The St. John's Island Complex

Review and Recommendations

St. John's Island Complex: Review and Recommendations

This study was conducted by the St. John's Island National Marine Laboratory (Tropical Marine Science Institute, National University of Singapore) for the research project "Horizon Mapping: An Integrated Concept Plan for St. John's Island" funded by the National Research Foundation under the Marines Science Research and Development Programme.

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Cover photograph by Marcus FC Ng

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Chapter 1

Introduction

With climate change and growing population needs, Singapore is under the threat of environmental instability, resource vulnerability and resultant socio-economic implications (Rees 1992, Campbell 1998, McMichael et al. 2003, Niccolucci et al. 2007, Bastianoni et al. 2013, Galli et al. 2015, Charfeddine and Mrabet 2017, Rudolph and Figge 2017, Lin et al. 2018). Being heavily dependent on global sources for food, water, energy and other valuable resources (e.g. construction material), there is an urgent need to develop and embrace novel solutions and transform institutional and social habits in order to mitigate future impacts (Hall et al. 2003, Penning-Rowsell and Tunstall 2006, Sovacool and Brown 2010, Heintz et al. 2012, Challies et al. 2016). To improve resource resilience in the face of global changes, Singapore is targeting to produce 30% of its nutritional needs by 2030 (from less than 10% today) (Chang 2019). Along with this "30 by 30" goal, Singapore is also aiming to move towards zero waste production as our landfill (or sea-fill) at Pulau Semakau is projected to be completely full by 2035 (Ministry of the Environment and Water Resources 2019). Concurrently, Singapore is striving to be a global maritime hub, with the Tuas Mega Port positioned as a leading trans-shipment port set to be operational in phases from 2021 (Koh 2019). A holistic approach to planning is therefore highly necessary to accommodate conflicting short-term sectoral needs in Singapore's limited coastal and marine environment in order to optimise area use for environmental and socio-economic benefits. As Singapore strives to be a global maritime hub, achieve resource efficiency and climate resilience, and become a smart, eco-conscious, and environmentally responsible nation, how we choose to develop our coastal and marine environment will affect the long-term viability and prospects of our island state.

Figure 1 Aerial view of St. John's Island and a portion of Lazarus Island. These islands are part of a planning region in Singapore known as the Southern Islands. Photo courtesy of Wong (2019).

The Southern Islands of Singapore is a planning area demarcated by the Urban Redevelopment Authority (URA), which includes St. John's Island, Lazarus Island, Kusu Island, Pulau Tekukor, the two Sisters' Islands and Sentosa Island (Urban Redevelopment Authority 2019a, 2019b). In land-scarce Singapore, there is growing interest to optimise the use of our Southern Islands. Aside from Sentosa Island, these islands remain as one of the last areas in Singapore that have been untouched by extensive development. There exists an opportunity for the Southern Islands to contribute to Singapore's future goals and strategic needs while preserving the rich heritage. A thorough understanding of the Southern Islands' land and seascapes (e.g. natural ecosystems, heritage landmarks, areas of natural resource) and social setting (e.g. multiple sectoral needs and public stakeholder perceptions) are therefore important to fully appreciate what these islands have to offer.

1.1 | A Review of and Recommendations for the St. John's Island Complex

St. John's Island (SJI) and Lazarus Island (LAZ), which are connected by a causeway and henceforth collectively known as the St. John's Island Complex (SJI-C), are home to a multitude of important natural, historical and cultural features. The rich marine, coastal and terrestrial biodiversity on the SJI-C makes the islands an ideal location for environmental research, conservation and education. The western coast of SJI is protected within the Sisters' Islands Marine Park (SIMP) and the Marine Park Outreach and Education Center (MPOEC) is stationed on SJI. A lagoon on the southwestern side of the island, named Bendera Bay, is also managed by the National Parks Board Singapore (NParks) for environmental conservation and education purposes by community stakeholders (Friends of the Marine Park). There is rich cultural history to be found on both islands, with SJI being a former quarantine center and LAZ inhabited by Malay villages in the past. With rich natural and cultural heritage, and ease of accessibility with public ferry services, these islands have gained popularity as an "off the beaten track" destination. In addition, SJI is also an active marine science research hub housing the St. John's Island National Marine Laboratory (SJINML), a National Research Infrastructure (NRI) managed by the National University of Singapore, and the Marine Aquaculture Centre (MAC) of the Singapore Food Agency.

A study of the SJI-C was conducted to provide an overview of the natural, cultural and social landscape of the Complex with the specific purpose of consolidating existing information for the future planning of the SJI-C. These include:

1) Reviewing the existing main functions of and resources on SJI-C, i.e. critical ecological and historical information for the SJI-C and surrounding waters, marine science research facilities, R&D and education activities.

2) Obtaining relevant stakeholder perceptions to understand the current uses, knowledge, and attitudes towards the SJI-C, including any conflicting interests, demands and expectations.

3) Identifying sensitive and important areas for consideration, e.g. unique and sensitive habitats, culture and nature conservation priorities), and put forth key recommendations for the future of the SJI-C.

4) Proposing recommendations for the future of the SJI-C based on the information obtained from the review (1), stakeholder perceptions (2), and sensitive areas and other land use considerations (3).

1.2 | Study area

This review examined the key functions of the **St. John's Island Complex (SJI-C)**, which consists of St. John's Island (SJI) and Lazarus Island (LAZ) (**Figure 3**). LAZ comprises of the original Lazarus Island, Pulau Seringat and Kias, which were joined in the 2000s, and will be referred to as so unless specified. The surrounding islands, namely Kusu Island, Pulau Tekukor and the Sisters' Islands, would also be discussed in brief in Chapter 3. The Southern Islands in this study will include these islands and exclude Sentosa Island.

The SJI-C can be found approximately 3.5 km from the mainland of Singapore. Public access to the islands is through ferry services from the Marina South Pier (20 to 30 minutes ride). Despite experiencing reclamation works and shoreline protection, these islands still retain significant natural and cultural heritage, and have not been developed to the same extent as the mainland or their neighboring island, Sentosa. The Sentosa Development Corporation (SDC) managed these islands from 1976 to 2017 (Sentosa Development Corporation 1976), and the islands were handed to the Singapore Land Authority (SLA) since (Tay 2017).

Figure 2 Photograph of St. John's Island. Photo by Marcus FC Ng.

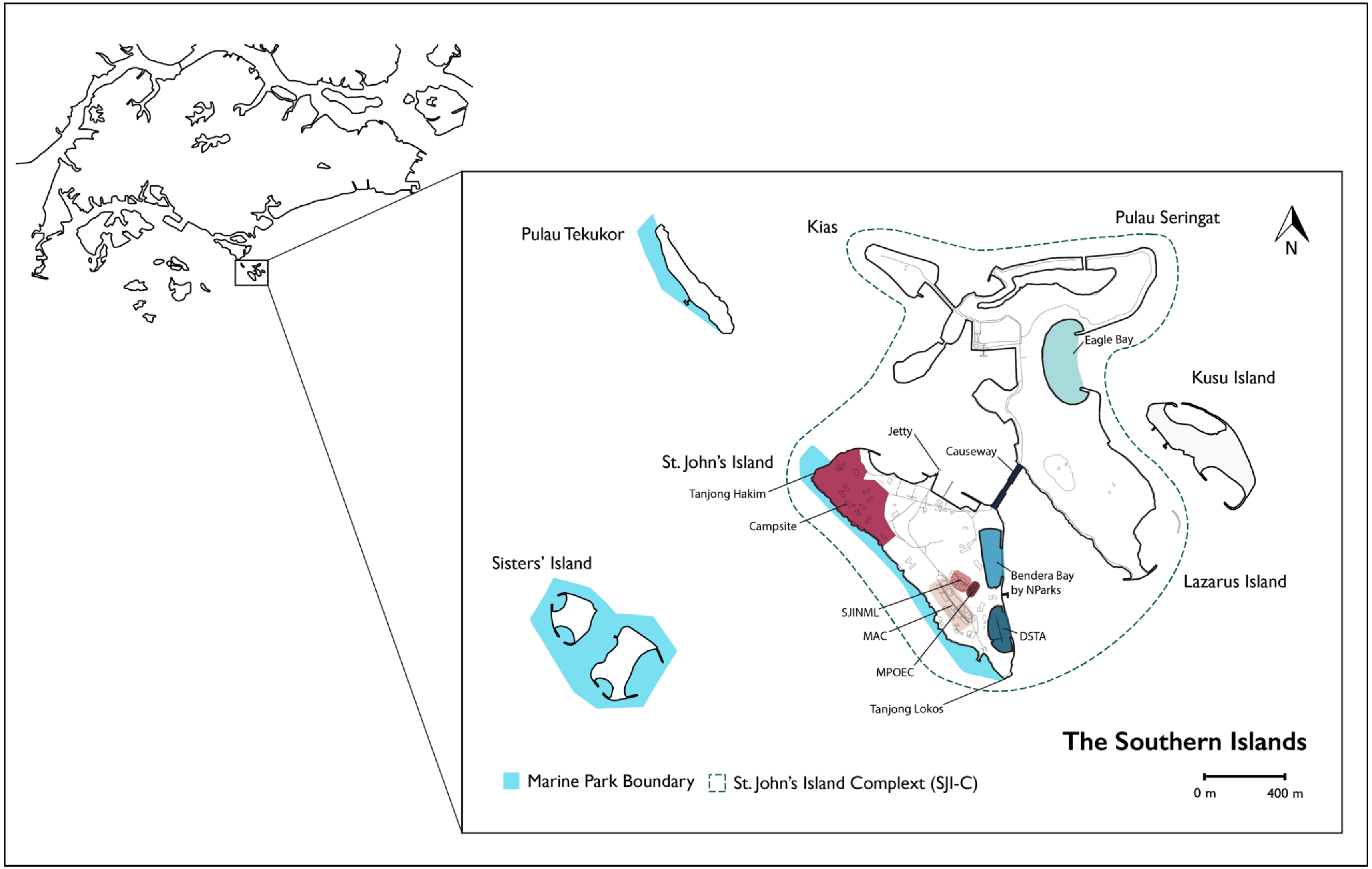


Figure 3 Map of the St. John's Island Complex (SJI-C), within the Southern Islands. The abbreviations refer to the following: "SJINML" refers to the St. John's Island National Marine Laboratory, "MAC" refers to the Marine Aquaculture Centre, "MPOEC" refers to the Marine Park Outreach and Education Centre, "NParks" refers to the National Parks Board, and "DSTA" refers to Defence Science and Technology Agency.

1.3 | Approach

This review and recommendations study was conducted from August 2019 to January 2021. The approach can be categorised into two segments – (i) literature consolidation and review, (ii) stakeholder surveys, (iii) recommendations.

1.3.1 | Literature consolidation and review

Desk-based research was conducted to gather information on the following: land use history, natural heritage, cultural heritage, and science, research and education landscape of SJI-C.

Land use history. Aside from relevant journal articles and dissertations, previous and current Master Plans and Concept Plans by the Urban Redevelopment Authority (URA), annual reports from past managing agencies of the Southern Islands, maps from the National Archives online database and new articles from the NewspaperSG online database were used. This information was cross-referenced, documented and presented in Chapter 2.

Natural Heritage. Relevant journal articles, dissertations and publications on the SJI-C and the other Southern Islands were searched for and reviewed. Information such as habitat cover, species diversity, ecological changes over time and threats were obtained from the available literature. Experts in the field and nature enthusiasts were also engaged through interviews to supplement the available literature and this information were cited as personal communications in this study. These results are presented in Chapter 3.

Cultural Heritage. Information was gathered through collaboration with the Department of Southeast Asian Studies and the Asia Research Institute at the National University of Singapore (NUS). A documentation of the cultural history of the SJI-C was conducted as part of a study funded by the National Heritage Board. Secondary and primary sources were collected for this project. Secondary sources were based on information on the islands in the NUS Library and museums, historical and current newspaper articles, books and other online articles written about the islands, such as blog posts. In turn, primary sources of information included previous plans made for the islands, interviews with individuals from relevant statutory boards, institutions, and organisations, oral histories of former islanders available in the National Archives of Singapore (NAS), and original interviews with former residents and visitors to the islands. Ground-truthing was also conducted to document any historical structures forgotten and even hidden by the dense vegetation that have taken over the island over the years. Former residents and their kin were identified and recruited through social media, through their annual social gathering, as well as a snowball sampling method where initial contacts were asked to refer us to other persons of interest, beginning with those who were previously living on SJI. Interviews with former residents gathered stories about their lives using thematic triggers such as 'family life' and 'schools and education' and took part in a mapping exercise with old photos to further enhance the interviews. The results are presented in Chapter 4.

Science and research. Publications and other sources from the research facilities, which included the SJINML and the MAC, was used to collect information on the history of science and research on the islands, notable research findings and knowledge gaps. These results are presented in Chapter 5.

Education and outreach. Information on the educational and outreach programmes provided by the SJINML, MPOEC and other relevant groups were documented and reviewed. Similarly, studies on optimising environment outreach and education were found and compared against that on the SJI-C for the review. These results are presented in Chapter 5.

1.3.2 | Stakeholder engagement

To understand different stakeholder perceptions and needs for the SJI-C, the general public and members of the nature, education and research communities were engaged through a variety of avenues.

A public perception survey was conducted on the visitors of the SJI-C, and the general public. The survey aimed to obtain general public perceptions of the SJI-C, as well as the specific profile of visitors to the islands and their experience, knowledge and views on the future of the SJI-C. The survey was distributed in the form of an online survey through social media, electronic mail and instant messaging as well as to visitors at the MPOEC for three months (1 October 2019 – 31 December 2019). Face-to-face visitor surveys were also conducted on four separate weekends to ensure representation of island visitors in the responses. Verbal interviews were also conducted during face-to-face surveys to collect supplementary data.

A participatory mapping exercise was conducted in November 2019 to document the attitudes and opinions of the nature and recreational communities that actively use the Southern Islands. Representatives from the research (e.g. scientists from NUS and Nanyang Technological University), education (e.g. school teachers), recreation (e.g. boating, fishing, kayaking, SCUBA diving, sea sports), nature conservation (e.g. WildSingapore, Blue Water Volunteers, Team Seagrass) and history and culture (e.g. former islanders, historians) groups were engaged through the Friends of Marine Park (FMP) platform. The exercise required participants to identify specific areas of the SJI-C that would be best used for nine possible key functions — education, research, tourism development, residential, conservation, sea sports, fishing, aquaculture and military. Members were split into groups and given blank maps to outline zones for the functions and annotate their rationale. Each group was accompanied by at least one facilitator from the study team to organise responses and ensure that all feedback was documented. The maps, along with the rationale, were then consolidated and presented in Chapter 6.

