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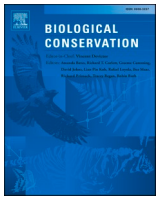

Policy analysis

Using systematic conservation planning to align priority areas for biodiversity and nature-based activities in marine spatial planning: A real-world application in contested marine space

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ABSTRACT

To support sustainable growth of ocean-based economies, many countries are engaging in marine spatial planning (MSP) processes, which require robust decision-support tools. Systematic conservation planning (SCP) is commonly used in decision-making to guide spatially efficient protected area expansion. Here we contend that SCP can also be used to streamline MSP negotiations by developing a coherent, integrated portfolio of sites for multiple sectors that depend on biodiversity being maintained in a good state, as a counterpoint to spatial priorities for those commercial and industrial activities that have negative environmental impacts. We demonstrate this in Algoa Bay, South Africa, given the social-ecological complexity of the bay, and its central location in the first national MSP process. In anticipation of this national process, a civil-society-led Community of Practice was established with a core team to lead stakeholder engagement, data acquisition and management, and SCP analyses. More than 500 stakeholders participated in the project and many contributed spatial data or engaged in

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expert-based participatory mapping. Spatial products were supplemented with existing, published datasets. Altogether, conservation targets were set for 115 biodiversity features and 22 nature-based activities, with the cost layer built from data on 10 commercial and industrial activities, cumulative pressures (n = 31) on ecosystems, and planning-unit area. All targets were met in 15% of the study area, of which only a third (4%) was outside of marine protected areas, demonstrating that it is possible to align multi-sector priorities for intact biodiversity. This approach can be widely applied in MSP to support sustainable ocean economies.

1. Introduction

Ecosystem-based marine spatial planning (MSP) is an emerging process globally as countries seek to grow their ocean-based economies sustainably (Chalastani et al., 2021, Harris et al., 2022, Lombard et al., 2019a,b). Fundamental to this is safeguarding a representative portion of biodiversity and key ecological processes in connected, adequate and efficient networks of sites that support maintained provisioning of key ecosystem goods and services (Possingham et al., 2006; Harris et al., 2019a; Tittensor et al., 2019). Achieving this requires that the identified sites be carefully managed, and ideally, become formally protected in marine protected areas (MPAs) in alignment with international protection targets (Obura et al., 2021). There is also an increasing focus on designing areas that safeguard biodiversity in a way that simultaneously enhances the myriad of nature-based benefits for people (Annis et al., 2017; Friedman et al., 2020; Lombard et al., 2019a,b; Selig et al., 2019). This is especially important in coastal areas where sites rich in biodiversity are also associated with urban development, and thus where the pool of stakeholders is diverse, complex, and their respective interests are potentially conflicting (Noble et al., 2019). One way to streamline MSP negotiations and enhance spatial efficiency is to develop a coherent, integrated portfolio of spatial priorities across sectors that depend on biodiversity being kept in a natural or semi-natural state as a counterpoint to the spatial requirements of industrial, potentially destructive activities. The ensuing challenge, though, is how to achieve this integrated spatial prioritization for biodiversity and nature-based activities in the real world.

Systematic conservation planning (SCP, Margules and Pressey, 2000) is commonly used to identify representative, well-connected networks of priority sites for a range of biodiversity features (e.g., ecosystem types, species distributions, ecological processes), often with the objective of protected area expansion or design (Ban et al., 2011). Complementarity, spatial efficiency, and conflict avoidance are central to SCP, maximising likelihood of implementation because both the extent of the site networks representing numerous biodiversity features and the areas of overlap with competing uses are minimised (Devillers et al., 2015). Consequently, SCP has been proposed as a tool that can advance the MSP process (Álvarez-Romero et al., 2018; Harris et al., 2019b) because it focuses negotiations on legitimately contested space. We propose to take this step further and reframe the SCP process to develop integrated spatial prioritizations for protecting biodiversity (e.g., reefs) and sustainable nature-based activities (e.g., scuba diving, open-water swimming) concurrently, where possible, and to use the outputs as departure points in MSP processes that must also address spatial allocation for destructive, extractive commercial activities (e.g., demersal trawling, pollution outfalls).

In technical terms, this means that only those activities that are incompatible with maintaining an area in a natural or semi-natural state are included in the SCP as costs, and targets are set for nature-based activities as though they were – in a traditional SCP sense – biodiversity features. It is fully recognized that some of these activities now framed as being 'compatible' with biodiversity can have serious negative impacts on the environment, e.g., impacts of recreational fishing on target species (e.g., Cooke et al., 2014). Nevertheless, in the context of MSP, we contend that it is beneficial to align the interests of a range of sectors that have reasonably compatible requirements for natural or semi-natural areas for their use. Effectively, this requires accepting the lesser impacts of activities that are not extremely destructive to ecosystems and species, in order to gain the benefits of aligning many users and sectors, and hence improve the chance of collective success in securing areas that require sustainable management (e.g. within appropriate specified zones with regulations with an agreed spatial plan) rather than (necessarily) strict, formal protection. For this approach to be effective, it is imperative that the impacts of the perceived 'compatible' activities are extremely well-managed, including potentially incorporating zoned marine space, e.g., securing both take and no-take areas to manage sectors such as recreational fisheries (Grorud-Colvert et al., 2021).

