that point. These two measures shifted the catch south and into more valuable areas for abalone production.

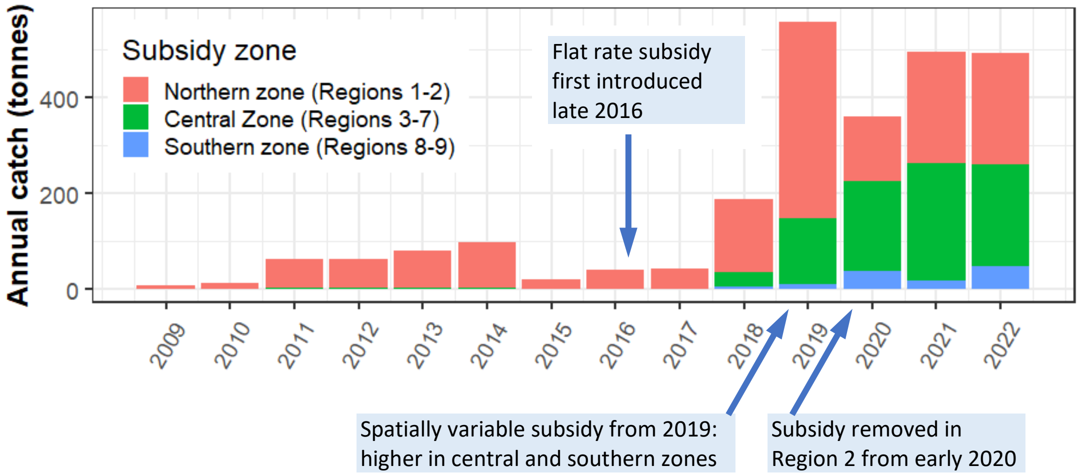


Figure 1. Total annual catch of the commercial fishery for Longspined Sea Urchins in Tasmania, showing catch per subsidy zone (using original specification of subsidy zone in 2016, but zones have changed over time), and showing inception of and major changes in subsidy.

To determine the impact of the commercial fishery on the Longspined Sea Urchin population, a size-structured stock-assessment model of urchin density was developed using fisheries-independent survey data for 9 east coast regions numbered north to south. The model was run with and without commercial fishing with results showing that **without commercial fishing urchin density would be almost double** in the most heavily fished region (2) of St Helens (Fig 2.) with noticeable impacts in other fished regions further south. Declines in urchin abundance and increases in kelp cover are being detected at heavily fished locations (Fig 3).

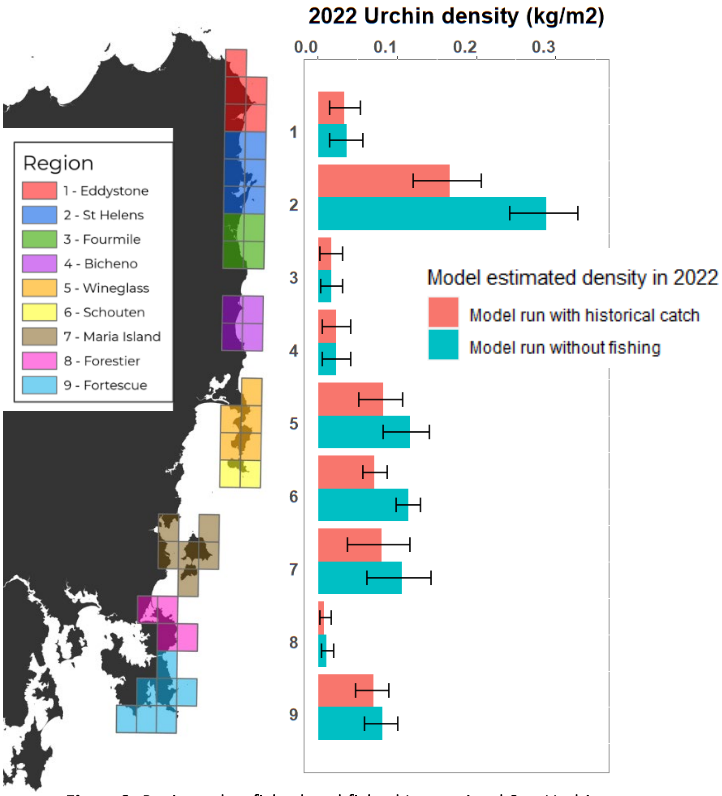


Figure2. Projected unfished and fished Longspined Sea Urchin density from a size-structured stock-assessment model using fisheries-independent survey data for 9 regions down the Tasmania east coast.