A survey to identify current use and potential of the Southern Islands for research was conducted by the SJINML during their annual stakeholder meeting in December 2019. The survey documented expert opinions of stakeholders in the Research and Development sector and education communities with active links to the Southern Islands through their association with SJINML. The survey was distributed in the form of a physical form as well as an online survey. The results of all stakeholder engagement efforts are presented in Chapter 6. The survey questions and material used through the engagement sessions can be found in the Appendix.

1.3.2 | Recommendations

Based on the findings from the initial scoping (review study and stakeholders engagements) and incorporating Singapore's present and future needs (in particular in relation to climate change resilience), we will put forth recommendations for the sustainable development of the SJI-C. An integrated concept plan will consider feasibility of zoned land-use maps for activities, development and enhancements.

Chapter 2

Land Use History

2.1 | The St. John's Island Complex

The St. John's Island Complex (SJI-C) is made up of St. John's Island (SJI) and Lazarus Island (LAZ), which includes Pulau Seringat and Kias. These islands were under the management of the Sentosa Development Corporation (SDC) for four decades (1976–2017), before management was transferred to the Singapore Land Authority (SLA) in 2017 (Tay 2017).

Development works including reclamation, shoreline protection and the installment of facilities were undertaken on the islands to prepare for recreational and resort development in the 1970s, and again in the 2000s (see summary of development works in **Table 1**) (Sentosa Corporation Development 1976, 1977). Since then, SJI has increased in size from 33.2 ha to 41.23 ha (Sentosa Corporation Development 1976, 1977, Ministry of Culture 1971). LAZ (original area), Pulau Seringat and Kias also went through a large-scale modification where they were joined together to form one continuous island in the early 2000s, forming the largest island in the SJI-C (Tan 2009).

Table 1 Summary of major developments that took place on the SJI-C since 1974. These developments were compiled from See (1993), Teh (2004a), Teh (2004b), Teh (2006), Tan (2006) and Tan (2009).

Period	Site	Development
1870s – 1970s	SJI	- Natural vegetation cleared - Revetment constructed on western side - Beacon erected on Tanjong Lokos
1974 – 1977	SJI	- Extensive renovation works - Reclamation and shore protection - Provision of recreations facilities
1981 – 1982	SJI	- Construction of jetty
1970s – 1980s	LAZ (original area)	- Reclamation works - Installment of navigation beacon
2000 – 2006	SJI and LAZ	- Reclamation works to join LAZ, Pulau Seringat and Kias - Construction of causeway and Eagle Bay
2002 – 2003	SJI	- SJINML and MAC facilities constructed - DSTA facility
~2014	LAZ	- Private jetty, shelter and toilet facility constructed

2.2 | 1870s to 1970s

SJI first experienced major developments to construct a quarantine station that catered to the large influx of people entering the island for quarantine checks in 1870s (See 1993). The quarantine station became operational in 1874. See (1993) noted that during this period, the natural vegetation was cleared, and ornamental species were introduced to the island. The rocky shores and coastal cliffs on the western side of the island was left relatively untouched. After which, the island remained with little modifications during the Japanese Occupation (See 1993). Post war, See (1993) documented that there were improvements in amenities on the island. A stretch of revetment was also constructed at the foot of the coastal cliffs and a beacon was erected on Tanjong Lokos (See 1993). By 1935, the quarantine station had expanded considerably and was known as the largest in the world. In the 1950s, the station was converted into a holding place for political detainees, and from 1955 onwards, the station was converted again to house opium and other drug addicts for rehabilitation.

In the earliest Master Plan 1958 released by the Urban Redevelopment Authority (URA) (1958), the SJI-C were not included in the map and hence, was not listed for any use.

2.3 | 1970s to 1990s

From 1974 onwards, SJI experienced multiple waves of development to provide an alternative recreational ground for Singaporeans when the original location at Changi was closed down to make way for Changi Airport (**Figure 4**) (Sentosa Development Corporation 1976, The Straits Times 1976a). These phases of development plans were carried out by the Port of Singapore Authority (PSA) and SDC (Sentosa Development Corporation 1977). Development on island commenced when the opium treatment centre was relocated to mainland Singapore in April 1974 and took place from the end of 1974 to 1977 (Lim 1988, See 1993). Leong (1979) estimates that the development package cost S$1.8 million, while SDC was reported to have spent up to S$3 million (The Straits Times 1976a, The Straits Times 1976b). It was also reported in The Straits Times (1976a) that this development was in addition to SDC's S$50 million programme in 1975 to develop offshore islands into resort centers, although not all of its plans were eventually fulfilled.

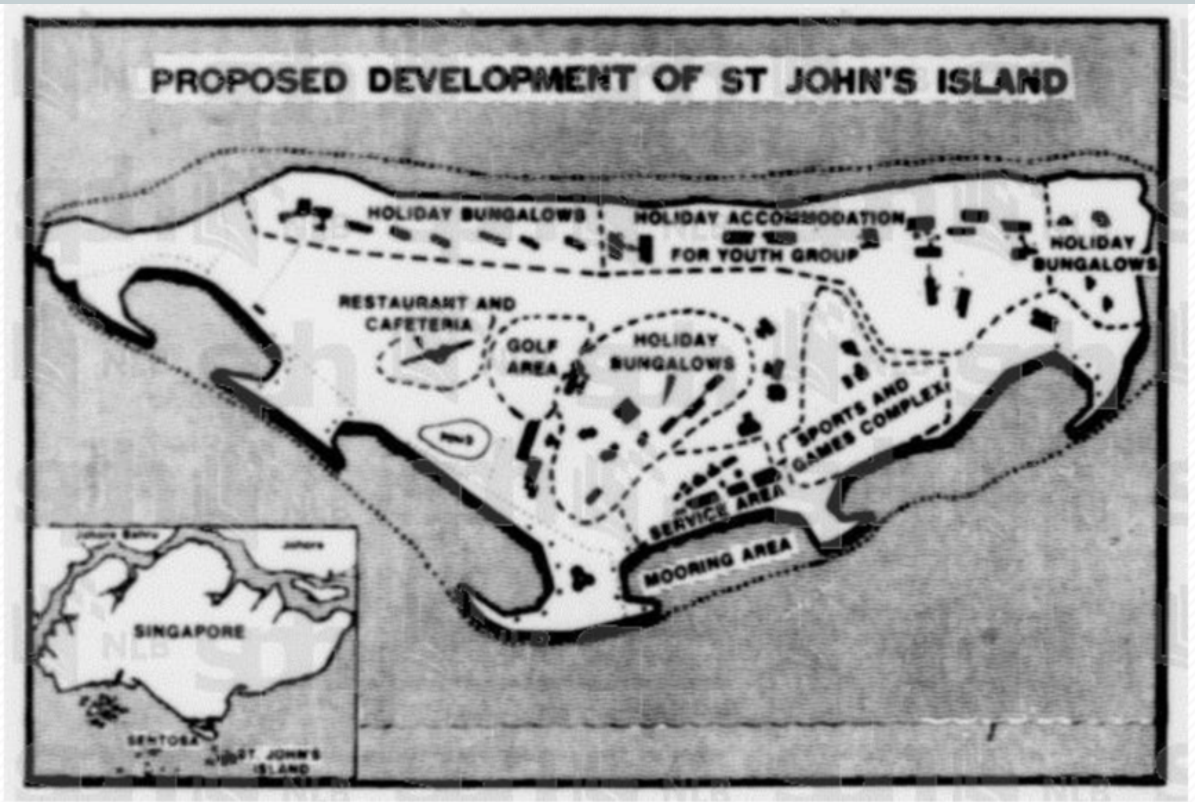


Figure 4 Map included in The Straits Times article in 1976 showing the proposed development of St. John's Island (The Straits Times 1976a).

These developments on SJI included reclamation (using fill material from the nearby Sisters' shoal) and shore-protection works (mostly in the form of seawalls), resulting in the creation of three swimming lagoons and an addition 6.1 ha of land to the original 33.2 ha (Tan 1976, Ministry of Communications and Information 1986, Chia et al. 1988, See 1993). These reclamation works were mainly carried out on the eastern coast of the island (**Figure 5**), thereby modifying the natural coastline and giving rise to man-made lagoons with beaches and breakwaters. In addition, there were extensive renovation works to convert the treatment center into holiday camps with a maximum capacity of 500 people, and to upgrade existing infrastructure such as the jetty, roads and drains (Sentosa Development Corporation 1977, Leong 1979, Lim 1988). Recreational facilities such as football fields, basketball courts, refreshment kiosks, and bungalows were also constructed (Sentosa Development Corporation 1977, The Straits Times 1976a, Henderson 2001). Landscaping works involving the planting of coastal vegetation and grasses to the reclaimed land were also carried out (See 1993). The island was then opened to the public in 1976 for recreation (The Straits Times 1976b, See 1993).

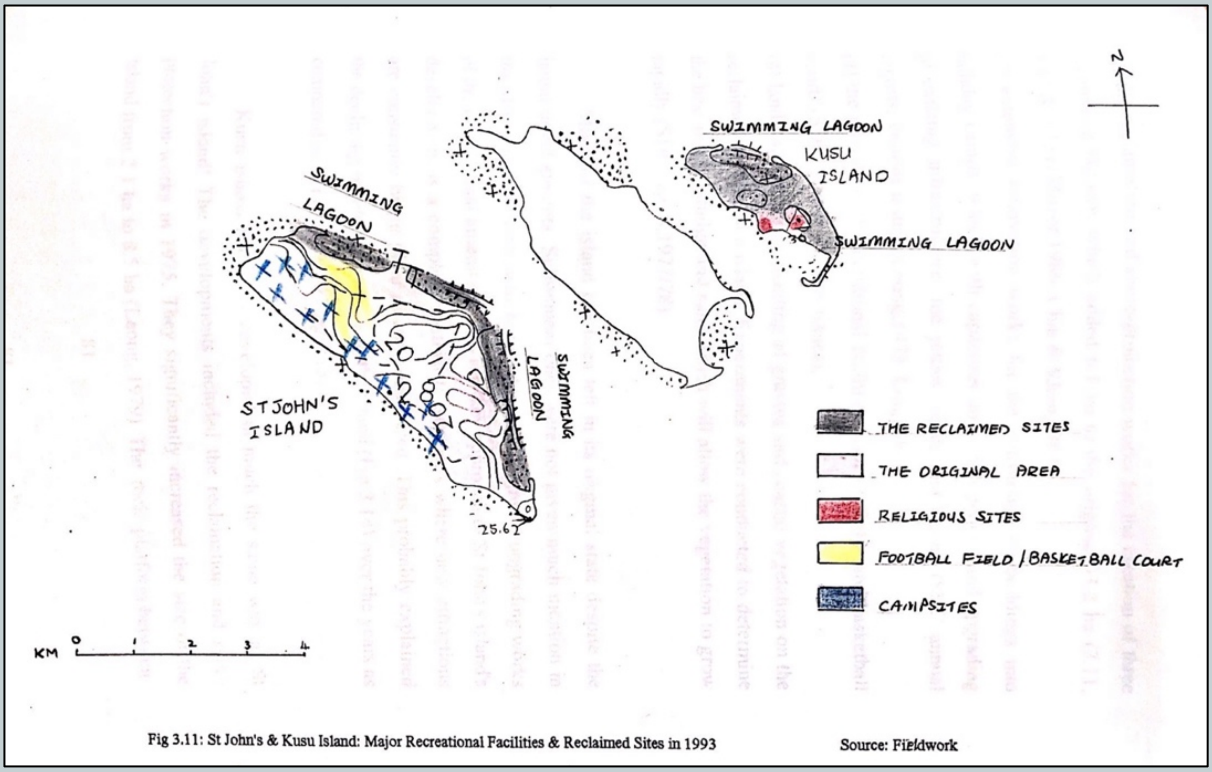


Figure 5 Map showing the sites of reclamation on SJI (along with the original area of LAZ and Kusu Island) in 1993. This map was adopted from See (1993).

During this time, a navigational aid was installed on LAZ, along with another on Pulau Ubin, costing a total of S$1.45 million (The Straits Times 1972). The beacon on the island was meant to improve landing approaches for aircraft arriving from Jakarta and Australia (The Straits Times 1972). The beacon was later used in college courses to train technical personnel from Asian countries, along with other modern navigation aids (New Nation 1979). In 1978, LAZ (original area) had also been designated for recreational development (The Straits Times 19878). Plans for the creation of swimming lagoons and a family holiday camp were announced (The Straits Times 1978). The Straits Times (1978) also reported more than S$11 million being invested on reclaiming LAZ, Buran Darat and Pulau Renggit.

In the Master Plan 1980, the SJI-C was included in the map and but was not scheduled for any specific use (Urban Redevelopment Authority 1980). Since the initial stage of development, minimal changes were made to SJI aside from the construction of a jetty in 1981–1982. Newspaper articles to promote these islands as a recreational site were also published (The Straits Times 1986).

During these development works, shallow reef flats were buried and lost (Ho 1992, Wong 1992). Chan (1980) also observed that reclamation works have contributed to the sedimentation levels of coastal waters around the island and reduced visibility. High levels of sedimentation adversely impact the settlement of coral larvae, smother coral colonies and hinder the survival of coral reef communities (Chou 1988, Ho 1992, Erftemeijer et al. 2012). The loss of vegetated areas also reduced green corridors for seed dispersing birds (See 1993).

2.4 | 1990s to present day

Major development and reclamation plans were announced for the Southern Islands in on newspaper platforms and spanned a period from 1988 to 2008 (based on various newspaper articles and anecdotal accounts). An initial total of S$280 million was allocated for the project (Henderson 2001).

Resort development on LAZ was first announced briefly in a 1986 article reporting a timeline for development projects all over Singapore with ‘Lazarus Island Resort’ being one of them (The Straits Times 1986). The Singapore Tourism Board (STB) then began asking for concept plans and proposal throughout 1988 – 1989 (Business Times 1988a, Business Times 1988b, The Straits Times 1988, Business Times 1989a, Business Times 1989b). In 1989, a resort development proposal was put forward for LAZ (original area) and Pulau Seringat, which led to a Parliamentary approval for reclamation works to be conducted in 1996 and this project was formally announced by the Singapore Tourism Board (STB) in 2000 (Henderson 2001). In 1999–2000, large-scale reclamation projects commenced to prepare the islands for further development under the management of the Southern Islands Development (SID) (The 2006). This included joining Kias, Pulau Seringat and LAZ into one contiguous island, now loosely known as LAZ, and joining LAZ to SJI via a causeway in 2004 (See 1993, Teh 2006) (**Figure 6**). A one-kilometer stretch of beach on the extended LAZ, now commonly known as Eagle Bay, was constructed using large quantities of sand imported from Indonesia, which were checked for sand fly eggs prior to use (Tan 2006, Teh 2006). A thousand mature coconut trees were also planted to enhance the island ambience (Teh 2006). This development of the beach won an award by the Landscape Industry Association in 2006 (Tan 2006). Southern Islands Development also invested into S$120 million on infrastructure to provide water, electricity, gas and telecommunication from Sentosa to LAZ (Teh 2006).