The aim of this study is to use SCP to identify an integrated portfolio of priority areas across diverse sectors that all require sustainably managed, natural and semi-natural coastal and marine ecosystems to safeguard biodiversity and continue to provide nature-based benefits to people as an input to a multi-sector MSP process. We use Algoa Bay in South Africa as a model system to test this approach because it is a highly contested space, with extremes of intense industrial activities, exceptional biodiversity, and high value and use of natural spaces and biodiversity by local residents and tourists. It is also neatly positioned in the broader context of South Africa's intent to grow the ocean economy as part of Operation Phakisa: a presidential initiative to help fast-track economic development (Republic of South Africa, 2014), and the national emerging MSP process (Government of South Africa, 2019a; Harris et al., 2022). Recent MPA expansion, particularly the large Addo Elephant National Park Marine Protected Area in the east of Algoa Bay (Sink et al., 2019; Government of South Africa, 2019b), has already formally secured many of the key biodiversity features in the area. Therefore, our aim deliberately does not include identifying additional areas for strict protection (e.g., more no-take areas) but rather focuses on identifying priority areas for integrated sustainable management (e.g., expanded "take" zoned MPAs), especially in the contested marine space in the west of the Bay. These areas would form the basis of a coherent set of spatial priorities to be secured through appropriate zoning and regulations within the emerging national MSP process (Government of South Africa, 2019a). The objectives are to: establish a community of practice and build relationships with stakeholders based on clear and open channels of communication; collect information from as many stakeholders and sources as possible in a variety of possible formats to suit the different stakeholders' needs; run a SCP to identify the integrated priority areas; and more broadly, to provide a case study of fine-scale MSP that the national MSP process and other local areas can use.

2. Methods

2.1. Study area

2.1.1. Background

Algoa Bay is a microtidal, log-spiral bay in the south-east corner of South Africa (Fig. 1a). This area is recognized nationally and internationally for its exceptional diversity, e.g., it includes two MPAs (Sink et al., 2019), is within an Ecologically or Biologically Significant Marine Area (EBSA; MARISMA Project, 2020), a Hope Spot (Mission Blue, 2017), and has two Important Bird and Biodiversity Areas (Marnewick et al., 2015) and Key Biodiversity Areas. It also includes the coastal city of Gqeberha (formerly, Port Elizabeth), two industrial ports, a variety of commercial fisheries, hosts numerous sporting events, and has

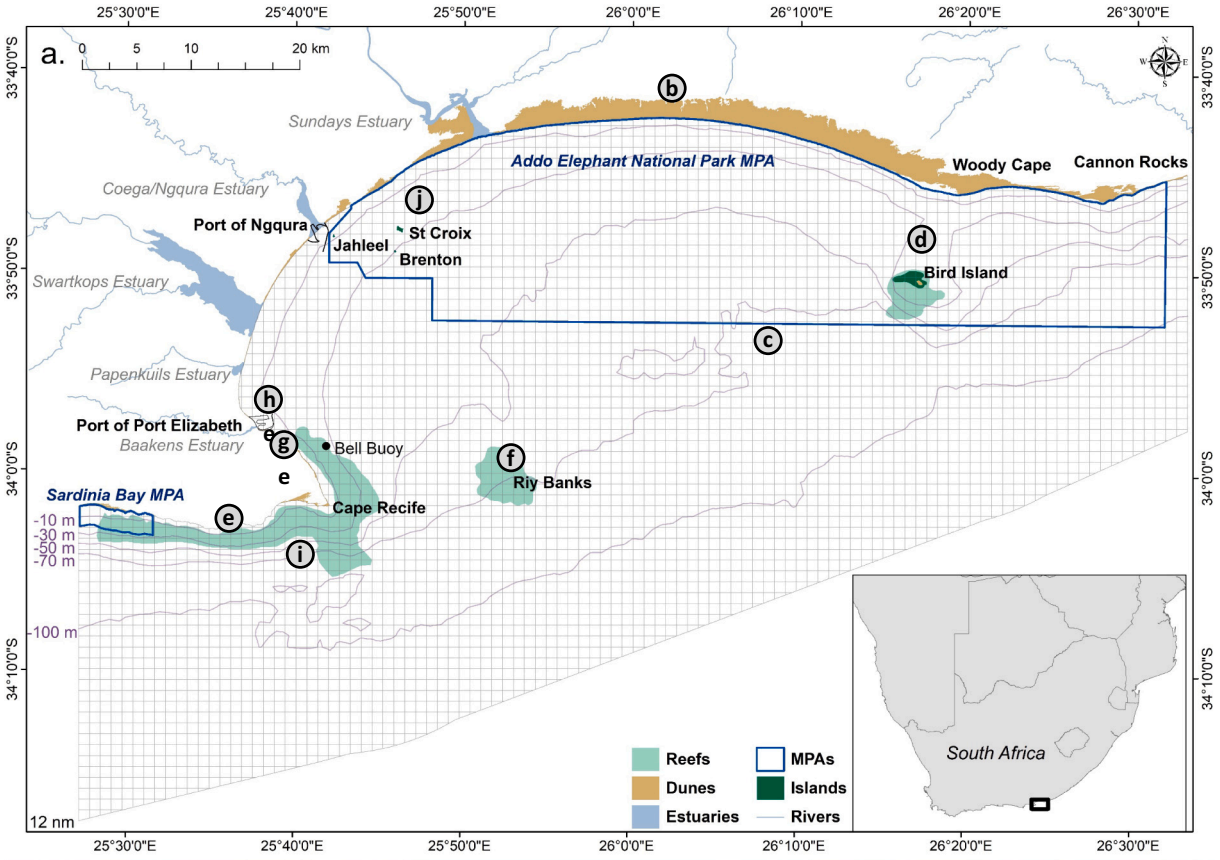

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Fig. 1. (a) The planning domain spanning Algoa Bay in South Africa, divided into the 1 km^2 planning units. Estuaries and salient locations are labelled, and key features (reefs, dunes and islands) are illustrated. Data sources: coastal ecosystems (Harris et al., 2019a); isobaths (De Wet and Compton, 2021); territorial sea (Flanders Marine Institute, 2018); MPAs (Sink et al., 2019). The complex social-ecological system includes spectacular biodiversity features, e.g., (b) Alexandria dunefield; (c) migrating whales; and (d) colonies of threatened seabirds; sustainable activities, e.g., (e) recreational fishing; (f) scuba diving; and (g) sports events, including high-profile races like the Ironman African Championship; and industrial uses, e.g., (h) two industrial ports (Port of Port Elizabeth/Gqeberha shown) and (i) commercial fisheries, e.g., squid jig fishing; and has been the focus of controversial spatial conflicts between sectors e.g., (j) oiled African penguins being rescued from St Croix Island after an oil spill from ship-to-ship bunkering. Photo credits: Paul Martin (b), Lloyd Edwards, Raggy Charters (c, d, j) Linda Harris (e–h), Frikkie van der Vyfer (i).