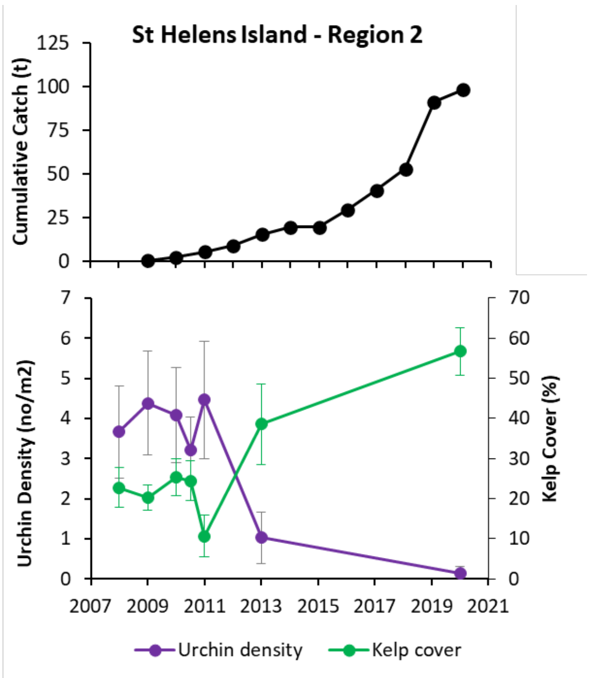


Figure 3. Top: Cumulative Longspined Sea Urchin harvest at St Helens Island, a heavily fished area of Region 2. **Bottom:** Changes in kelp cover and urchin density observed at a 0.6 ha long-term monitoring site at St Helens Island.

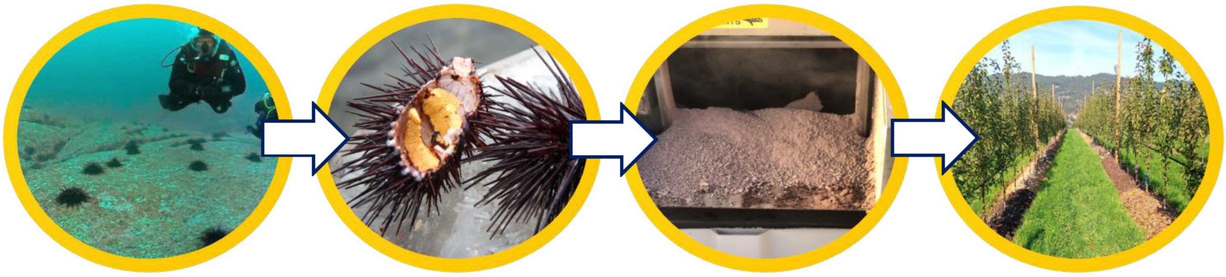
Appendix II: Challenges and opportunities for diver-based Longspined Sea Urchin control

(Dr John Keane and Associate Professor Scott Ling).

Challenge for diver control	Resolution and/or opportunities
Processor availability, processor knowledge and market development	A shortage of sea urchin export processing facilities is a key constraint to an enhanced national sea urchin industry. Additional facilities would activate latent effort in the dive sectors, stimulate employment and economic activity. Facility establishment costs, urchin processing knowledge and international market development are current limitations that could be resolved with investment.
Urchin processing waste	90% of landed urchin biomass is waste. IMAS with the Tasmanian Institute of Agriculture have been developing organic agriculture products from this, and semi-commercial trials are very promising. Further R&D and investment is required for commercialisation. Aim to turn a dumping cost into a valuable by-product.
Diving depth limitations	The use of Nitrox (oxygen enriched air) enables divers to harvest deeper. In Tasmania harvest on Nitrox is commonly to 25m. Nitrox has infrastructure and increased daily costs, but can also increase safety. This encompasses the majority of the productive kelp zone. Barrens below 25m remain problematic.
Low urchin density; low to no profitability for diver due to reduced daily catch	Barren prevention: Subsidies can be used to spatially direct harvest to areas where urchin density is lower (but increasing) and high risk of barren formation is present. Subsidies offset revenue lost with lower catch rates.
Remote area costs; costs of operating at large distances from port	Subsidies can be used to spatially direct harvest to remote locations by offsetting the increasing costs with increasing travel distance (e.g. fuel). This opens up new grounds for harvest and reduces impacts over larger scales.
Urchin roe quality; variable in space and time, urchins in extensive barrens can have poor roe quality, not suitable for harvest	Urchin roe quality is variable in space and time, and varies from near worthless to $100's/kg for A-Grade. R&D to enhance roe quality across all stages of production, including in water biomass enhancement, handling, transport and processing, could lead to significant gains in industry revenue meaning higher price to the diver from the processor and less government expenditure for a subsidy.
Selective harvest of larger urchins; smaller urchins may maintain barrens	Divers can be subsidised to remove smaller urchins while harvesting - termed a 'Take-all' harvest. This method can accelerate restoration efforts and can be applied to regions where zero barrens are desired. However, will need ongoing control efforts.
Overfishing of urchins leading to stock and processor collapse	Careful spatial management. Sustaining an annual harvest to keep the processing sector viable: models currently being by IMAS can manage this risk. While overfishing and stock collapse may be seen as a positive ecological outcome in the short term, urchins and barrens will likely return in the medium term. Loss of the key control mechanisms will potentially mean significant reinvestment required to re-establish processing facilities / IP / international export markets.