Figure 6 Major developents to the SJI-C. (Left) Eagle Bay constructed on the new Lazarus Island (now including Pulau Seringat and Kias. (Right) Causeway that connects St. John's Island and Lazarus Island constructed. Photos by Lee (2019) and Rachel Oh.

In 2002 – 2003, research facilities for marine science and aquaculture research were constructed on SJI (Tan et al. 2010). The Southern Islands Department (SID) of the Singapore Tourism Board (STB) at the time strongly supported these new developments and the SJINML and the MAC formed a prominent research cluster on the island. At around the same time, Defence Science and Technology Agency (DSTA) commenced their works on the southern corner of the island.

At this time, the Master Plan 2003 was released and revealed development plans for the SJI-C for the first time (Urban Redevelopment Authority 2003). The Pulau Seringat and Kias areas of LAZ were marked for “residential purposes” and “residential with commercial purposes”, while the central area of LAZ including Eagle Bay was marked for hotels and beach purposes, and the southern area of LAZ was marked for sports and recreation. SJI was listed as open space.

In 2004, plans for the resort development of the islands continued to evolve. The Singapore Tourism Board (STB) announced their intent to construct resorts on the Southern Islands, particularly at SJI, LAZ and Pulau Seringat (Teh 2004a). This was supposed to include ‘a five-star 290-room hilltop hotel, a three-star 170-room beachfront hotel, 70 waterfront homes and 1,700 units of housing’ (Teh 2004a). There was also suggestion of linking Sentosa to SJI via a land link to increase accessibility (Teh 2004b). Two years later in 2006, it was announced that the islands were furnished with beautiful beaches and waters and ready for further resort development (Teh 2006, Tan 2006). Concept plans were then solicited, which resulted in the announcement of a plan to transform the LAZ, Seringat and Kias cluster into a smaller but luxurious resort (Teh 2006, Sim 2007). This campaign eventually came to an end with the stepping down Mrs. Pamelia Lee in 2008 (Goh 2008). No major developments have since taken place on the SJI-C except for the construction of a private jetty, shelter and bathroom facility on LAZ before 2014 (Chang 2014).

In the Master Plan 2008, areas on LAZ were still listed for “residential”, “hotel” and “sports and recreation” purposes, and SJI was still listed as open space (Urban Redevelopment Authority 2008). In subsequent iterations of the Master Plan in 2014 and 2019, the planning decisions for SJI remained (Urban Redevelopment Authority 2014, 2019). However, the areas on LAZ previously marked for “residential” and “hotel” purposes were now re-designated as a “reserve site”. In 2017, Sentosa Development Corporation (SDC), the then managing agency for the islands, reported that there were no immediate plans for the development of the islands (Tay 2017). In the same year, SDC returned the managing role of the islands back to SLA (Tay 2017). In 2017–2018, water and electricity lines were extended from LAZ to SJI to supply SJINML, MAC and DSTA facilities.

Chapter 3

Our Natural Heritage

The SJI-C and the rest of the Southern Islands house a variety of ecologically important natural habitats with rich biodiversity, along with areas of strong geological significance. This natural aspect of the islands is a major contributor to the islands' ambience and charm (see Chapter 6). To maintain the natural habitats and biodiversity of the islands is to maintain its charm. This section includes key information required to do so. It provides an overview of the geological landscape and key natural habitats and features around the SJI-C and the other islands in the Southern Islands, their biodiversity and threats to their existence. These habitats included coral reefs and coral communities, seagrass beds, mangroves, rocky shores, sandy beaches, coastal forests and managed vegetation.

Figure 7 Rocky shores, coastal cliffs and coastal forests on SJI. Photo by Ria Tan.

The importance of natural ecosystems

Natural ecosystems have strong environmental, educational, research and tourism value (Tan et al. 2010). The environmental services habitats can provide include regulating the water cycle, purifying air, recycling nutrients and trapping or breaking down pollutants (Tan et al. 2010). Studies have also shown that better management of these natural habitats can help reduce our ecological footprint and maintain the quality of life by decreasing ambient temperatures and providing a more appealing and relaxing atmosphere (Ong and Sia 2002, Chou 2010, Tan et al. 2010, Ong 2015).

The resilience of natural habitats is largely supported by the rich biodiversity found in the habitats, highlighting the importance of conserving biodiversity to ensure the continued maintenance of the ecosystems (Tan et al. 2010). As such, an understanding of the ecosystems is needed to develop effective and appropriate management plans (Tan et al. 2010). Taking stock of an area's natural heritage is also an essential part in any study that precedes an environmental impact assessment and subsequent planning decisions (Environmental Resources Management 2001, Sadler and McCabe 2002). This includes consolidating baseline information about natural and man-made features, existing protected areas or features and sensitive environmental areas (Environmental Resources Management 2001). Such information will play a crucial role in making more informed decisions and in devising a more environmentally sensitive course of action (Environmental Resources Management 2001, Sadler and McCabe 2002).

3.1 | The Geological Landscape

The following write up was contributed by a geologist (Stephen Chua, 2019).

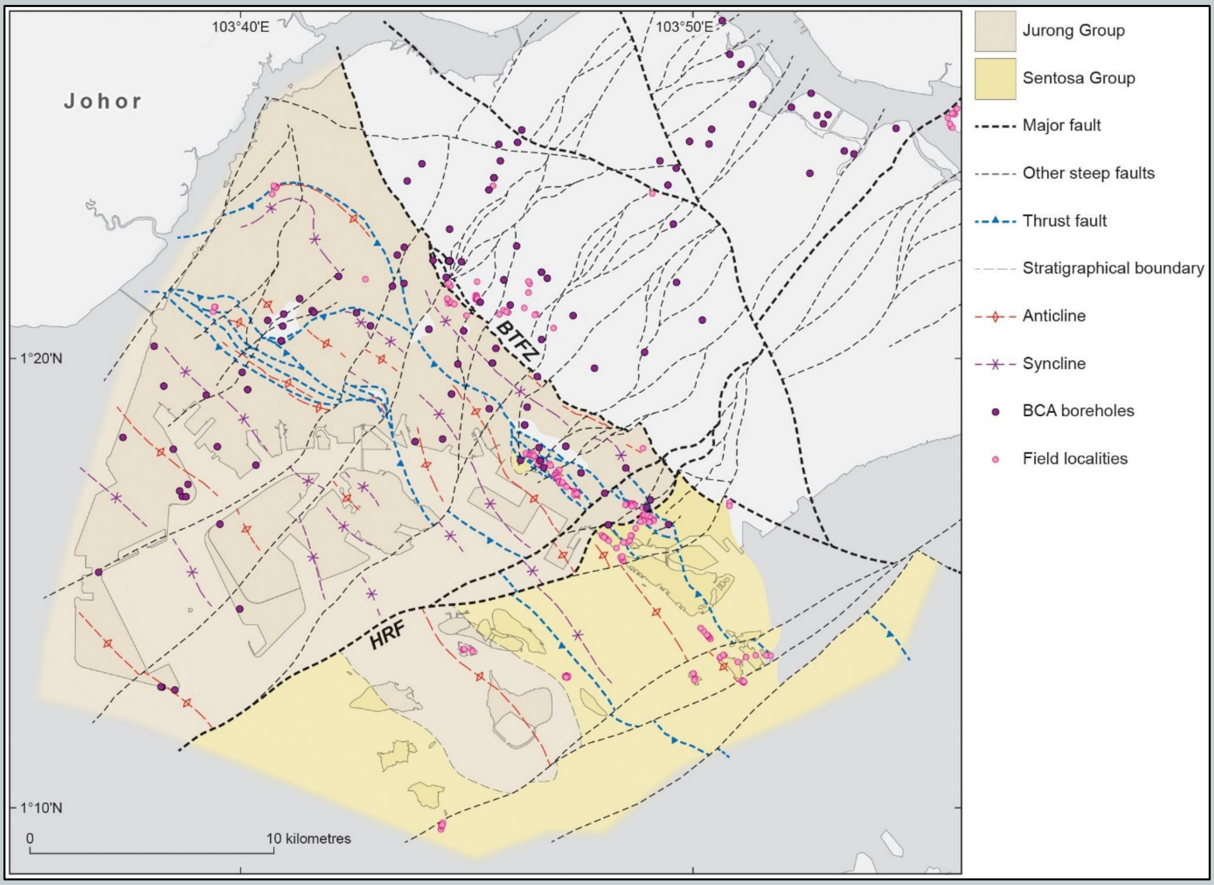


Figure 8 The distribution of the Jurong Group and Sentosa Group strata across Singapore. Linework in the map include faults, thrust faults, anticlines, synclines, and stratigraphic boundaries. The Sentosa Group strata are mainly encountered south of the Henderson Road Fault (HRF).

Recent studies on the geological landscape of Singapore (including the Southern Islands) resulted in the reinterpretation of Singapore's geologic setting (Dodd et al. 2019) (**Figure 8**). The previous nomenclature (DSTA, 2009) of the geology of SJI primarily comprise the Jurong Formation – namely the Rimau (Jr) and Queenstown Facies (Jq) (refer to Figure 12).

Recent reclassification redefined the hitherto-recognised Jurong Formation by promoting it to group status (Jurong Group) as well as the creation of the Sentosa Group. The Jurong Group now stops stratigraphically at the topmost Boon Lay Member dated to the Middle Triassic (~240 Ma) which is subsequently overlain by the Upper Triassic Sentosa Group (~210 Ma). The boundary between the Jurong Group and the Sentosa Group is separated by an unconformity inferred from a c. 30 Ma time gap in deposition (**Figure 9**). This new Sentosa Group comprises the Tanjong Rimau Formation and the Fort Siloso Formation - The former was deposited in a braided to meandering fluvial environment and can be observed as thick, trough cross-bedded to planar sandstone bars. The latter was deposited in the form of fine-grained lacustrine, shallow marine silt- and sandstone as the environment transitions into a marginal marine system. These reclassifications have been endorsed by the Building and Construction Authority (BCA) and will be published in an upcoming geological memoir of Singapore.

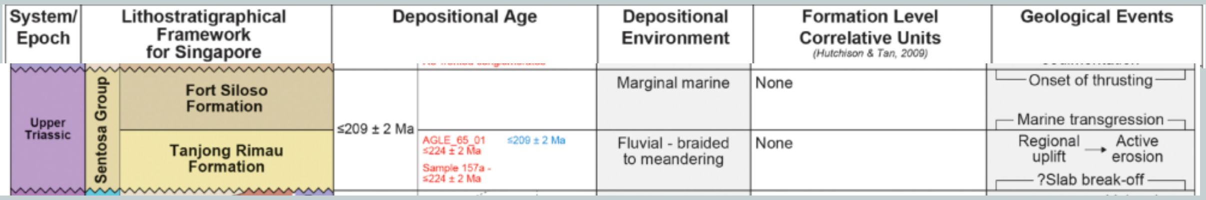


Figure 9 The ICS compliant lithostratigraphic framework for Singapore developed in this study, with only the Sentosa Group displayed. In addition, 'depositional age' information, including new U-Pb age determinations of detrital zircons (red text), along with already published geochronological information (blue text), have been summarised per unit.

The Sentosa Group. The Sentosa Group is named after Sentosa Island in the 'Southern Islands' planning area of Singapore. This group is on a whole located offshore, but also outcrops on the Southern Islands and Western Islands as well as in Labrador Park on mainland Singapore (Fig. 10). The Sentosa Group comprises the Tanjong Rimau Formation and the Fort Siloso Formation. The stratotypes for both formations are well-exposed on Sentosa Island, along with the boundary-stratotype. (Dodd et al. 2019). The Southern islands are largely surficially expressed in the newly named Sentosa Group, which comprises the Tanjong Rimau and the Fort Siloso Formations (**Figure 10**). **Figure 10** reveals the stress field in the region demonstrating a NW-SE trending folding, with SJI and Lazarus Island bounded by two proximal faults in their northern and southern extents.

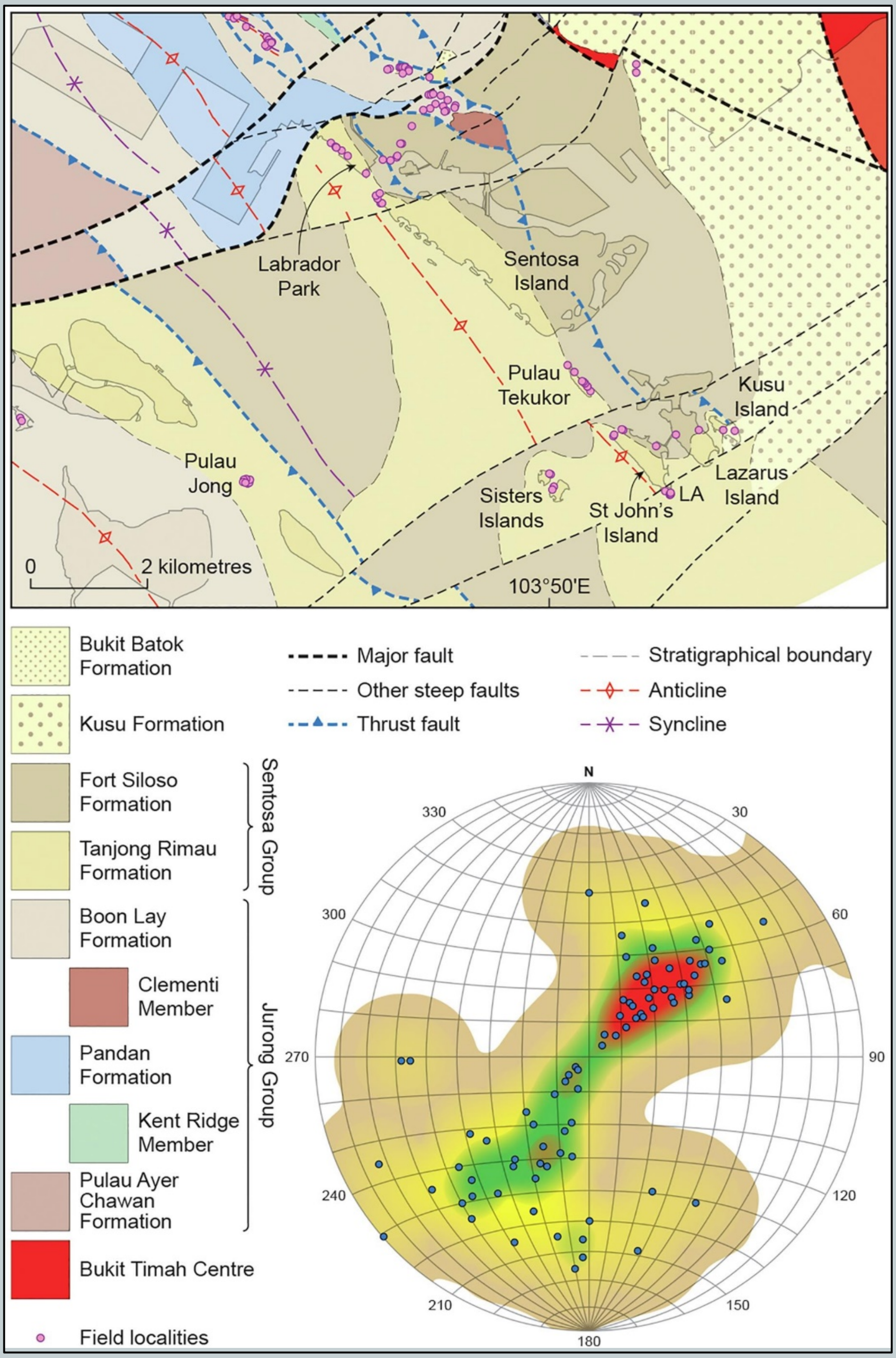


Figure 10 Bedrock geological map of southern Singapore, including the 'Southern Islands'; key field localities visited are superimposed on the formation level lithostratigraphy. LA – Lokos Anticline at Tanjong Lokos, St. John's Island. The stereonet shows bedding measurements in Sentosa Group strata from Sentosa Island and Labrador Park to St. John's and Lazarus Islands (equal area lower hemisphere projection, n = 81), NW–SE trending folding is clearly demonstrated (Leslie et al. 2019).