increasing levels of human activity. In short, it is a complex social-ecological system, with both exceptional biodiversity and a variety of human uses with competing interests (Fig. 1b–j), e.g., ship-to-ship bunkering (at-sea transfer of oil from one ship to another) adjacent to colonies of threatened seabirds that are visited by boat-based ecotourism operators (Ryan et al., 2019). Bunkering has resulted in oil spills several times since operations commenced, which have oiled Endangered African penguins (Fig. 1j). Oiling penguins is of particular concern given the rapid decline in population abundance (Sherley et al., 2020), with knock-on socio-economic implications for boat-based tourism. This is one of several examples demonstrating the need for a robust MSP for Algoa Bay. For more details on the biodiversity and activities in Algoa Bay, see the Supplementary material.

2.1.2. Planning domain

The planning domain extends 150 km along the shore from Sardinia Bay MPA to Cannon Rocks (Fig. 1a). The landward extent follows the dune base (Harris et al., 2019a), and the seaward extent is the outer edge of the territorial sea, 12 NM offshore (Flanders Marine Institute, 2018). Estuaries were excluded from the planning domain because they are covered by separate estuary management plans rather than MSP; however, cross- realm links between estuaries and the marine realm were included. The planning domain was divided into 4116 1-km^2 planning units; a unit size that was reasonably matched to the range of resolutions of the different spatial datasets and the size of the study area. All spatial data were prepared and analyzed in ArcGIS 10.6.

2.2. Establishing the Community of Practice and stakeholder-engagement processes

A Community of Practice (CoP) was established to undertake the Algoa Bay Project (Dorrington et al., 2018; Rivers et al., 2022). The CoP is a multi-disciplinary civil-society consortium, funded by the National Research Foundation and led by six South African Research Chairs, and numerous researchers from universities and national research institutions based in the study area and surrounds. A stakeholder liaison and a data team were appointed to establish clear lines of communication between researchers and stakeholders, and a planning team was appointed to run the SCP (hereafter collectively called the core team). Stakeholders and potential data providers were identified from records of the previous spatial planning processes underpinning the Addo Elephant National Park MPA, and from personal networks of the planning team and CoP. More than 500 stakeholders were initially identified and categorized into 11 broad stakeholder groups, e.g., tourism and recreation, and research. Initial contact was made with stakeholders by phone, email and small meetings, followed by several project information sessions held in the form of large stakeholder workshops. During the workshops, stakeholders chose to be passive or active participants. Passive participants wanted to be kept informed on project proceedings and progress through the stakeholder liaison, and active participants wanted to contribute data via the data team.

2.3. Input data

The data team compiled a database of existing spatial data from published research (e.g., Chalmers, 2012) and from previous planning projects (e.g., Addo Elephant MPA planning process). This entailed obtaining the original datasets or digitizing hard-copy maps or other non-spatial information. Next, the active participants were contacted. Recognizing the diversity of users within the stakeholder group, data-collection methods needed to be varied to suit individual requirements. Where raw spatial data (e.g., GPS co-ordinates and shapefiles) were available and stakeholders were comfortable to share the information in that format, the datasets were included as provided, unless further data processing was required (see Supplementary material for details). However, if stakeholders were not comfortable to share the raw data, e.g., to protect the intellectual property of scientists' unpublished data, then the raw data were summarized using the planning unit layer (Fig. 1a). As a third option, stakeholders were invited to identify priority areas on the planning unit layer for specific features or uses within their area of expertise, either manually or electronically, with or without guided support, one-on-one or in group meetings. Where data were provided on printed copies of the map, these were digitized by the data team. Throughout the data-collection process, the core team met regularly to check progress and iteratively identify data gaps that were then filled by targeted data searches and engaging with active participants and additional experts, as necessary.

The data-collection method, described above, was followed for compiling data on biodiversity features, nature-based activities, and industrial activities (Table 1). In addition to the collated published information, data were obtained from 32 people from 20 institutions (approximately 6% of the total stakeholder pool). After all the datasets were compiled, where there were several maps representing the same feature, these were either combined (e.g., several stakeholders contributing information on the distribution of the same activity within Algoa Bay) or the most appropriate dataset was selected (e.g., the most up-to-date map of ecosystem types). Once the input data had been finalized (see Supplementary material for details), biodiversity features and nature-based activities were coded to the planning unit layer and targets were set for each of these input layers (Section 2.4). Then, the commercial and industrial activities were combined into an integrated layer representing cost (052.5).

2.4. Target setting

Running Marxan requires a user-defined amount (target) to be set per feature, representing the amount of that feature that needs to be represented in the final selection (Ball et al., 2009). A pragmatic approach to target-setting was used, as recommended by Porter et al. (2011). Lower proportional targets for larger, more extensive features and relatively higher proportional targets for smaller features with a limited extent. Targets were calculated as follows, using an additive process: 60% of the first 100 ha; 50% of 100–500 ha; 40% of 500–1000 ha; 30% of 1000–5000 ha and 20% of areas greater than 5000 ha.

2.5. Cost surface

A cost surface was used in the Marxan analysis to avoid areas that are in poor ecological condition (based on maps of cumulative pressure, Sink et al., 2019) or used intensively by incompatible activities. The cost surface was calculated as follows (see Supplementary material for more details):

$$\text{Cost} = \text{EX} + 3(\text{CP}) + 5(\text{SI}) + \text{SL} + \text{AN} + \text{D} + \text{M} + \text{SJF} + \text{IT} + \text{SLF} + \text{CL} + \text{SPF}$$

Table 1
Summary of the input data (biodiversity features, nature-based activities, and commercial and industrial uses) that were included in the Marxan analysis, and the data sources. For more details, see the Supplementary material.