Appendix III. Longspined Sea Urchin waste commercialisation (Dr Harriet Walker).

Sea urchin soil amendment / fertiliser



The story

Background

The long-spined sea urchin *Centrostephanus rodgersii*, is a **major threat** to kelp forests and the marine biodiversity of Tasmania's east coast. Since the late 1970's, urchin populations have migrated from mainland Australia down the east coast of Tasmania, due **to increases in water temperatures and warming ocean currents.**

Urchins graze extensively on kelp beds **producing lifeless sea beds**, otherwise known as "barrens", **displacing ~150 marine species.** Other parts of Australia, and the world, are facing similar urchin problems.

Urchin control & utilisation

There are now approximately **18 million** long-spined sea urchins off the coast of Tasmania, **a 75% increase in population density** from 2002 to 2017.

Commercially harvesting sea urchins for their **roe** has helped to **control urchin populations** in Tasmania. Yet, the roe only accounts for **~10% of the urchin biomass,** and in small production areas like Tasmania, this waste is **destined for landfill.**

Providing a commercial market for this **nutrient-rich waste stream** through processing it into an **organic soil amendment** promotes a **circular economy** through repurposing, recycling and value-adding, whilst tackling broader issues, such as **environmental and economic sustainability.**

Processing technique

The research related to the sea urchin product and the product specifications outlined in this factsheet are from sea urchin waste processed via a facility that grinds the material, before turning it in an enclosed, heated (70°C) chamber for at least 14 hours.

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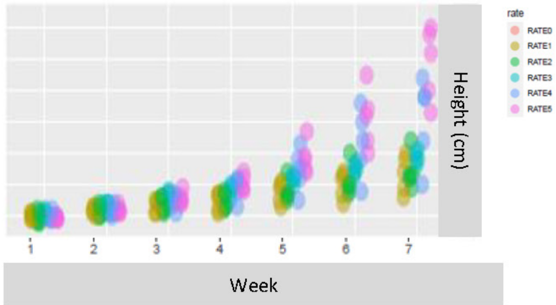
Research

Fertiliser

A preliminary pot trial using the sea urchin (SU) product on potted sunflowers at five different rates (1, 2, 4, 8, 10% SU) showed that the more SU that was applied, the bigger the sunflowers became. The 10% SU rate promoted equal productivity to that of a conventional fertiliser.



The fertiliser abilities of SU continues to be explored at different rates on different soils in other crops, such as potatoes, lettuce, grapevines & apples.

Liming-plus product

SU has shown a great liming potential in trials to date. With the processing technique used, the greater the processing time, the greater the product break-down and the smaller the particle size, resulting in a greater liming potential. For example, in a heavy clay soil, ~20 t/ha of 14hr (coarser) SU and ~10 t/ha of 48hr (finer) SU was shown to elicit a ~1.0 soil pH increase 4 months after top-dressing. This pH change was equivocal to the change induced by a conventional liming product applied at the recommended rate (5 t/ha).

Appendix III. Longspined Sea Urchin waste commercialisation, continued.