Sentosa Island outcrops were previously examined and interpreted as 'a continental red-bed molasse succession recording alluvial-lacustrine sediments' deposited in a half-graben setting, referred to as Lake Sentosa (Oliver and Prave 2013). However, Dodd et al. (2019) provides an alternative interpretation incorporating knowledge of the structural arrangement of Singapore and additional sedimentary evidence exposed on neighbouring islands (**Figure 11**).

The Tanjong Rimau Formation represents the lowermost unit of the Sentosa Group and was deposited when large volumes of immature sediments were actively eroded from the Singapore region of the Semantan Basin (hinterland). The sediment was transported predominantly through braided to meandering fluvial systems (**Figure 11E**) that produced thick, trough cross-bedded to planar cross-bedded sandstones as a series of longitudinal bars, transverse bars, point bars, and channel elements. Thinly interbedded, laminated mudstone and very fine-grained sandstones represent some element of overbank preservation. These fluvial systems may have eroded into and re-worked the underlying Jurong Group strata.

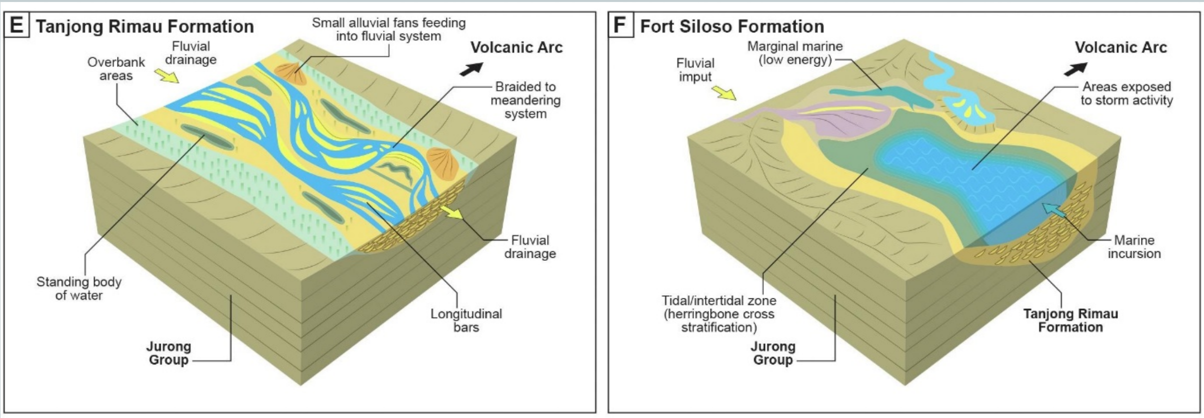


Figure 11 3D, schematic block diagrams of the depositional environments for the formations within the new lithostratigraphical framework for Singapore. (E) The fluival, braided to meandering environment of the Tanjong Rimau Formation. (F) The low energy, marginal marine depositional environment of the Fort Siloso Formation, which was deposited following the marine transgression of the underlying Tanjong Rimau Formation.

The stratigraphically highest parts of the Tanjong Rimau Formation display upwards-increasing evidence of marine indicators suggesting a progressive marine incursion into the fluvial setting during this time. This is supported by the interpretation of a 'beach' or 'shore' environment, formed possibly under conditions of uplift and late Triassic sea-level rise.

The transition from the Tanjong Rimau Formation into the overlying Fort Siloso Formation depositional environment is marked by the eventual dominance of marine processes over fluvial processes and supported by the upwards absence of coarse-grained sediments. The Fort Siloso Formation was deposited in a low energy, marginal marine to fluvio-deltaic/fluvio-lacustrine setting (**Figure 11F**) where tidal processes influenced deposition. A low-energy tidal flat likely surrounded a suite of low-relief tidal channels, depositing repeated successions of very fine-grained sands, forming inclined heterolithic stratification. The absence of coarser-grained sediments was likely controlled by the flooding of the hinterland during the transgression (sea-level rise), possibly due to sea-level highstand conditions that was present by late Triassic times (Dodd et al. 2019).

Areas of interest. There were nine locations of geologic interest on the SJI-C and Kusu Island identified by Oliver and Gupta (2017) (**Figure 12**). As these locations were identified before the reinterpreted boundaries, the maps do not reflect the updated nomenclature. In particular, Location 6 and 7 are further elaborated below.

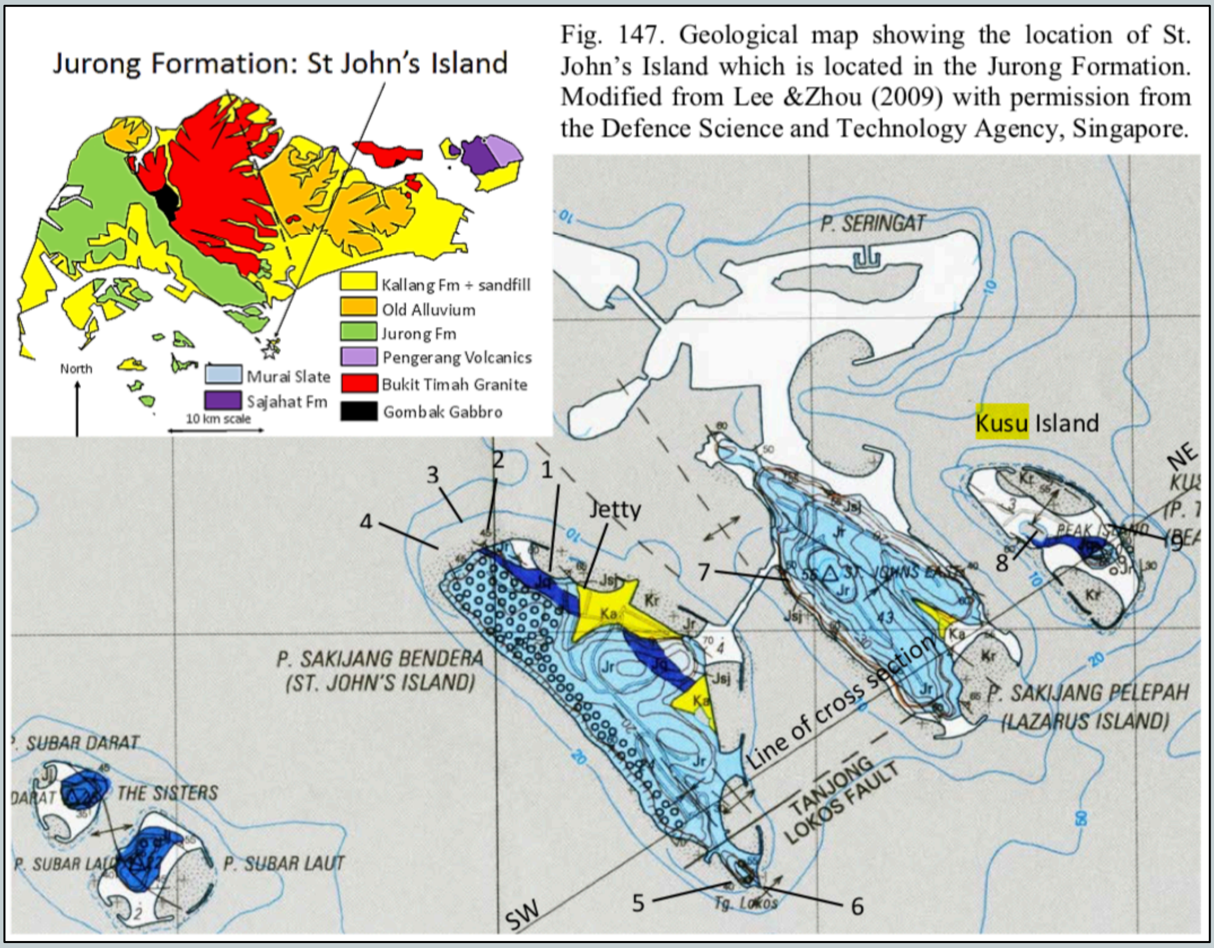


Figure 12 Map showing the nine locations of geologic interest on the SJI-C and Kusu Island as identified by Oliver and Gupta (2017).

Location 6 is known as the **Lokos Anticline** and is found on SJI (Oliver and Gupta 2017). An anticline is a geological feature where bedrock is folded with its ends sloping downwards away from the crest of the fold. This anticline is exposed on the cliff below the radar station on the southern tip of the island at Tanjong Lokos (**Figure 13**). It shows the original bedding with the ends of the fold (fold limbs) dipping northeast and southwest (**Figure 13**) (Oliver and Gupta 2017).

Location 7 is found on LAZ where laminated mudstone, siltstone and sandstone are observed (Oliver and Gupta 2017). In certain areas, a ~15 cm thick band of contorted coal seams can be found (**Figure 14**). As the roots of plants were not observed, this band can be assumed to be derived from plant material that has been carried in by currents, and thus can be interpreted as deposits along lakeshores (Oliver and Prave 2013), or in low-energy marginal marine environments (Dodd et al. 2019, Chua C. W. S. 2019).

Geologic significance. Geological features on the SJI-C and Kusu Island provides rare opportunities to appreciate the geological richness of Singapore in a natural setting (**Figure 15, Figure 16**) (Chua C. W. S. 2019). These features can offer valuable understandings on subsurface conditions of Singapore, and conservation of these features on the islands can provide further insight into the geologic past of the islands and Singapore (Chua C. W. S. 2019). With further research and studies, important discoveries, such as discovering when fringing corals first colonised around these islands, would be possible (Chua C. W. S. 2019). These features also hold strong educational value for members of the public and students to be introduced to the geological richness of the islands (Chua C. W. S. 2019).

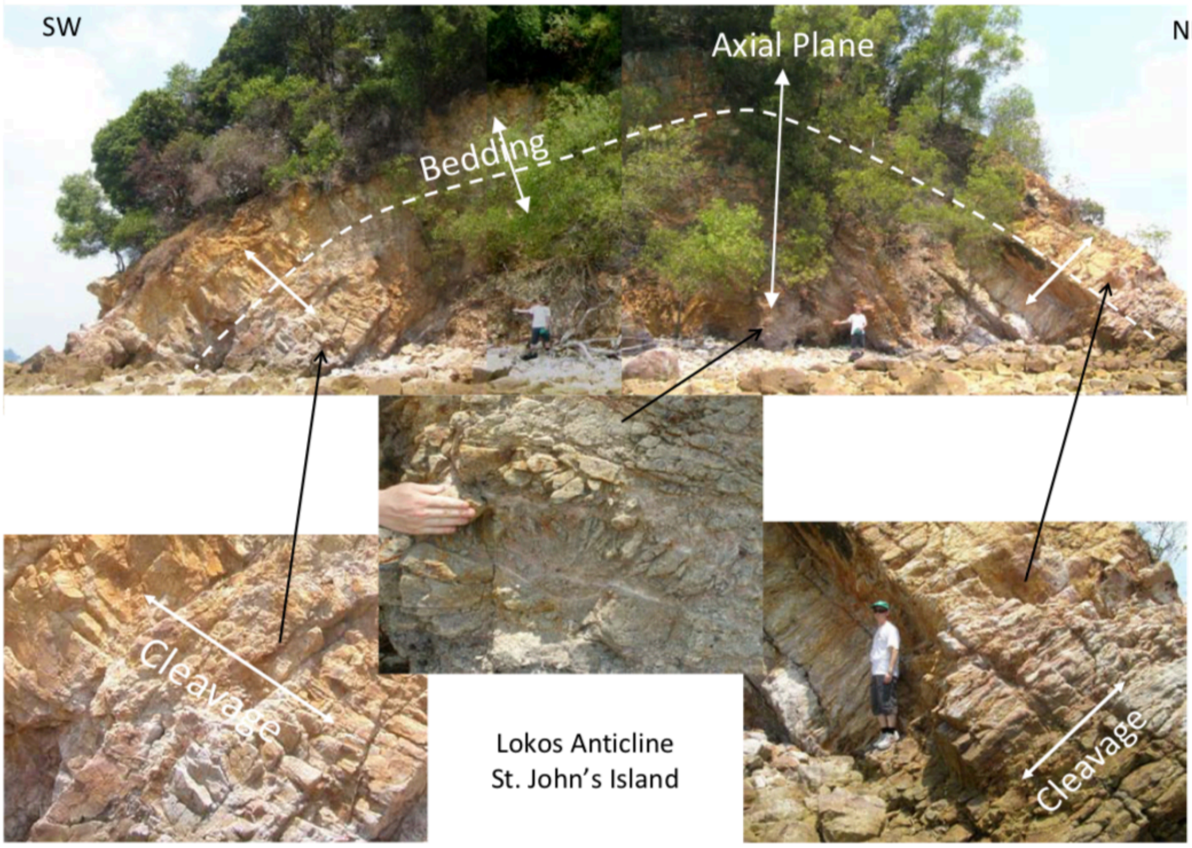


Figure 13 The Lokos Anticline at Location 6 on SJI. An anticline is a geological feature where bedrock is folded with its ends sloping downwards away from the crest of the fold. Centre photograph shows brittle crushed sandstone in the core of the fold. This photograph was obtained from Oliver and Gupta (2017).