Features (n)		Description	Data source
Biodiversity features (115)			
Ecosystem types (19)	National classification (16)	Coastal and marine ecosystem types.	Published National Spatial data through the National Biodiversity Assessment (NBA) 2018 (Harris et al., 2019a; Sink et al., 2019).
	Fine-scale reef data (2)	Potential and confirmed reef areas, where reef or rocky shore areas were assigned as 'Confirmed' reef (100) and mixed shore/subtidal assigned as 'Potential' reef (50).	Digitized side-scan sonographs from local government; unpublished spatial data from national maritime government agency (South African Navy Hydrographic Office); spatial data set from previous Government Conservation Planning project (Addo Elephant National Park MPA); published National Spatial data through the National Biodiversity Assessment (NBA) 2018 (Sink et al., 2019); expert mapping with local stakeholders (researchers and commercial and recreational anglers).
	Abalone-supporting reefs (1)	Reef systems known to have abalone present in Algoa Bay.	Published literature (Chalmers, 2012; Godfrey, 2003; SFRI, 1986; Tarr and Anderson, 1987); expert mapping with SANParks.
Birds (16)	Shorebirds and coast-associated birds (10)	Damara tern nesting and feeding sites and Roseate tern and Antarctic tern roosting sites in Algoa Bay and coastal bird species richness and abundance from the South African Bird Atlas Project (SABAP2).	Published spatial data from the South African Bird Atlas Project (SABAP2); expert mapping with stakeholders (environmental agencies).
	Threatened colonial seabirds (6)	Colonies, and relative presence and core areas used by African penguins and Cape gannets in Algoa Bay.	Reanalysis of raw data from papers by local researchers (e.g., Botha et al., 2017; Thiebault et al., 2018, Pichegru et al., 2010, and some unpublished data).
Cetaceans (5)	Cetacean distributions (5)	Cetacean sightings from at-sea boat trips of dive charters and boat-based whale watching operations, as well as on-shore sightings.	Expert mapping with local at-sea tourism operators and other stakeholders.
Turtles (1)	Turtles (1)	Turtle sightings.	Expert mapping by local stakeholders.
Sharks and rays (20)	Sharks and rays (20)	Distributions of various sharks and rays in Algoa Bay.	Expert mapping by scientists.
Fish (41)	Linefish species distributions (39)	Distributions of 39 common linefish species.	Unpublished catch data from recreational angling competitions (2018/9) and older roving creel data (Chalmers, 2012); unpublished data from local researchers; expert mapping workshop with local stakeholders (recreational anglers; local researchers).
	Fish aggregation, recruitment and nursery areas (2)	Composite analyses of multiple fish larvae species indicating their areas importance. Baitball occurrences.	Published data provided by local researcher (Pattrick et al., 2016).
Squid (2)	Important squid spawning areas (2)	Important squid spawning/nesting areas in Algoa Bay.	Expert mapping with local research scientists affiliated with the South African Squid Management Industrial Association and local universities.
Biodiversity priority areas (2)	Ecologically or Biologically Significant Marine Areas (1)	Algoa to Amathole EBSA.	Published Regional Spatial data by the Marine Spatial Management and Governance EBSA project (MARISMA Project, 2020).
	Marine Protected Areas (1)	Addo Elephant National Park MPA and Sardinia Bay MPA.	Spatial data set from previous Government Conservation Planning project (Addo Elephant National Park MPA) and digitization of Government Gazetted delineated protected areas (Government of South Africa, 2019b, 2000).
Culturally significant areas (4)	Heritage sites and shell middens (4)	Positions of shipwrecks, shell middens and other archaeological areas of importance.	Spatial data provided by the South African Heritage Resource Agency (SAHRA).
Design elements (5)	Conservation Planning Adjacency and Zoning Features (5)	Areas in close proximity to protected areas, islands, estuaries to align priorities with existing protection and near features with high value for ecological processes.	Derived from existing ecosystem and protected area data.
Nature-based activities (22)			
Sports and activities (16)	Recreational coastal and water-based activities (16)	Dive sites, popular bird- and cetacean-watching sites, kiteboarding areas, stand-up paddle-boarding areas, life-saving competition and training areas, triathlons and open-water swimming competition and training areas, surf-ski areas and yachting routes and areas.	Expert mapping with local government, tourism agencies, sport and recreation clubs, sports and recreation businesses, health and safety agencies.
Recreational and subsistence fishing (6)	Recreational fishing: shore based (2)	Competitive and other recreational shore fishing areas.	Expert mapping with competitive shore fishing organizations, recreational shore fishing competitors, researchers from local universities.
	Recreational fishing: non-shore based (3)	Priority areas for recreational spear-, kayak- and ski-boat fishing.	Expert mapping with local fishing clubs (e.g., members from the Port Elizabeth Deep Sea Angling Club) and published spearfishing locations (Rubidge, 2006).
	Subsistence fishing intensity (1)	Subsistence fishing intensity determined per 2-km stretch of coastline.	Fishing survey from previous Government Conservation Planning project (Addo Elephant National Park MPA), and additional expert mapping.
Cost layer (12)			
Ports, shipping and other related activities (5)	Mariculture zones Dredge dumping zones Anchorage zones (including	Mariculture zones, dredge dumping zones and anchorage zones in Algoa Bay. Note that ship-to-ship bunkering is included in the anchorage zones.	Digitized from the nautical chart maps available on iBoating web app (http://fishing-app.gpsnauticalcharts.com/i-boating-fishing-web-app/fishing-marine-ch

(*continued on next page*)

Table 1 (*continued*)

