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Supplementary information

1. Purpose of this Document

This document details the methodology behind our physio-economic modelling for our manuscript 'Using historical responses to shoreline change on Australia's Gold Coast to estimate costs of coastal adaptation to sea level rise'.

2. Physio-Economic Modelling Method

2.1. Estimating Costs of Historic Responses

We first estimated the costs of historic responses to the implied sea level rise from our application of the reverse Bruun Model. With a detailed catalogue of the type and extent of works undertaken (Table 1 in main manuscript), we undertook a literature review and made personal correspondence to ascertain the costs of implementation and maintenance of equivalent coastal defence interventions from projects around the world (Supplementary Table 1). From this catalogue of interventions, we calculated high, medium, and low costs of construction and maintenance costs in 2018 dollar terms (Supplementary Table 2).

Table 1. Catalogue of construction and maintenance costs from around the world (normalised to 2018 USD).

Year	Location	Type	Capital Unit Cost 2018 USD	Annual Maintenance as % of Capital	Source
2013	Kirra Australia	Groyne	$ 26,064/m		
2017	Narrowneck Australia	Seawall	$ 3,276/m		http://news.cityofgoldcoast.com.au/media-releases/protecting-narrowneck-future
2016	Kurrawa Seawall Replacement	Seawall	$ 4,706/m		http://news.cityofgoldcoast.com.au/media-releases/new-partnership-protect-kurrawa-beach
2016	Kingscliff Seawall + Nourishment	Seawall	$ 13,061/m		http://www.tchp.com.au/wp-content/uploads/2017/06/Kingscliff_Matters_Brochure.pdf
2017	Belongil Seawall	Seawall	$ 8,735/m		personal Communication James Carley project designer
2017	Gold Coast Beach Nourishment Project 2017	Nourishment	$ 3/m3		http://www.goldcoast.qld.gov.au/gold-coast-beach-nourishment-38539.html and http://news.cityofgoldcoast.com.au/media-releases/nourishing-our-beaches-future
2011	Portugal	Groyne	$ 15,509/m	7%	(Roebeling, et al. 2011)
2011	Portugal	Nourishment	$ 9/m3		(Roebeling, et al. 2011)
2007	United Kingdom	Seawall	$ 1,601/m	1%	(Turner et al. 2007)
2016	United Kingdom	Groynes	$ 4,317/m		(Williams et al. 2016)

2016	United Kingdom	Seawall	$ 10,073/m		(Williams et al. 2016)
2018	Portugal	Seawall	$ 11,957/m	7%	(do Carmo 2018)
2018	Portugal	Groyne	$ 14,963/m	6%	(do Carmo 2018)

Table 2. Summary of high, medium, and low values for coastal protection approaches (2018 US $).

Coastal Protection	High	Low	Mid	Maintenance
Groyne	$26,064/m	$4,317/m	$15,190.50	7–6%
Seawall	$13,061/m	$1,601/m	$7,331.00	7% to 1%
Nourishment	$9/m3	$3/m3	$6/m3	†

† Beach nourishment, in this context, is considered a hybrid capital expense and maintenance expense.

2.2. Projecting Vicennial Rates of Sea Level Rise

Based on data from the CoastAdapt website [1], we calculated rates of sea level rise (SLR) for vicennial time periods through to 2090, taking 2005 (the year the sand bypass become operational) as year 1. This output is reported in supplementary Table 3. Note that due to differences in the modelling behind the formulation of the RCPs, RCP4.5 records a greater rate of SLR during the 20th century [2].

Table 3. Rate of sea level rise (metres in time step) (IPCC, 2014).

Time	Year	RCP 2.6		RCP 4.5		RCP 6.0		RCP 8.5	
		Raw	Rate	Raw	Rate	Raw	Rate	Raw	Rate
2005	1	0	0.0056	0	0.006	0	0.0056	0	0.006
2030	26	0.14	0.0055	0.15	0.006	0.14	0.006	0.15	0.008
2050	46	0.25	0.007	0.27	0.0085	0.26	0.008	0.31	0.012
2070	66	0.39	0.0075	0.44	0.011	0.42	0.012	0.55	0.019
2090	86	0.54		0.66		0.66		0.93	

2.3. Modelling Equivalent Back-Casted Sea Level Rise

We then back-casted implied SLR for each RCP. These values are reported in Table 4 (Supplementary). From this matrix of values, we estimated the implied sea level rise at the time of each project's implementation. Sea level rise is always estimated relative to the IPCC 2005 baseline. For each project we determined the years from present over which the implied sea level rise would occur, based on the projections for the four RCPs for the Gold Coast.

Table 4. Modelled equivalent back-casted sea level rise under RCP scenarios.

Year	SLR	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
		Year	Year	Year	Year
1960	0.039280	2012	2011	2012	2011
1965	0.157119	2033	2031	2032	2030
1970	0.541189	2090	2079	2080	2069
1975	0.951446	2144	2116	2114	2091
1980	1.304965	2191	2148	2143	2109
1985	1.518822	2220	2168	2161	2120
1990	1.667212	2240	2181	2173	2128
1995	1.854883	2265	2198	2189	2138

2.4. Economic Parameters

The final step was to estimate the present value (PV) costs of the projected (hypothetical) projects from their year of required implementation. We applied a relative low discount rate of 3%, as a mid-

point. In addition, we included additional costs to account for regular annual maintenance costs and replacement costs for assets to be replaced beyond their functional life, as follows, and summarised in Supplementary Table 4:

The functional life of a sea wall and groyne is assumed to be 100 years before complete replacement is required. These costs are factored in to replace any sea walls that need replacing. These costs are also subject to inflation.

Maintenance costs for sea walls and groynes is set at 1% per annum, in accordance with Gordon's assumptions [3]. Maintenance is assumed to not be required for beach nourishment, as this intervention is assumed to be a maintenance option in itself.

We undertook sensitivity analysis at discount rates of 1% (a 'social' discount rate) and 7.5% (the rate recommended for project assessment by the Australian Government).

Table 5. Variables used in model.

Variable	Value	
Inflation	1.7%	of 1
Discount	3%/1%/7.5%	of 1
Maintenance	5%	of 1
Seawall/Groyne Life	100	years

References

1. NCCARF & Australian Government, "CoastAdapt, Sea-level rise and future climate information for coastal councils. Available online: https://coastadapt.com.au/sea-level-rise-information-all-australian-coastal-councils#QLD_GOLD_COAST. (Accessed on 6 March 2020, 22 January 2020).
2. Wayne, G. (2013). The Beginner's Guide to Representative Concentration Pathways. Retrieved from https://skepticalscience.com/docs/RCP_Guide.pdf
3. Gordon, A. D. (1989). Sydney's Sea Defences. In Ninth Australasian Conference on Coastal and Ocean Engineering, 1989: Preprints of Papers (p. 149).