Figure 14 Contorted coal seam within Fort Siloso Formation at Location 7 on LAZ. This photograph was obtained from Oliver and Gupta (2017).

Figure 15 Rock formations at Pulau Tekukor. Photo by Stephen Chua.

Figure 16 Near-vertical folded rock formations at Pulau Tekukor. Photo by Stephen Chua.

3.2 | The Terrestrial Landscape

Out of the Southern Islands, SJI and LAZ have the largest land areas. The flora on the islands associated with the Sisters' Islands Marine Park (SIMP), SJI, the Sisters' Islands and Pulau Tekukor have been extensively documented by Hung et al. (2017a, 2017b, 2017c) (**Figure 17**), while records of the vegetation on LAZ found were mostly anecdotal (Tan 2011). Reports on the vegetation found on Kusu Island were not found. The terrestrial landscape of these islands mostly consisted of coastal forest and managed vegetation (Tan 2011, Hung et al. 2017a, 2017b, 2017c).

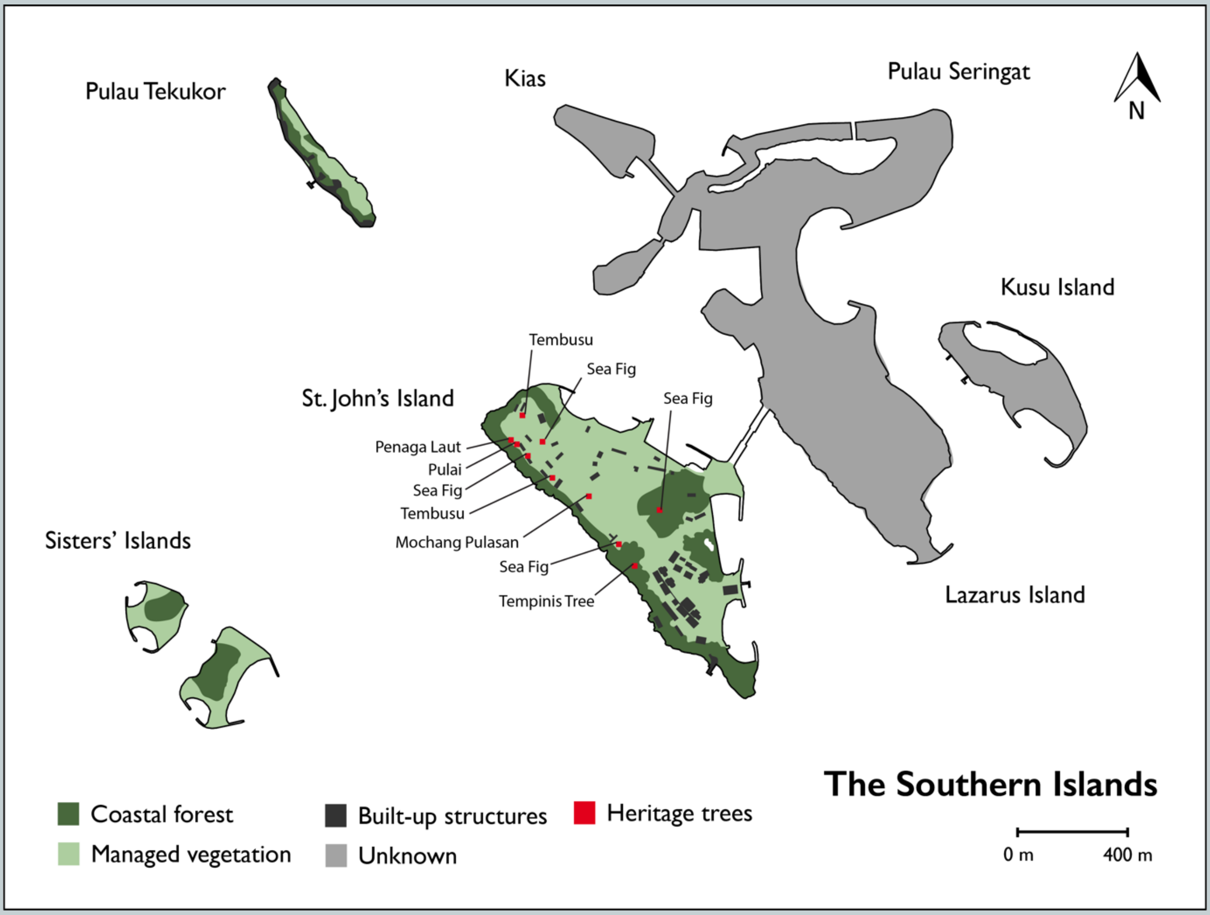


Figure 17 Distribution of coastal forest and managed vegetation in the Southern Islands (Hung et al. 2017a, 2017b, 2017c). The distribution of vegetation on Lazarus Island and Kusu Island were not reported. Heritage trees marked by the National Parks Board (NParks) on SJI are indicated (two Tembusu trees, four Sea Figs, one Tempinis tree, one Machang Pulasan, one Penaga Laut and one Common Pulai).

For SJI, the total land area currently stands at 41.32 ha (Hung et al. 2017c), with 13.19 ha of coastal forest (**Figure 18**) (32%), 24.98 ha of managed vegetation (60.6%), 2.94 ha of built-up structures (7.1%) and a small 0.12 ha water body connected to the sea (0.3%). The terrestrial landscape of SJI has been heavily altered from previous development plans (See 1993). The island has a total of 258 vascular plant species, out of which 154 are native species (60%) (Hung et al. 2017c). Of the native species, there were 22 nationally Critically Endangered species, 15 nationally Endangered species and 20 nationally Vulnerable species (Hung et al. 2017c).

Small Sisters' Island (2.76 ha) consists of 0.94 ha of coastal forest, 1.80 ha of managed vegetation, and 0.02 ha of built-up structures (Hung et al. 2017a), while Big Sisters' Island (4.53 ha) is made up of 1.67 ha of coastal forest, 2.84 ha of managed vegetation, and 0.02 ha of built-up structures (Hung et al. 2017a). Out of the 144 vascular plant species the islands support, there were 90 native species recorded including ten nationally Critically Endangered species, eight nationally Endangered species and fourteen nationally Vulnerable species (Hung et al. 2017a).

Figure 18 Natural coastal forest of SJI. Photo by Ria Tan.

Pulau Tekukor (5.07 ha) is made up of 4.01 ha of natural vegetation and 1.06 ha of other landscape features and supports a total of 151 vascular plant species (Hung et al. 2017b). Out of the 86 native species, there are one presumed nationally Extinct species, ten nationally Critically Endangered species, four nationally Endangered species and seven nationally Vulnerable species (Hung et al. 2017b).

3.2.1 | Coastal forest

Figure 19 Coastal forest and natural cliffs at SJI. Photo by Ria Tan.

Coastal forests were identified using floristic surveys with certain plant species such as *Calophyllum inophyllum* and *Xylocarpus rumphii* as indicators (Hung S. pers. comms 2019). These plants species are commonly naturally found in coastal areas due to their ability to grow in environments with high wind speeds, low humidity, high temperatures, and high light levels (Hung S. pers. comms 2019). The coastal forest is the remaining natural vegetation found on the Southern Islands (Tan 2011, Hung et al. 2017a, 2017b, 2017c), and they are distributed on SJI, LAZ, Sisters' Island and Pulau Tekukor (**Figure 17**, **Figure 19**).

Biodiversity and ecological significance. Like other forest types, the coastal forest provides a range ecological services for many organisms. Leaves, fruits and other organic matter from these forests are a source of nutrients and enrich nearby marine habitats (Lee Kong Chian Natural History Museum, n.d.). This type of forest has been identified to have significant conversation potential due to its rarity in Singapore. Currently, the only example of coastal forests on the mainland can be found in the Labrador Nature Reserve (Hung et al. 2017c).

On SJI, several nationally critically endangered species have been found to not only persist but also have high occurrence in the coastal forests (e.g. *Calophyllum inophyllum*, *Tristaniopsis obovata* and *Xylocarpus rumphii*). The widespread occurrence of *C. inophyllum* (Clusiaceae) is ecologically significant as it is able to attract many insects due to its sweet-scenting flowers, and bats to disperse its fruits (Corner 1988). This makes *C. inophyllum* and the coastal forest on SJI of high conservation value as it positively contributes to the biological diversity of this habitat (Hung et al. 2017c). Rare plant species such as the *Rapanea porteriana* and the seashore mangosteen (*Garcinia hombroniana*) can be also found on SJI and LAZ (Tan et al. 2010).

On LAZ, the Linnga pouteria (*Pouteria linggensis*) was the original sole tree documented in Singapore, which has now also been found (in larger numbers) at Chek Jawa, Pulau Ubin (Tan et al. 2010). A very rare shrub known as the *pelir musang*, which is Malay for "civet cat's testicles" (*Fagraea auricultata*) can be found on LAZ and Pulau Tekukor (Tan et al. 2010). The Critically Endangered *Fagraea auriculate* and *Sindora wallichii* tree were also observed (Tan 2011). It was also speculated that the *Sindora wallichii* tree could be the last surviving one found in the Southern Islands (Tan 2011).

On the Sisters Islands, some nationally threatened species have fairly large wild populations indicating substantial levels of genetic stock and is thus valuable for the persistence of their native genetic stock (Hung et al. 2017a). This is the case for *Podocarpus polystachyus*, a Nationally Critically Endangered species found thriving with saplings growing nearby mature trees on Big Sisters' Island. It is speculated that there are less than 50 trees of this species left in the wild in Singapore (Tan 2008). Similarly, for Pulau Tekukor, some of threatened species have relatively large wild populations and thus, attention should be given to ensure the persistence of the native genetic stock.

Figure 20 Natural coastal forest at the southern part of Lazarus Island. Photo by Rachel Oh.

The natural coastal forests of the Southern Islands have also been suggested to be a potential resting stop for migratory land birds (Yong D. L. pers. comms. 2019) (**Figure 21**). Personal observations during peak migratory season in mid-October have been made only for SJI, LAZ and Kusu Island, however the avian biodiversity of the Southern Islands can be assumed to be similar due to their proximity and highly similar vegetation type (Yong D. L. pers. comms. 2019). Some migrant passerines sighted include the Arctic Warbler (*Phylloscopus borealis*), Eastern Crowned Warbler (*Phylloscopus coronatus*) and the Amur Paradise Flycatcher (*Terpsiphone incei*) (Yong D. L. pers. comms. 2019). Migrant raptors that have also been sighted include the Japanese Sparrow Hawk (*Accipiter gularis*) and Oriental Honey Buzzard (*Pernis ptilorhyncus*) (Yong D. L. pers. comms. 2019). More notably, the globally vulnerable Brown-chested Jungle Flycatcher (*Cyornis brunneatus*) was also sighted on the SJI (Yong D. L. pers. comms. 2019).

Resident birds on the islands can be expected to amount to at least 30 species (Yong D. L. pers. comms. 2019). The diets of the birds are often generalists (omnivorous or nectivorous) due to the disturbed conditions of the forests (Yong D. L. pers. comms. 2019). Raptors spotted commonly include the White-bellied Sea Eagle (*Haliaeetus leucogaster*) and the Brahminy Kite (*Haliastur indus*). The Great Billed Heron (*Ardea sumatrana*) is another prominent bird species commonly sighted along the coasts given its diet of fishes (Yong D. L. pers. comms. 2019).

Figure 21 (Top left) Brown-chested Jungle Flycatcher (*Cyornis brunneatus*). (Bottom left) Great bill Heron (*Ardea sumatrana)*. (Top right) Arctic Warbler (*Phylloscopus borealis*). (Middle right) Amur Paradise Flycatcher (*Terpsiphone incei*). Photo by See Toh Yew Wai. (Bottom right) Japanese Sparrow Hawk (*Accipiter gularis*). Photos by Francis Yap and See Toh Yew Wai.

3.2.2 | Managed vegetation

The dominant vegetation found on the Southern Islands is managed vegetation (**Figure 17**). (Hung et al. 2017a, 2017b, 2017c). This type of vegetation is characterised by the clearing of previously existing natural forests and the replacement of it with cultivated species, often exotic, on this island (Hung S. pers. comms. 2019). These areas require human intervention for regular maintenance and typically include cultivated shrubs and/or hedges, planted trees and turf, amongst others (Hung S. pers. comms. 2019). Largely within the managed vegetation area, the National Parks Board (NParks) marked 10 heritage trees for their exceptional size and botanical, social, historical, cultural and/or aesthetic value (**Figure 22**). They include two Tembusu trees, four Sea Figs, a Tempinis, a Machang Pulasan, a Penaga Laut and a Common Pulai and their locations can be seen in **Figure 17** (NParks).

Figure 22 Heritage trees on SJI were marked out by the National Parks Board (NParks). (Left) Sea Fig Heritage Tree. (Right) Tempinis Heritage Tree. Photos by Marcus FC Ng.

On SJI, terrestrial and amphibious snakes (seven species), mud lobsters and macaques were observed (Chim 2014, personal observation) (**Figure 23**). The mud lobster mounds can be observed easily on the grass patches near the swimming lagoons and near the southeastern lagoons. These mounds are often used to indicate the presence of the mud lobsters (*Thalassina kelanang*) as they inhabit the soft mud deep underground (Yeo 2013). These lobsters create a network of tunnels underneath the mounds (WildSingapore). A troop of six macaques have also been observed to inhabit these areas, commonly spotted near the trees on the eastern part of the island and on the mangroves on the northeastern part.

Figure 23 (Top) Gold-ring cat snake (*Boiga dendrophila*) spotted along food path. (Bottom right) Painted bronzeback (*Dendrelaphis pictus*) spotted among the grass. (Bottom left) Mud Lobster (*Thalassina kelanang*). Photo by Chim Chee Kong and Ron Yeo.

3.2.3 | Threats to the terrestrial environment

Aside from direct coastal development, coastal vegetation has been dislodged during strong storms resulting in strong waves (Tan et al. 2010). Combined with soil erosion, these often result in only the most strongly rooted ones left (Tan et al. 2010).

On the Sisters' Islands, the invasion of non-native plant species is a potential problem due to its small area, and thus strategic intervention in regulating, containing or eliminating invasive species would be imperative for future plans (Hung et al. 2017a).