Features (n)		Description	Data source
	ship-to-ship bunkering)		
	Shipping lanes (4)		arts-navigation.html?title=A+Port+Elizabeth +boating+app#9.45/-33.8813/25.8934).
	Shipping intensity (1)	Areas of highest shipping intensity in Algoa Bay.	High shipping intensity areas digitized from the Marine Traffic website (https://www.marinetraffic.com/en/ais/home/centerx:-12.0/centery:25.0/zoom:4).
Commercial fishing (5)	Commercial linefishing (1)	Data-derived layer for commercial linefishing intensity in Algoa Bay.	Vessel Monitoring System (VMS) data from the Department of Forestry, Fisheries and the Environment.
	Commercial shark longline fishing (1)	Data-derived layer for commercial shark longline fishery in Algoa Bay.	Complete set of shark longline data obtained from the Department of Forestry, Fisheries and the Environment with start and end coordinates of sets.
	Commercial squid fishing (1)	Data-derived layer for commercial chokka squid fishery in Algoa Bay.	VMS data from the Department of Forestry, Fisheries and the Environment.
	Bottom trawling (inshore) (1)	Data-derived layer for trawl tracks in Algoa Bay.	Observer trawl track data from the Department of Forestry, Fisheries and the Environment.
	Small Pelagic Fishery (1)	Intensity of use by the small pelagic fishery across Algoa Bay.	Published spatial data from the NBA 2018 (Sink et al., 2019).
Additional activities (1)	Cumulative pressure map from the NBA 2018, based on data from 31 pressures	Map of cumulative intensity of 31 activities and pressures, such as waste-water outfalls, coastal development, coastal disturbance, alien invasive species, and industrial fisheries.	Published national spatial data from the National Biodiversity Assessment (NBA) 2018 (Sink et al., 2019).
Extent (1)	Planning unit extent + 5	The extent of the planning unit in hectares plus 5	Planning unit layer (developed for this study)

where: the total cost of a planning unit (Cost) was a combination of twelve different spatial layers. Each individual spatial layer was coded with values between 0 and 100 based on the intensity of the activity (or 0 or 100 where the activity was respectively absent or present); EX = the extent of the planning unit in hectares plus 5 (to avoid partial planning units along the edge of the planning domain having a near-zero cost); CP = cumulative pressures as developed for the NBA 2018 (Sink et al., 2019), comprising 31 pressures (coastal development, coastal disturbance, wastewater discharge, freshwater-flow reduction, invasive alien species, dredge spoil and ammunition dumping, port and harbor activities, shipping, recreational and subsistence fisheries, industrial fisheries, aquaculture, mining, petroleum); SI = shipping intensity; SL = shipping lanes; AN = anchorages (including ship-to-ship bunkering areas); D = dredge spoil dumping; M = mariculture; SJF = squid jig fishery; IT = inshore trawl; SLF = shark longline fishery; CL = commercial linefishing; and SPF = small pelagic fishery. Shipping intensity (based on all vessel tracks) was weighted most heavily because shipping-related pressures (pollution, noise etc.) are a primary driver of ecological degradation in Algoa Bay and because it serves as a proxy for many other pressures that are associated with these vessels (e.g., anchor sites, bunkering, main access areas to ports, key areas used by the range of industrial fisheries). We did not conduct a formal sensitivity analysis to determine the robustness of the relative weightings because the spatial pattern of relative areas of higher and lower cost was more important than the actual cost values themselves. Evaluation of a number of different weighting options showed very similar patterns of total cost. Based on our local knowledge, we judged this spatial pattern to adequately reflect cost in Algoa Bay. Further, although a formal sensitivity analysis was not undertaken, a number of Marxan runs with these different weightings of the cost surface were undertaken, and these produced outputs with very similar spatial patterns of irreplaceability. Nevertheless, sensitivity tests are recommended (Ardron et al., 2008), particularly when the actual values in the cost layer carry more importance.

2.6. Spatial prioritization

The standard input files were created for use in Marxan. The analysis was conducted in Marxan version 1.8.10 (Ball et al., 2009) using the CLUZ interface (http://www.kent.ac.uk/dice/cluz/) in ArcView 3.2, following guidelines for data preparation and analysis in the Marxan good practices handbook (Ardron et al., 2008). Note that the existing MPAs were not hardwired into the solution because the goal was to identify areas important for sustainable management (rather than protected area expansion) that could later be split into areas inside and outside the MPAs. The Species Penalty Factor (SPF) values and Boundary Length Modifier (BLM) parameters were calibrated using an iterative manual calibration method, compliant with the objectives outlined in the Marxan good practices handbook (Ardron et al., 2008). Marxan was ultimately run using the following settings: SPF = 1,000,000,000; BLM = 2; runs = 1000; iterations = 1,000,000.

Marxan generates a selection-frequency map as an output, which gives a representation of how important each planning unit is for meeting targets by summing the number of times each planning unit is selected for inclusion in the solution out of the user-defined number of runs. Once a stable selection-frequency output from Marxan was obtained, a set of focus areas (highest priority natural and semi-natural areas) was developed to facilitate easier inclusion in implementation planning and emerging MSP processes. To do this, the most frequently selected planning units (areas selected more than 60% of the time) were selected and fixed into the solution. Marxan was iteratively rerun to ensure targets were met, with additional sites being added to the selected areas at each stage. Finally, the selected planning units were split into the following three categories: focus areas inside MPAs; focus areas outside MPAs; and other parts of MPAs.

3. Results

3.1. Input data

Altogether, 137 biodiversity features and nature-based activities were mapped and included in the SCP (Table 1, see Supplementary material for maps). These included 115 biodiversity features: ecosystem types (19); shorebirds and seabirds (16); cetaceans (5); turtles (1); sharks and rays (20); fish, including aggregation, nursery and recruitment areas (41); squid spawning areas (2); biodiversity priority areas, i.e., MPAs and the EBSA (2); culturally significant areas (4); and design elements for SCP (5). Twenty-two nature-based activities were included as well (Table 1). These included popular areas for a variety of sports and activities, e.g., surfing, triathlons, and birdwatching (16); and a variety of recreational and subsistence fishing activities (6). Lastly, the cost layer (commercial and industrial uses) was developed from data on 10 commercial and industrial activities, cumulative pressures (n = 31) on ecosystems, and planning-unit area (Table 1) to avoid selecting contentious areas as far as possible. The commercial, industrial activities included ports, mariculture zones, bunkering areas, dredge dumping zones, anchorage areas, and five major inshore commercial fisheries (Table 1).