Table 1. Comparison of the sea urchin products nutrient composition against similar commercial marine by-product soil amendments

Nutrient	Unit	Sea urchin	Seasol liquid concentrate	Seasol super soil wetter and conditioner	Seasol advanced	Ocean 2 earth fish compost
N	%	1.00	0.1	0.04	1.5	0.66
P	%	0.05	0.01	0.002	0.2	0.38
K	%	0.28	1.5	0.7	1.4	0.19
S	%	0.46	0.1	0.029	0.039	0.14
Ca	%	33.5	0.043	0.021	0.039	2.63
Mg	%	1.47	0.034	0.008	0.004	0.48
Na	%	1.05	0.32	0.11	0.105	0.19
Fe	ppm	215	65	220	60	1.1
Mn	ppm	2.36	3	2	1	160
Zn	ppm	28.2	7	8	2	50
Cu	ppm	1.75	1	1.5	<0.5	10
Co	ppm	0.08	<0.5	<0.5	<0.5	4
B	ppm	38.9	8	2	2	60
Mo	ppm	0.18	<0.5	<0.5	<0.5	Trace
pH	1:5 method	7.94	10.5 – 11.4	10.5 – 11.4	10.5 – 11.4	7.11

PRODUCT HIGHLIGHTS

- Higher in nitrogen (N) than similar commercial marine by-product soil amendments/fertilisers on the market – *Nitrogen is the most limiting nutrient for plant growth, and it can be difficult to find in large quantities in organic soil amendments*
- High in calcium (Ca) – *Calcium is the main component of liming products, which are used to de-acidify soils to promote optimal growing conditions. Conventional liming products are obtained through the mining of natural resources and/or the high energy processing of rocks*
- High in key micronutrients, such as boron (B), iron (Fe) and zinc (Zn) – *important for plant health, growth and flowering*
- Meets Australian Standards for composts, soil conditioners and mulches (AS4454-2003) - *meets organic contaminant and pesticide concentrations, pathogen (Salmonella spp., Faecal coliforms) and heavy metal thresholds, and basic physiochemical requirements*

For more information: *please contact: harriet.walker@utas.edu.au | +61 3 6267 9659 | utas.edu.au/tia*

Appendix IV. Deepwater control options for Longspined Sea Urchin Barrens in eastern Tasmania (Professor Craig Johnson).

Currently there are few options to control urchin barrens in deeper water, and most of the barrens occur in water deeper than 20 m while about half of the barrens occur in water deeper than ~24-25 m, which is the realistic max depth for most of the dive fishery (Table A1). Options to manage urchins in intact kelp beds and at least early to mid-stage incipient barrens include rebuilding lobster stocks and, for shallower depths, utilising the *Centrostephanus* dive fishery and/or tactical culling (at local scales).

For extensive barrens the situation is quite different since we know from the large-scale experiment at Elephant Rock (Johnson et al. 2013; Ling & Johnson 2021) and modelling (Marzloff et al. 2016) that there is essentially zero probability of lobsters being able to reduce urchin populations on extensive barrens to a level that will enable kelp to recover within >>50 years. Thus, for extensive barrens, management options exist only for relatively shallow water (<20-25 m) and require direct human intervention through the dive fishery for *Centrostephanus* or tactical culling.

For water deeper than ~26 m there is currently no meaningful management option to rehabilitate urchin barrens to kelp beds. Tackling the problem at these depths will require intensive (and relatively expensive) technological intervention. The two most likely candidates to consider are using quick-lime to kill urchins (so-called 'liming'), and autonomous (i.e. untethered) 'smart' robots able to identify and kill *Centrostephanus* in situ. Liming has been trialled over several decades in other countries with mixed success. Liming works by burning the integument of the urchins, which facilitates infection that subsequently kills the urchins. Disadvantages of liming include collateral mortality of other soft-bodied marine benthic organisms (e.g. sea stars, molluscs including abalone, anemones), the need for repeated applications to reduce urchin densities sufficiently to regenerate kelp, and the large expense required to deliver ubiquitous cover of lime at scale in deep water (20-40 m). It is also unlikely that use of lime to kill urchins would receive strong social licence in Australia.