On Pulau Tekukor, efforts to restore and expand rare species existing in small population have been recommended (Hung et al. 2017c). For example, the *Fagraea auriculata*, a Critically Endangered species, can be propagated through air-layering, a method chosen for its high successful rooting rate for the same species (Yeo et al. 2011, Hung et al. 2017c). Hung et al. (2017c) have also identified other species such as the *Rhodomyrtus tomentosa* and the threatened *Tristaniopsis* species to be conserved in similar ways.

There is an increasing demand for using native plants like those on the islands for horticultural landscaping and thus, ensuring the persistence of these wild populations and the availability of genetically diverse saplings will be important (Yeo et al. 2011). As such further studies could be conducted to assess the genetic stock and variability of the naturally occurring species and explore the effectiveness of various conservation methods (Hung et al. 2017c). With knowledge of the genetic pool of wild populations, a diverse range of saplings could be collected from a range of genotypes for future restoration projects (Reusch et al. 2005, Leger and Espeland 2010).

3.3 | The Coastal Environment

The coastal landscape comprises of the natural habitats found along the coastline, which is defined to be the edge of land during high tide (Lu et al. 2005). There are three main types of coastal habitats found in Singapore, and they are also found in the Southern Islands – sandy shores, rocky shore and cliffs and mangroves (Tan et al. 2010).

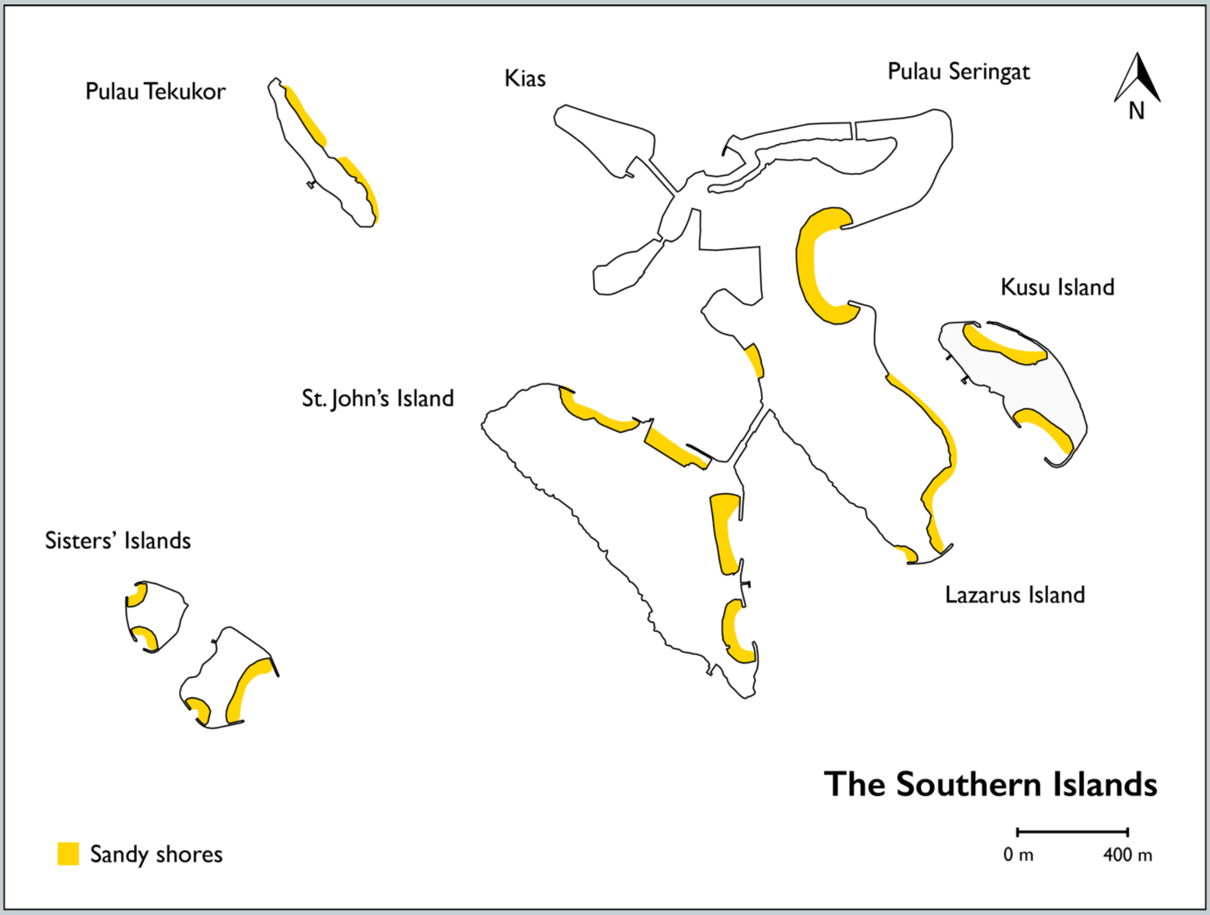


Figure 24 Distribution of sandy shores in the Southern Islands (except Sentosa) (Hung et al. 2017a, 2017b, 2017c, WildSingapore, Google Earth). Most of the sandy shores found in the Southern Islands are man-made from development works on the islands except those the eastern coast of Pulau Tekukor and southern coasts of LAZ (See 1993, Tan et al. 2010, Hung et al. 2017a, 2017b, 2017c).

Both natural and man-made sandy shores can be found in the Southern Islands (**Figure 24**). Sandy shores found in lagoons are often man-made as a result of coastal development works (See 1993). Natural sandy shores can be found at the eastern coast of Pulau Tekukor and southern coasts of LAZ (**Figure 25**) (See 1993, Tan et al. 2010, Hung et al. 2017a, 2017b, 2017c).

History. During the land reclamation and shoreline protection works over the last three decades, seawalls and breakwaters were constructed to form artificial lagoons for recreation (Chia et al. 1988, Tan 2006, Teh 2006). Within these lagoons, sandy beaches were constructed for recreational use using fill material from the nearby Sisters' Shoal and Beting

Kapal for reclamation at SJI and using fill material from Indonesia for the reclamation at LAZ (Chia et al. 1988, See 1993, Teh 2006, Tan 2006). The breakwaters constructed also helped prevent the materials from being eroded away and allow beaches to take form (Chia et al. 1988). Natural sandy beaches were documented on the SJI, LAZ and Kusu Island pre-reclamation (See 1993). There were likely natural beaches on the Sisters Island as well due to similar island features.

Biodiversity and significance. Though more commonly associated with recreational activities, sandy shores can also provide a suitable habitat for organisms that make use of the sand for shelter and food (NParks). Biodiversity such as the ghost crabs and sand bubbler crabs that burrows through the sand for food and shelter are common at these shores (NParks). Sea birds have also been observed to hunt by the water's edge and those commonly sighted include the Striated Heron and the Great-billed Heron (NParks).

Figure 25 Sandcastles on the shore. Photo by Ria Tan.

More importantly, the biodiversity of these sandy shores should not be considered in isolation. As with most coastal landscapes, impacts on one habitat often have implications on other adjacent habitats. Sandy beaches in SJI and LAZ have been recorded to support seagrass beds and coral communities within and beyond the lagoon, which indicates that any disturbance to these sandy shores would impact these habitats as well.

Sandy beaches also have high economic and recreational significance (Tan et al. 2010). In addition to providing a recreational location and scenic views, beach vegetation plants at natural sandy beaches are very well-adapted to environments along the urban street (Tan et al. 2010). As such, these plants are potential urban ornamentals as they are able to withstand high temperatures, low humidity, strong winds and strong sunlight (Tan et al. 2010). Some plants such as the sea hibiscus (*Talipariti tiliaceum*) can also be found along the urban streets of Singapore (Tan et al. 2010).

3.3.2 | Mangrove patches

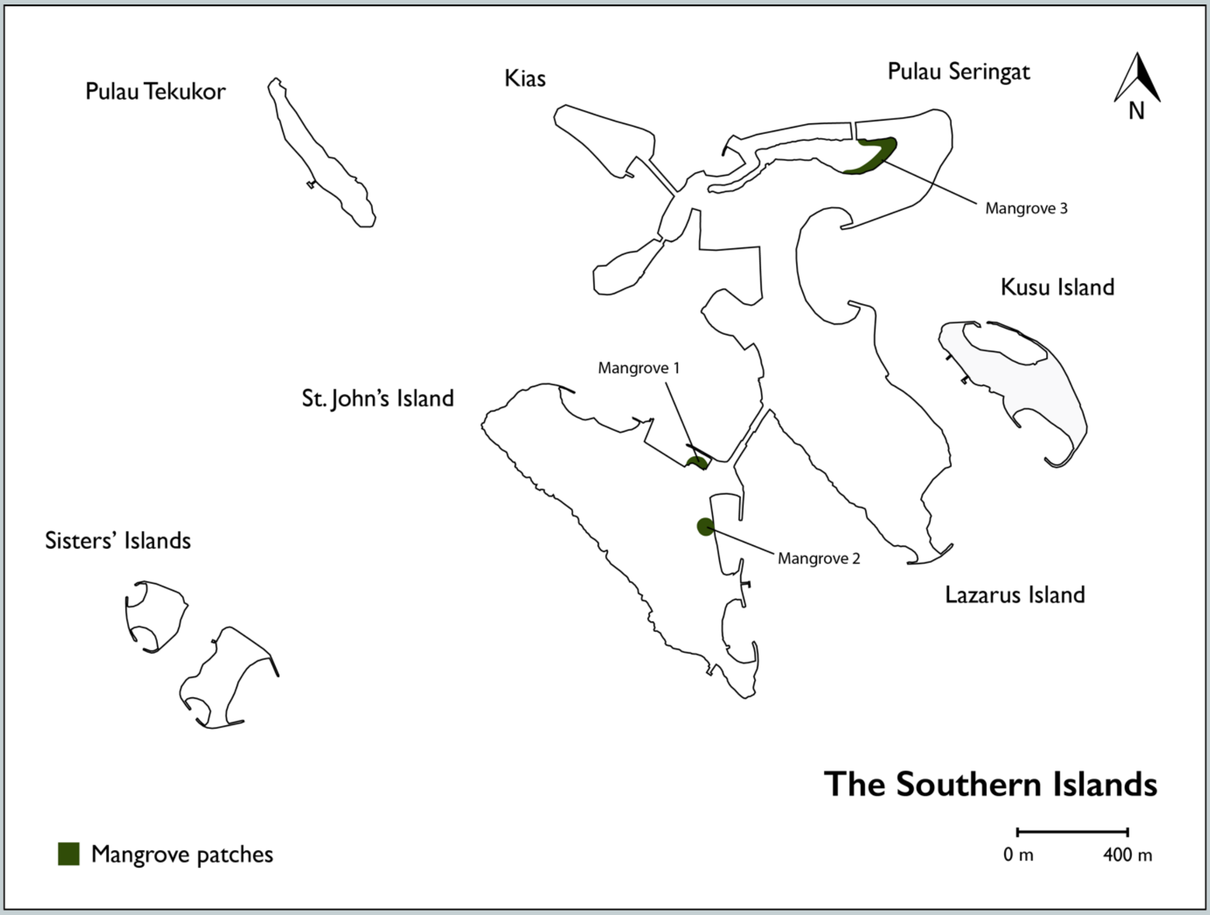


Figure 26 Distribution of mangroves in the southern islands (Hung et al. 2017c, Tan J. pers. comms. 2019).

Mangroves are highly specialized trees that grow in an anaerobic (lacking oxygen), unstable (loose sediment), salty environments along the coastlines, at the interface between land and sea (Ng and Sivasothi 2001, Saenger 2002, Hogarth 2007, Yang et al. 2013). Mangroves provide substantial services to the environment and society, including coastal protection (Well et al. 2006, Yee et al. 2010, Yang et al. 2013), and acting as crucial habitats for terrestrial, estuarine and marine organisms (Primavera 1998, Saenger 2002, Hogarth 2007, Ellison 2008, Ng et al. 2008).

In the Southern Islands defined in this study, only three mangrove patches have been recorded – two on SJI and one in the northern lagoon of LAZ (**Figure 26**) (Hung et al. 2017c, Tan J. pers. comms. 2019). On SJI, both patches are found on the eastern part of the island, one north of the causeway linking SJI to LAZ (**Figure 27, Figure 28, Mangrove 1**) and the other is found surrounding a small water body behind the Bendera Bay lagoon (See 1993, NParks 2012, Hung et al. 2017c) (**Figure 26, Mangrove 2**).

Figure 27 Mangrove patch on the northeastern part of SJI (labelled Mangrove 1 in distribution map). Out of the three patches, this patch is most accessible and is viewed by visitors regularly. The area of this patch is recorded to be approximately 0.1 ha (Yang et al. 2011). Photo by Rachel Oh.

Due to the similar height trees and lack of succession found in Mangrove 1, it is possible that the trees may have recruited at around the same time due to changes in hydrodynamics following past island development (specifically the construction of the breakwater in front of it). The area of Mangrove 1 was reported to be 0.1 ha (Yang et al. 2011). A preliminary one-off survey of Mangrove 2 revealed the area to be largely untouched, possibly due to the fact that until November 2019, access to its vicinity has been restricted (Bendera Bay used to be part of the DSTA facility). Large mature Nipah palm trees were found (**Figure 30**), a rarity in Singapore's remaining coastal areas (including our northern shores). Little has been documented about the mangrove patch found on LAZ (**Figure 26, Mangrove 3**).

Figure 28 The Bakau Pasir (*Rhizophora stylosa*) and Tumu (*Bruguiera gymnorrhiza*) (less noticeable in this photograph) found in Mangrove 1 on the northeastern part of SJI. The Bakau Pasir has prominent prop roots while the Tumu has knee roots that protrude above the ground (NParks). Photo by Rachel Oh.

Biodiversity and significance. The biodiversity found in the Mangrove 2 and Mangrove 3 have yet to be fully documented. However, in Mangrove 1, two types of trees have been recorded – the Bakau Pasir (*Rhizophora stylosa*) and the Tumu (*Bruguiera gymnorrhiza*) (NParks) (**Figure 29**). A rare Critically Endangered mangrove species known as the Api-api jambu (*Avicennia marina*) is also found on this mangrove patch (Ng and Sivasothi 2001, Yang et al. 2011). It is only found in two other places in Singapore – Pulau Tekong and Pulau Unum (Ng and Sivasothi 2001).

Although most of Singapore's mangrove forests and patches are found along the northern shores of Singapore. the small mangrove patches found on the SJI-C are of interest for research, conservation and education value. These patches add to the richness of habitats that can be found in the Southern Islands and serve as important avenues for environmental research and education to highlight the global importance of mangrove ecosystems.