3.2. Spatial prioritization

Areas of high selection frequency (Fig. 2a) included most of the area within 5 km of the shore, particularly between Sardinia Bay and the Port of Port Elizabeth/Gqeberha. Other areas of high selection frequency included the islands and surrounding waters, key features such as Riy Banks, and 10–20 km offshore of the Alexandria dunefield. The results also reinforce the location and importance of the two MPAs in the study area, both of which have strong selection in this analysis, despite the different framing of the SCP and the different input datasets. From this selection-frequency map, one third (33.2%, 1314.3 km^2) of the study area was designated as priority areas for biodiversity and nature-based activities, comprising: 11.6% (460.5 km^2) focus areas inside MPAs; 17.2% (679.3 km^2) other parts of MPAs; and 4.4% (174.5 km^2) focus areas not in MPAs (Fig. 2b).

The entire Sardinia Bay MPA was selected as a focus area inside MPAs (Fig. 2b), indicating the high biodiversity value and importance for biodiversity-based benefits for people of this relatively small (12.9 km^2) MPA that is a particularly popular recreational beach. The Addo Elephant National Park MPA is much larger and encompasses many critical biodiversity features and areas that deliver key benefits, e.g., the islands supporting threatened colonial seabirds, and Sundays Estuary mouth that is popular with recreational fishers. The pattern of selection frequency also aligns with and supports the current zonation of the MPA, with the areas of higher selection frequency aligning with the stricter Restricted zones of the MPA, and the areas of lower selection frequency with the less-strict Controlled zones (Fig. 2b). The focus areas outside MPAs include areas with important biodiversity-based benefits for people, and key biodiversity features, ecological processes, and ecosystem types. These areas purposefully exclude highly industrialized zones and include nature-based tourist attractions. They are of similar biodiversity value to the priority areas in MPAs and additionally have high societal value.

4. Discussion

Promoting alignment of ecological, heritage and recreational interests across sectors that require biodiversity to be maintained in a natural or semi-natural state facilitated an efficient design of integrated priority areas. In fact, targets for all 137 biodiversity features and nature-based activities were met in just 15% of the study area, of which, only a third (4.4%) is outside existing MPAs. This means that these sectors can jointly present a highly efficient, integrated input into an MSP process as a counterpoint to commercial and industrial uses, with two-thirds of the study area still available for the latter activities to take place. This demonstrates that it is practical to design areas that safeguard biodiversity, and achieve the required biodiversity protection targets (Obura et al., 2021), in a way that simultaneously enhances the delivery of a range of nature-based benefits for people (Annis et al., 2017; Friedman et al., 2020). In addition to the tight efficiency of the design, the likelihood of implementation is enhanced by having included data on commercial and industrial uses in the analyses and avoiding areas important for these activities as far as possible (Lombard et al., 2019a,b). Consequently, it is anticipated that MSP negotiations will be streamlined by proactively pre-empting possible conflicts and restricting contested areas to specific places rather than perceived broader incompatibility. Key to achieving this was the highly consultative approach that included a comprehensive group of stakeholders, together with using a reframed application of SCP to align spatial priorities across sectors with similar requirements for ecosystem health and environmental management. The results of this study thus bode well for South Africa in the face of the emerging MSP process (Government of South Africa, 2019a).

We believe that the inclusive stakeholder-engagement process was a critical part of the success of the project (Rivers et al., 2022). Central to this was having a central 'hub' where the data team and stakeholder liaison were based, and with whom the stakeholders were engaging (sometimes repeatedly), which facilitated building relationships. We also catered for stakeholders' individual needs by engaging in a way that they were comfortable (e.g., options for contributing data; meeting in their preferred format). By articulating the goal of the planning process and how stakeholders' data would be used made stakeholders more comfortable to share their data, especially those who have a vested interest in securing areas in a natural to semi-natural state for biodiversity and/or their own activities. In contrast, those stakeholders who felt threatened by the process and felt that their access to currently available resources would be restricted because of the process, perhaps as a legacy of past planning processes that have indeed restricted activities, were less willing to participate. Overall, however, based on the level of engagement and data received from stakeholders, we found the format of the stakeholder-engagement process to be highly successful and productive, focusing on continuous information sharing, inclusivity, and meeting and engaging with stakeholders in a variety of ways based on their preferences. This approach aligns with established principles for developing strong multi-stakeholder partnerships which have become popular for tackling the complex challenges of sustainable development (e.g. Brouwer et al., 2019). We note that this was our perception of the process, and it would require a dedicated study to investigate how the process was perceived from the stakeholders' perspective. This does raise the question, though, whether the scale at which the country intends to roll out MSP might be better suited to smaller areas (e.g., more at the scale of districts than provinces) because smaller study areas allow for closer engagement with stakeholders and fine-scale data collection, especially in coastal areas. Such intensive engagement at such a fine scale may not be required in all cases, e.g., where coastal population density and use is very low, and so a combination of district and provincial scale could also be sensible, even the more so considering the time and resources required to undertake local-scale engagements nationwide.

The identified focus areas are intended to inform the new marine area plans (which include designated zoning and regulations) required by the MSP Act (Government of South Africa, 2019a). This process is already underway through their inclusion in the National Coastal and Marine Spatial Biodiversity Plan (Harris et al., 2021), which is a national map of biodiversity priority areas (also designed using SCP) and is proposed as the biodiversity sector's input into MSP. The Algoa Bay focus areas are thus also expected to potentially contribute to the portfolio of sites from which the next 5% of South Africa's marine protection will be identified. The recent expansion of the national MPA estate from 0.4% to 5.4% of the mainland exclusive economic zone is a major improvement (Sink et al., 2019), but still falls short of the stated objective (10% protection) in the National Protected Area Expansion Strategy (Department of Environmental Affairs, 2016) and international commitments to achieving international protection targets (Obura et al., 2021). If these focus areas are eventually included in MPAs, then the zoning must ensure maintenance – rather than exclusion – of the nature-based activities. Either way, for the approach of creating an integrated, multi-sector prioritization for natural and semi-natural areas to be effective in the real world, all compatible and conditionally compatible nature-based activities need to be managed for sustainability and to minimise impacts on biodiversity.