Use of robots to locate, identify and kill urchins in deep water remains an open possibility, but requires more research to properly evaluate and validate. Sydney company Hullbot (https://hullbot.com/; see page 25 below), with assistance from staff at IMAS (University of Tasmania) and the Australian Centre for Field Robotics (University of Sydney), have been developing a small and relatively inexpensive machine for this purpose. Their existing prototype can be deployed autonomously, it will seek and identify *Centrostephanus* individuals, hold position in surge, and successfully drill a 50 mm hole through the test of a target urchin. However, more refinement is required, including development of underwater navigation to ensure systematic and comprehensive coverage of the seafloor, and communication between multiple machines so that they can operate in 'swarm' mode to clear *Centrostephanus* from reef at meaningful scales. One advantage of the robot is that it can operate at night when *Centrostephanus* emerges from protective microhabitat to feed openly on rock surfaces.

Table A1. Depth distribution of sea urchin (*Centrostephanus rodgersii*) barrens in shallow (<20 m) and deep (>20 m) water on rocky reefs in eastern Tasmania. Data indicate the proportion of total barrens observed that occurs in a particular depth stratum and are based on planar area of barrens habitat. The towed video surveys in 2001/02 were at 13 sites approximately equidistant between Eddystone Pt and Recherche Bay (Johnson et al. 2005), and which were resurveyed in 2016/17 (Ling & Keane 2018). Data from 2021 are from an IMAS multibeam survey of rocky reef between Eddystone Pt and the Tasman Peninsula; these data are presently unpublished and were provided by Assoc Prof V. Lucieer (IMAS). More detailed information on depth distributions of urchin barrens is in Table A2 below.

Survey Date	Prop. of urchin barrens <20 m	Prop. urchin barrens >20 m
2001/02 (video tows)	0.40	0.60
2016/17 (video tows)	0.38	0.62
2021 (multibeam)	0.45	0.55

Appendix IV. Deepwater control options for Longspined Sea Urchin Barrens… continued.

Table A2. Distribution of urchin barrens by depth on rocky reefs in eastern Tasmania. Data indicate the proportion of total barrens observed that occurs in a particular depth strata. (i) Results of towed video surveys in 2001/02 and 2016/17 (see Johnson et al. 2005; Ling & Keane 2018 respectively) from 13 sites approximately equidistant between Eddystone Pt and Recherche Bay. (ii) Results of multibeam acoustic survey 2021 between Eddystone Pt and Tasman Peninsula.

(i) Towed video surveys

Depth (m)	Prop. barrens occurrence, 2001/02	Prop. barrens occurrence, 2016/17
6	0.00	0.02
8	0.02	0.02
10	0.04	0.03
12	0.04	0.04
14	0.06	0.06
16	0.09	0.06
18	0.07	0.06
20	0.08	0.08
22	0.06	0.08
24	0.08	0.09
26	0.09	0.08
28	0.07	0.07
30	0.04	0.08
32	0.08	0.04
34	0.14	0.03
36	0.02	0.07
38	0.03	0.09
40	0.00	0.00

(ii) Multibeam survey, 2021

Depth (m)	Prop. barrens occurrence
<5	0.0
5-10	1.3
10-15	12.4
15-20	31.1
20-25	28.1
25-30	18.7
30-35	8.0
35-40	0.2
40-45	0.2

Appendix IV. Deepwater control options for Longspined Sea Urchin Barrens… continued.

Hullbot Urchin Platform: https://hullbot.com/

1. **Hullbot Urchin Platform capabilities**

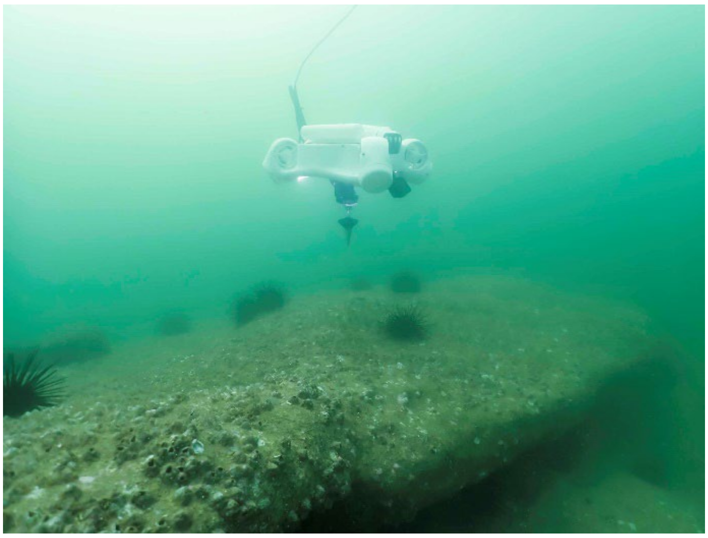
   The Hullbot Urchin Platform has demonstrated the following capabilities in field trials:

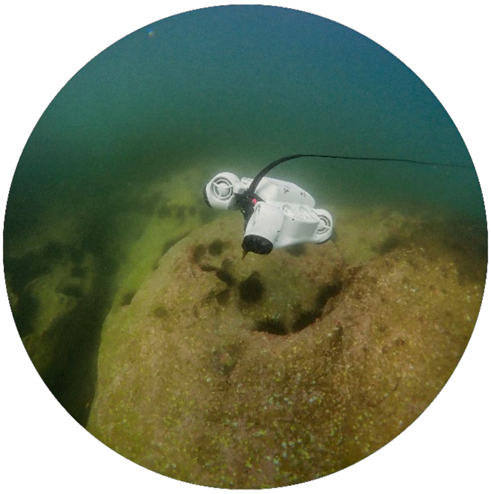
   - Locating, mapping, and identifying *Centrostephanus* in the field using its onboard computer vision system and powerful processing unit.
   - Holding its position and orientation using its custom high efficiency thrusters, even in high surge environments.
   - Moving and orienting itself in six degrees of freedom in the water column. Its finely tuned and adaptive control system enables precise position and orientation control.
   - Demonstrating the ability to rapidly destroy *Centrostephanus* individuals by drilling a 50mm hole through the centre of trial specimens in the field.

2. **Next steps in development**

   Further steps in the development of the Hullbot Urchin Platform for use in controlling invasive marine species like *Centrostephanus* include:

   - Expanded development of AI-powered detection, identification and tracking of *Centrostephanus*
   - Advances in automation of the system that will ensure the platform can carry out all of its capabilities with minimal human intervention. For example the platform may carry out the following actions in a fully automated sequence:
     - deploy from the docking station;
     - navigate to the desired area;
     - monitoring and assessing the conditions for optimal operation;
     - map the area whilst locating and identifying *Centrostephanus;*
     - compile a series of possible paths and trajectories that optimises for the rapid culling of *Centrostephanus;*
     - carry out the planned movements and culling of *Centrostephanus;*
     - return to the docking station;
   - Additional environmental monitoring and surveillance capabilities
   - Increased operational modes including increased depth and night deployment
   - Further advances in control system stability to enable platform stability in harsh conditions and precise control in and around complex reef and rock structures.
   - Communication between platforms to enable swarm deployment to exponentially increase the efficiency of *Centrostephanus* control with minimal additional human intervention.





Appendix V. Redmap: What's on the move around Australia – Downloadable at https://www.redmap.org.au/article/report-card/

Appendix VI. East Coast Giant Kelp Reforestation Strategy (Associate Professor Scott Ling).

Establishing a reforestation industry for Giant Kelp on Tasmania's East Coast

A 3-year $6 million investment in a strategy to create east coast jobs to recover bio-diverse and bio-productive kelp forest ecosystems.

Context

The east coast of Tasmania is a global hotspot of marine ecosystem change, with its biodiverse and productive reef ecosystems undergoing profound shifts in recent decades. The flagship of change is the dramatic loss (>95%) of the iconic Giant Kelp Forests formed by *Macrocystis pyrifera*. This loss prompted an endangered ecological community listing under the EPBC Act in 2012. Recent interest in seaweed-based aquaculture solutions has resulted in large numbers of Giant Kelp propagules being generated in east-coast hatcheries. Since the endangered community listing there has been limited understanding of how to re-establish Giant Kelp Forests. **Recently IMAS scientists have developed a rapid technique for successfully seeding hatchery-reared Giant Kelp propagules to natural reefs at forest scales**.

The profound changes on Tasmania's east-coast, resulting from the warm waters of the East Australian Current travelling further south, also includes an ongoing invasion by overgrazing sea urchins (*Centrostephanus rodgersii*). The sea urchin population has exploded to 20 million and is collapsing Tasmania's kelp habitats. Projections indicate that half of all reefs on the east coast could become urchin barren grounds by mid-2030s.

Restoring Giant Kelp Forests off the east-coast of Tasmania is contingent on a whole-of-reef ecosystem strategy that utilises hatchery-reared Giant Kelp propagules and removes the threat of sea urchins.