More importantly, in light of climate change mitigation and ensuring the livability of our city, mangrove forests serve as important 'carbon sinks' and play a significant role in carbon sequestration and regulating climate (Phang et al. 2015, Friess et al. 2016). Local researchers have estimated that Singapore's mangroves have the capacity to store 450,000 tonnes of carbon, which is equivalent to the annual emissions of 621,000 Singaporeans (Friess et al. 2016). These carbon stores are estimated to be a few folds greater than that of terrestrial forests (Ong 1993, Bouillon 2011, Donato et al. 2011). When mangroves are cleared and the usually waterlogged soils get oxidised, carbon stored is released as carbon dioxide into the atmosphere (Lovelock et al. 2011). A long-term climatological study in Singapore show that mangroves are able to cool down local temperatures by almost 3°C (Ong 2015).

Figure 29 Propagules of the Bakau Pasir spotted on Mangrove 1 of SJI. Photo by Rachel Oh.

Figure 30 Large mature Nipah palm found during a preliminary one-off survey of Mangrove 2, found on the southeastern part of SJI. Nipah palms of such size are a rarity in Singapore. Photo by Theresa Su.

3.3.3 | Rocky shores

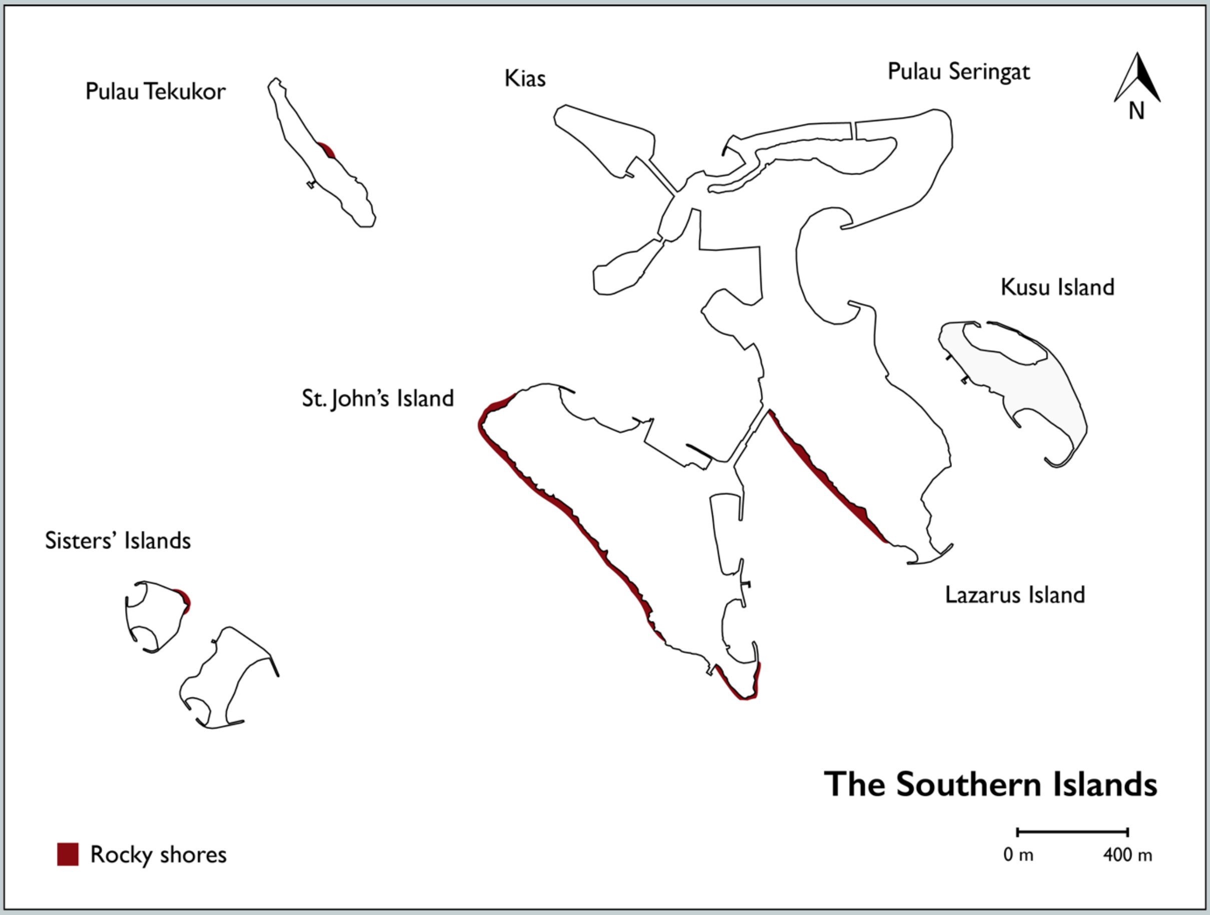


Figure 31 Distribution of rocky shores in the southern islands (Hung et al. 2017a, 2017b, 2017c, Lee unpublished data, Google Earth).

The natural terrain of the southern islands were predominantly rocky shores before extensive development took place (Wong 1985, Tan et al. 2010). Today, natural rocky shores can be found extensively on the western coasts of SJI and LAZ, and in a smaller area on Sisters Island (Small Sisters Island) and Pulau Tekukor (Chia et al. 1998, Hung et al. 2017b, Lee unpublished data) (**Figure 32**). Cliff formations can also be found on some of these rocky shores. On SJI, it is found on the northwestern tip and along the western coast of the island (Chia et al. 1998, Hung et al. 2017c, Lee unpublished data) (see Section 3.1 Geological Landscape) (**Figure 31**). On LAZ, it is found on the southwestern coastline (Tan et al. 2010, WildSingapore). These natural rocky shores are an endangered habitat, with few remaining in present-day Singapore (Todd and Chou 2005, NParks 2016, Hung et al. 2017c), making these remnant rocky shores in the Southern Islands so important. These rocky shores and cliffs have been recommended for protection by Turner and Yong (1999), in particular the western coast of SJI and LAZ for their high number of nationally threatened plant species and rarity.

Figure 32 Rocky shores at Tanjong Hakim, the northern tip of St John's Island. Photo by Ria Tan.

Biodiversity and significance. Rocky shores have solid rocks and large boulders, with little vegetation found at the shore (Chia et al. 1988, NParks, Lee unpublished data). The harsh environmental conditions (e.g. high temperatures, strong winds and sunlight) experienced in these habitats allow for only highly resilient biodiversity (Tan et al. 2010). Rocks on the shore can also radiate heat through the night from heat stored during the day (Tan et al. 2010). The marine faunal community that exist on SJI is similar to those found on most rocky shores, and includes barnacles, clams, gastropods and occasional corals or seagrasses at areas further from the shore (**Figure 33**) (Lee unpublished data).

Figure 33 Rocky shore associated biodiversity. Photos by Marcus FC Ng and Ria Tan.

3.3.4 | Threats to the coastal environment

Given the long-term coastal development plans undertaken on Singapore's shores, the dominant immediate threats to the coastal environment are direct reclamation works and shoreline protection resulting in the loss of habitat and the replacement of natural coastal environment with artificial structures like seawalls (Lai et al. 2015). Large proportions of rocky shore and mangrove habitats were lost (Wong 1985, Hilton and Manning 1995, Turner and Yong 1999, Tan et al. 2010, Lai et al. 2015), and may continue to be lost or modified in the future as the demand to construct seawalls to combat sea level rise induced from climate change increases (Airoldi et al. 2005, Moschella et al. 2005, Loke et al. 2018, Mohan 2019). Singapore's coastline is today dominated by artificial shoreline types (83%) and predominantly seawalls (63%) (**Figure 34**) (Lai et al. 2015).

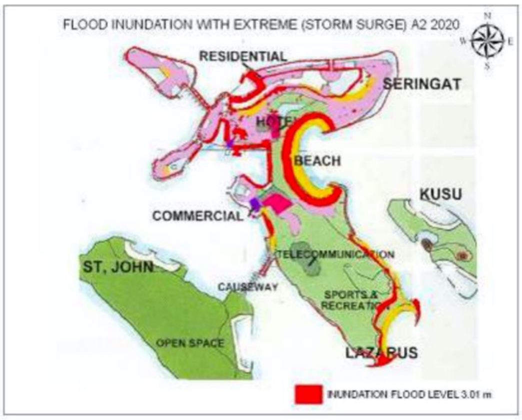
As Singapore sets to increase coastal defense against sea level rise, artificial structures, predominantly seawalls, might inevitable be the future of many coastal habitats. There is growing interest in understanding the ecology of seawalls and enhancing on biodiversity on artificial structures as a novel marine habitat globally and locally (Mitsch and Jørgensen 2003, Chapman and Underwood 2011, Firth et al. 2014, Loke et al. 2018). In Singapore, local scientists have attached purposefully designed complex concrete tiles on existing seawalls to increase the heterogeneity of the seawall surface, creating more microhabitats for a more diverse assemblage to be hosted on the seawall (Loke and Todd 2016, Loke et al. 2017).

Figure 34 Seawall and breakwater constructed on SJI as a result of land reclamation and shoreline protection works on the island. Photo by Rachel Oh.

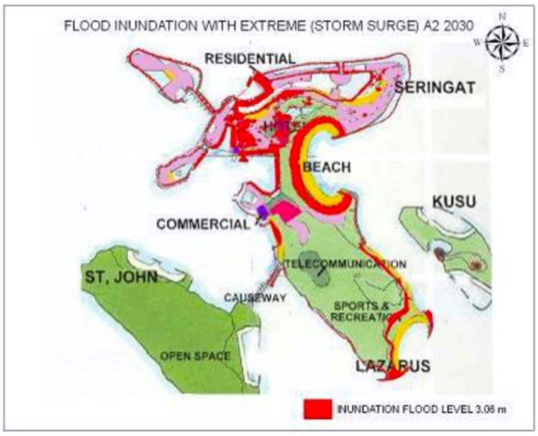
Sea level rise itself is also a threat to the coastal environment – both natural and built. In the Singapore Strait, average sea level rise between 1975 to 2009 was 2.9 ± 0.6 mm $year^{-1}$ (Tkalich et al., 2013). This is higher than the global trend of 1.7 mm $year^{-1}$. The predicted rise in sea level as well as increasing frequency of storm surges and extreme high-water events associated with climate change, would increase the inundation duration and confer added physiological stress to the coastal ecosystems such as mangroves and other types of coastal vegetation (Alongi, 2008; Gilman et al., 2008; Krauss et al., 2014). Seagrass ecosystems will also be affected by sea level rise. Sea level rise will increase water depth which will attenuate light penetration to seagrasses. Seagrasses that are distributed at their lowest depth limits (i.e. at minimum light requirement), such as those already affected by declining water quality due to nutrient or sediment inputs from coastal development and dredging, could be particularly vulnerable to sea level rise (Waycott et al., 2009).

There is a real concern that mangrove and seagrass ecosystems may not be able to keep pace with the rate of rising sea levels, especially for slower accreting mangrove and seagrass systems (see Tanzil et al., 2020). Furthermore, increased coastal development and artificial coastal defence structures also prevents these coastal ecosystems from migrating inland, and hence it is predicted that mangroves and seagrasses will decrease into narrower belts around coastal areas.

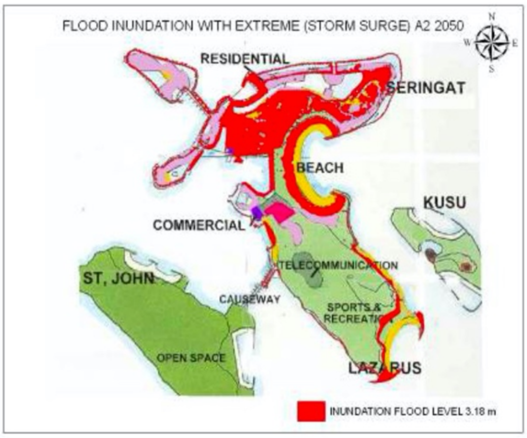
A study conducted by Teh et al. in 2010 examined the threat of a rising seas to Lazarus Island (including Kias and Seringat) and identified areas vulnerable to inundation based on future sea level projections (A2 emission scenario). The study assessed the extent of inundation for 4 different time frames: 2020, 2030, 2050 and 2100. Based on extreme scenarios of sea level rise combined with a 1 m storm surge during highest astronomical tide, by 2020 an inundation level of 3.01 m will flood 9.76 ha or 13% of Lazarus Island. By 2030 an inundation level of 3.06 m will flood 12.6 ha (16.7%) of land, with areas flooded increasing to 21.75 ha (29%) by 2050 and 42.144 ha (56%) of Lazarus Island by the end of the century (2100) (**Figure 35**).



Lazarus 2020, inundation level 3.01 m



Lazarus 2030, inundation level 3.06 m



Lazarus 2050, inundation level 3.18 m

Lazarus 2100, inundation level 3.55 m

Figure 35 Areas inundated on Lazarus Island (including Kias and Seringat) for various time frames (2020, 2030, 2050 and 2100) during highest astronomical tide plus storm surge of 1 m for A2 (extreme) sea level rise scenario (Teh et al., 2010)

3.4 | The Marine Environment

The marine environment is interconnected. This section reviews seascape around the SJI-C and two main marine habitats (i.e. coral reefs and communities and seagrass beds) found around the Southern Islands and notable biodiversity recorded thus far for these habitats.

3.4.1 | Seascape

Bathymetry. Situated at the southern tip of the Thai-Malay Peninsula on the inner continental Sunda shelf of the South China Sea, Singapore is surrounded by relatively shallow waters with mean water depth of ~30 m (Bird et al., 2006). The Straits of Singapore, in which the SJI-C lies, has complex bathymetry and consists of many little islands, underwater canyons and irregular channels with large depth gradients (Murali et al., 2005). Bathymetry across the Straits of Singapore varies from a few meters to >130 m, with a mean water depth of ~40m. The deepest waters around Singapore (~200 m) exist south of the SJI-C in an area called the "Singapore Deeps" (Bird et al., 2006) (**Figure 36**).