This study has provided insights into what an SCP can contribute to MSP, demonstrating that there is no need to restrict the SCP process to specifying the spatial needs of only the biodiversity sector. This aligns with the increasing focus on designing areas that safeguard biodiversity while simultaneously enhancing nature-based benefits for people (Annis et al., 2017; Friedman et al., 2020; Lombard et al., 2019a,b; Selig et al., 2019).

The study also demonstrated that it is possible to gather and include data in a variety of formats and still protect the intellectual property of unpublished data held by scientists, and capture expert knowledge from non-scientists using participatory-mapping methods. Given that this

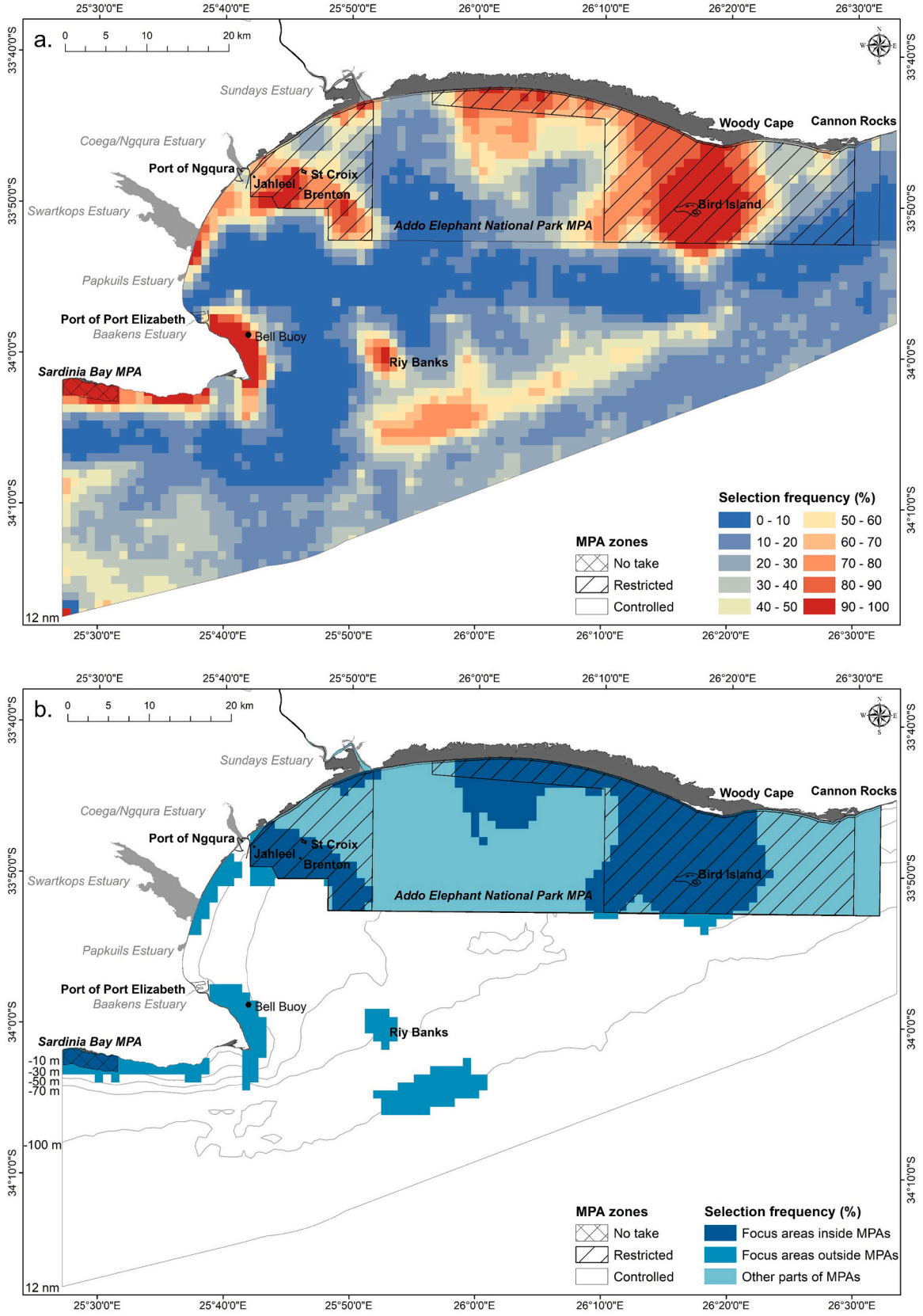

Fig. 2. (a) Marxan selection frequency (% of 1000 runs) of the planning units (low to high, blue to red); (b) Focus areas (highest priority natural and semi-natural areas) inside and outside of MPAs derived from the selection-frequency map. Both panels are overlaid by the zonation of the MPAs, where Sardinia Bay is a no-take MPA, and Addo Elephant National Park MPA includes both Restricted (no-take) and Controlled (some extraction is permitted subject to specific conditions) zones. Refer to the online version of the article for color figures. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

approach was successfully applied in a complex social-ecological system like Algoa Bay, it suggests that it will likely be scalable and applicable in other areas.