The '*East Coast Giant Kelp Reforestation Strategy'* combines the latest scientific advancements and management mechanisms to create a restoration economy for Tasmania's east-coast communities. This strategy is focussed on creating better habitats for better biodiversity, enhanced tourism experiences and replenishment of commercial and recreational fish stocks.

The **$6 million** strategy will provide a whole-of-ecosystem approach to reforestation of Giant Kelp to ensure resilient and thriving kelp dominated reefs into the future by*:*

1. Funding a high-production Giant Kelp hatchery on the east coast ($0.75 million)
2. Funding targeted urchin removals by commercial divers within Giant Kelp Reforestation Zones to pave-the-way for out-planting of Giant Kelp propagules ($1 million)
3. Funding local commercial divers to re-seed Giant Kelp propagules to the reef at multiple sites across the east coast totalling an initial 10 hectares ($2 million)
4. Funding the recreational dive industry to establish a volunteer-tourism internship program to train and educate divers to establish and maintain iconic Giant Kelp Forests as local dive/ snorkel/ tour boat attractions on the east coast ($0.25 million)
5. Funding a ramp-up the East Coast Rock Lobster Stock Rebuilding Strategy's translocation of lobsters by commercial fishers from southern Tasmania to the east coast to help safeguard restored kelp forests against future sea urchin incursions ($0.5 million)
6. Funding monitoring, evaluation, and optimisation of restoration of large self-sustaining Giant Kelp Forests to ensure persistence of this endangered community and to maximise gains in reef productivity for Tasmania's east coast ($1.5 million)

Appendix VI. East Coast Giant Kelp Reforestation Strategy … continued.

This strategy will be popular for east coast residents as it will directly and indirectly support:

- **Emerging marine restoration industries** – increasing interest from private and public enterprises focussed on ecosystem restoration of coastal environments, significant potential marine industry (e.g. Sea Forest), also encompasses kelp polyculture.
- **Commercial fishing industries** - explicit links to abalone and rock lobster fisheries respectively via the *Abalone Industry Reinvestment Fund* supporting urchin control measures, and the *East Coast Rock Lobster Stock Rebuilding Strategy*.
- **Recreational fisheries** - A passionate and connected recreational fishing community on the east coast who still have the opportunity to harvest wild abalone, crayfish and fin-fish but who have witnessed the dramatic changes in their marine environment over recent decades.
- **Tourism** - Enrichment of a rapidly growing natural tourism sector on Tasmania's east coast (e.g. tourist divers visiting restored kelp forests & voluntourism by recreational divers being actively involved in local restoration, tour companies will benefit by diversification of their tour products, e.g. tour boat and hiking tour operators).
- **Science underpinning restoration** – IMAS is leading world-class restoration initiatives with increasing focus on seaweed solutions for people and the environment, plus has an emerging marine threatened species research group. In establishing mechanisms to reduce the impact of the invasive sea urchin on the east coast, IMAS and the Tasmanian State government are leading the world in 'ecosystem-based reef fisheries management'. Reforesting Giant Kelp will represent an important high-profile project and a key outcome will be to clearly position Tasmania as a world leader in industrialising marine ecosystem restoration.

Detailed budget

Item	**Cost/unit**	**# units**	**subtotal**
Hatchery infrastructure and production of	500,000 propagules/ha or per million gametophytes		$0.75M
Urchin culling (harvest subsidy) to pave-the-way for successful out-planting of Giant Kelp propagules This wont work as proposed – you need targeted take-all removals from specific habitats. Better off saying $2200/day 150 diver days per year for 3 years = 1 mil	$2.5 per kilo of landed urchin wet weight (3 urchins per landed kilo on average) $2,200 per dive day	Subsidised catch of 400 tonnes (or 1.2 million urchins) 150 days pa	$1.0M
Giant Kelp seeding/deployment following urchin harvest conducted with Tasmanian Commercial Divers Association	TBA $2,200 per dive day		$2.0M
Establish a volunteer-tourism internship program to train and educate recreational divers in kelp forest restoration	Diver education and training in restoration techniques	Recreational divers	$0.25M
Ramp-up of rock lobster rebuilding on the east coast via translocation	$0.25M/yr for final 2 years of strategy once kelp forest established	90,000 lobsters per year, 180,000 in total	$0.5M
R&D including monitoring and evaluation	$0.5M/yr		$1.5M
Grand Total			**$6.0M**

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