For other countries or areas intending to follow a similar approach, we highlight the following lessons and recommendations from our experience. First, a dedicated project management team must be appointed, and a project identity with branding, social media presence and/or a website should be formed. This helps to build clear leadership and known points of contact throughout the process. Ideally, as was true in our case, the project team should include people from the local area to build on existing trust relationships with stakeholders. Second, a clear planning goal must be identified and communicated widely. Third, a stakeholder group that is as broad and as inclusive as possible needs to be compiled, where individuals are allowed to choose varying levels of participation. Fourth, meeting and engaging with the stakeholders must be in a format with which they are comfortable. This might mean far more additional effort on the part of the project management team (e.g., five meetings at each of the fishing clubs versus one collective meeting at a neutral location), but this is best for making each stakeholder feel comfortable. Fifth, the needs of the stakeholders must be respected. For example, scientists' raw data needs to be protected and their participation can be encouraged by offering co-authorship. The public must be engaged in participatory mapping, and their requirements must be heard and included, and any sensitive data must be respected to build and maintain trust. Finally, particular attention and effort is required for engaging with stakeholders who are reluctant to participate but whose activities or information is otherwise unmappable. Their participation in the process is invaluable. This group usually comprises people involved in consumptive uses (e.g., recreational fishers), particularly if they have been previously affected by reduced access to resources following MPA proclamation or expansion.

Perhaps one step that was missing from this process was an initial engagement with stakeholders and residents to scope and map out their desired future for Algoa Bay. Based on the level of engagement in nature-based activities, public protests against the proposed mariculture expansion in the Bay (Daniels, 2019) and outcries over ship-to-ship bunkering in such close proximity to the Endangered African penguin colony (Ryan et al., 2019), there is clearly a strong voice from the community for biodiversity and nature-based activities to be maintained or expanded over industrial activities that threaten the former. It is not clear, though, how a desired future voiced by a local community interfaces with government-level planning and development to grow the national economy. In an extreme case, this could present as a government-level decision to construct a port in an area where local communities would prefer to maintain the natural environment, benefits from biodiversity, and their traditional and cultural heritage. This is something with which the country will need to grapple as the MSP process unfolds.

The success of the Algoa Bay Project lies not only in its integration of social and environmental goals in planning, but also in its approach that endeavours to reach consensus among the users of the Bay with the underlying principle of supporting sustainable, non-destructive activities and securing the Bay's marine and coastal ecological, heritage, recreational and aesthetic values for the long-term. The approach is aligned with the recognition that marine coastal environments are often socially complex public areas that need equitable spatial planning approaches that attempt to understand extractive and non-extractive uses and the social dynamics, as noted by Noble et al. (2019).

It has been noted previously that SCP can advance MSP (Harris et al., 2019b); we have taken this a step further in demonstrating that it can be useful for identifying integrated spatial priorities for multiple sectors with similar management objectives for the environment and avoiding areas important for other sectors as far as possible. In an MSP process, this can reduce conflicts over ocean space, streamline negotiations, reduce compromises, and increase the likelihood of implementing each sector's ideal priorities. The outputs of this research have been directly incorporated into the National Coastal and Marine Spatial Biodiversity Plan (Harris et al., 2021), which is the biodiversity sector's spatial input into the national MSP process. Although it is too early to predict outcomes of this national MSP, it is anticipated that the priority areas will largely be secured using appropriate zones and supporting spatial regulations as anticipated in the legally mandated national MSP process (Government of South Africa, 2019a) given that the identified areas would achieve environmental targets while avoiding areas important for other sectors. Another measure of success of the Algoa Bay Project is that the National Research Foundation has funded additional work to further the socio-economic components of the MSP process in the Bay, and to develop system dynamics models (SDMs) to measure trade-offs in different scenarios for the Bay's future (Lombard et al., 2019a,b, Vermeulen et al., 2020). These scenarios, which provide temporal outputs, can prioritize short-term over long-term gains, per sector, and for the Bay as an integrated social-ecological system. Work on the valuation of the ecosystem services provided by the Bay is also underway, and is being integrated with the SDMs (Vermeulen et al., 2020). The spatial outputs from the SCP analysis reported here, and the temporal outputs from the SDMs, will provide powerful tools to further the MSP process for Algoa Bay, and provide a novel proof-of-concept to scale up to other areas. This is central to the purpose of the spatial planning Community of Practice established to undertake the Algoa Bay Project (Dorrington et al., 2018; Rivers et al., 2022). Ultimately, the work presented here can advance the sustainable development of blue economies, which are imperative for developing countries, and help to secure the biodiversity and ecological processes that provide critical ecosystem goods and services.

CRediT authorship contribution statement

Stephen D. Holness: Conceptualization, Investigation, Formal analysis, Writing - Original draft, Writing - Review & editing. Linda R. Harris: Conceptualization, Investigation, Formal analysis, Writing - Original draft, Writing - Review & editing. Russell Chalmers: Formal analysis, Investigation, Writing - Review & editing. Deidre De Vos: Investigation, Writing - Original draft, Writing - Review & editing, Data curation, Visualization. Victoria Goodall: Methodology, Investigation, Writing - Review & editing. Hannah Truter: Investigation, Writing - Review & editing, Data curation. Ané Oosthuizen: Writing - Review & editing, Validation. Anthony T. F. Bernard: Writing - Review & editing, Investigation, Validation. Paul D. Cowley: Writing - Review & editing, Investigation, Validation. Charlene da Silva: Writing - Review & editing, Investigation, Validation. Matthew Dicken: Writing - Review & editing, Investigation, Validation. Lloyd Edwards: Writing - Review & editing, Investigation, Validation. Gordon Marchand: Writing - Review & editing, Investigation, Validation. Paul Martin: Writing - Review & editing, Investigation, Validation. Taryn S. Murray: Writing - Review & editing, Investigation, Validation. Matthew C. Parkinson: Writing - Review & editing, Investigation, Validation. Paula Pattrick: Writing - Review & editing, Investigation, Validation. Lorien Pichegru: Writing - Review & editing, Investigation, Validation. Pierre Pistorius: Writing - Review & editing, Investigation, Validation. Warwick H. H. Sauer: Writing - Review & editing, Investigation, Validation. Malcolme Smale: Writing - Review & editing, Investigation, Validation. Andréa Thiebault: Writing - Review & editing, Investigation, Validation. Amanda T. Lombard: Conceptualization, Writing - Original draft, Writing - Review & editing, Supervision.

Declaration of competing interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony

or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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Appendix A. Supplementary data

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