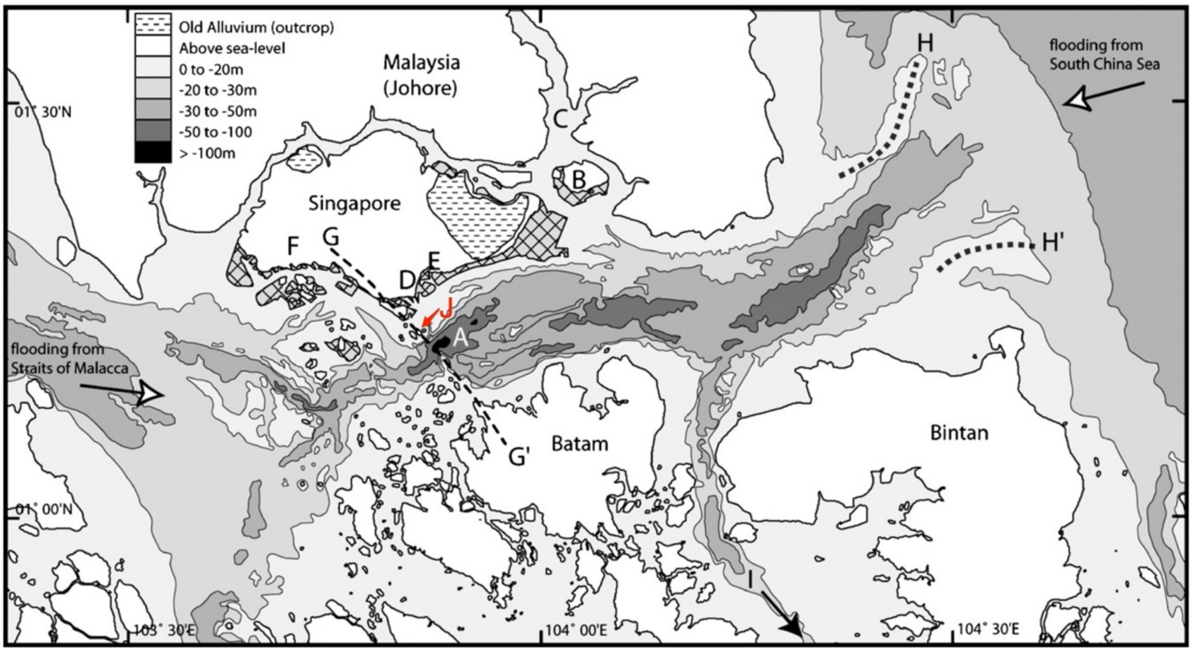


Figure 36 General features and bathymetry of the Straits of Singapore modified from Bird et al. (2006). General bathymetry from Admiralty Chart 2403 'Singapore Straits and Eastern Approaches'. Individual features as follows – A: The Singapore Deeps (maximum depth 204 m, B: Pulau Tekong, C: Johore River, D: Singapore Central Business District, E: Bedok, F: Jurong; G and G': Fault running from Kent Ridge in Singapore through St. John's Island, Pulau Sambo and Batam; H and H': splays of sediment at eastern end of Singapore Straits, I: Riau Strait between Bintan and Batam, with arrow indicating direction to overdeepened basin 104 m in depth at the southern exit to the Riau Strait, J: St. John's Island Complex.

Currents. The Singapore Strait constitutes part of a conduit that connects the South China Sea, the Java Sea and the upper northern Indian Ocean (Chen et al., 2005). The current circulation in the Singapore Strait is therefore closely related the circulations in the South China Sea, the Indian Ocean and the Java Sea. Regional monsoonal winds drive net seawater transport across the Strait of Singapore (**Figure 37**) – wind-driven circulation forces more saline, clearer waters from the South China Sea to the Singapore Strait during the northeast (NE) monsoon (November–March), while the southwest (SW) monsoon (May–September) allows intrusion of more turbid, lower salinity waters from the Malacca Straits and Java Sea (Rizal et al., 2012; Sin et al., 2016). During the NE monsoon, the South China Sea eddy accumulates water up at the eastern entrance of the Singapore Straits while the northern Indian Ocean eddy pulls water down at the other end of the Malacca Strait due to Ekman transport. An east-west hydrodynamic pressure gradient is thus created which produces a net drift from east to west in the Strait of Singapore. A reversal occurs for the SW monsoon in response to the circulation reversals in the South China Sea, the Java Sea and the northern Indian Ocean. The strong eastward current in the northern Indian Ocean pushes water level up at the northwest entrance of the Malacca Strait while the northward current passing by the South China Sea entrance of the Singapore Straits drags the water level down. The pressure gradient is thus reversed compared with that of the NE monsoon, and so does the direction of the net drift in the straits (Chen et al., 2005). This alternating monsoon current effectively drives the decoupling of local rainfall and salinity in the Singapore Strait i.e. counterintuitive salinity minima observed during the drier SW monsoon period and higher salinities during the wetter NE monsoon (Tanzil et al., 2016; 2019).

Apart from the Asian monsoon influence, currents and flushing in the Singapore Strait is also largely influenced by tidal regimes (**Figure 38**). The Singapore Strait connects the South China Sea, where tides are dominantly diurnal, to the dominantly semidiurnal Indian Ocean. At this transition, although the tidal water level oscillations are observed to be semidiurnal, tidal current oscillations are mixed, diurnal to fully diurnal (Maren and Gerritsen, 2012).

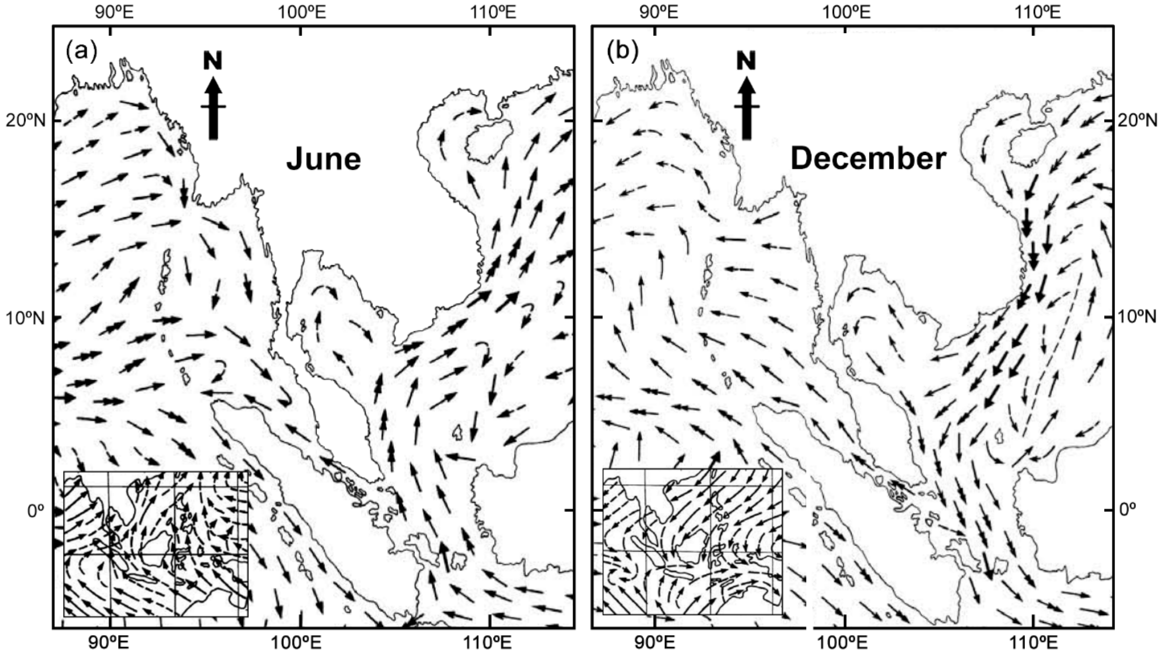


Figure 37 Surface current charts and average wind pattern (inset, lower left corner) for a) June and b) December (modified from Wyrtki 1961).

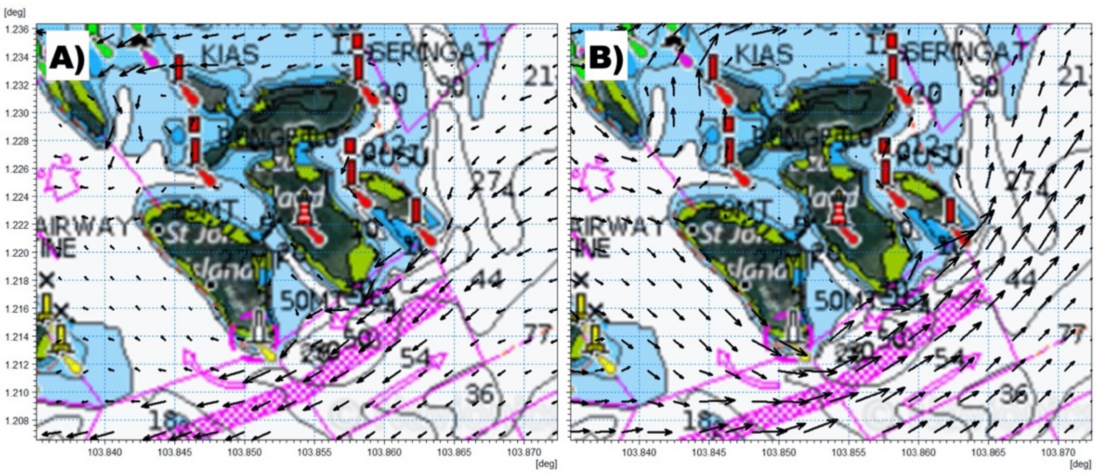


Figure 38 Surface currents at a) flood, and b) ebb tides around St. John's Island Complex.

General seawater parameters. Water quality around the SJI-C is considered good. Mean monthly surface seawater temperature around the SJI-C average ~29.5 ºC with a small annual range of ~3 ºC. Seasonally, sea temperatures peak ~May/June with a smaller peak in October/November, and a minimum in January (Tanzil et al., 2019). Salinity around the SJI-C follows a clear annual cycle with maxima ~November and March (coinciding with the start and end of the NE monsoon), and a minimum ~August (coinciding with the peak of the SW monsoon) (Tanzil et al., 2016, 2019). There is also a slight dip in salinity ~December–February coinciding with Singapore's peak rainfall period (Tanzil et al., 2016; Sin et al., 2016). Monthly salinity around SJI-C average ~31 psu, with an annual range of ~3 psu (~28.5–32.5 psu. Underwater light penetration and photosynthetically active radiation (PAR) tends to be highest in March/April and October/ November, with minima in June/July/August and December/January. For more information on specific water quality, see Tanzil et al. (2019).

3.4.2 | Coral reefs and coral communities

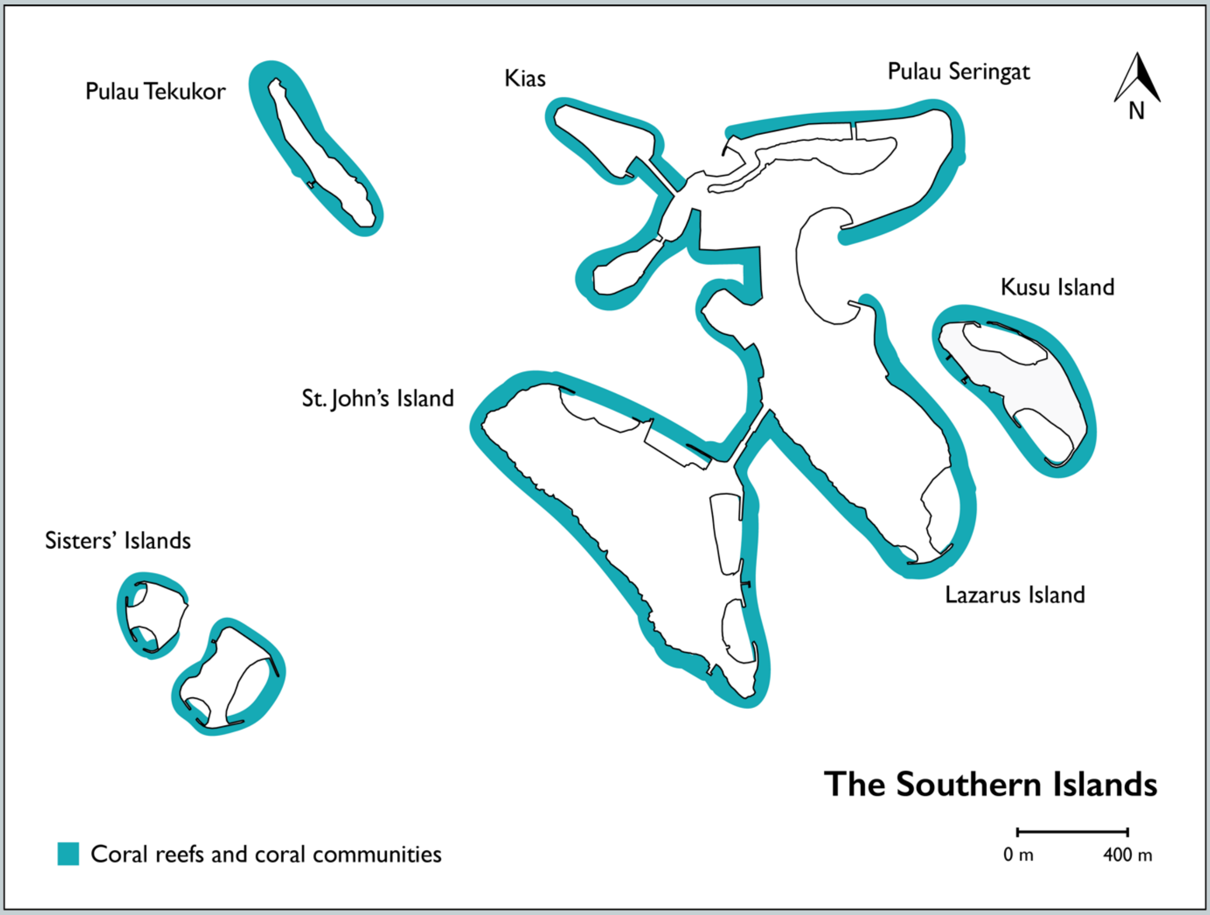


Figure 39 Distribution of coral reefs and coral communities in the Southern Islands (excluding Sentosa) (Republic of Singapore Yacht Club et al. 1991, NParks 2012, Lee unpublished data). Reefs communities formed on and off artificial structures seawalls were also included in this area.

Singapore's remaining 13.25 km^2 of coral reefs exist in a highly urbanised and dynamic coastal environment (Tun 2012, Tanzil et al. 2013). In contrast to mangroves, most of Singapore's reefs are located in shallow waters (<8 m water depths) off our southern coastline and islands (Republic of Singapore Yacht Club et al. 1991, Guest et al. 2016). Despite being subjected to elevated sedimentation rate, nutrients, turbidity and depressed light penetration, corals in Singapore still exhibit high species diversity (255 species of scleractinian corals) (Huang et al. 2009) and high coral growth rates when compared to neighbouring reefs within the region (Tanzil et al. 2013, 2016). Most coral reefs and coral communities in the Southern Islands were found fringing the coastlines, including on and off artificial structures such as seawalls (**Figure 39**, **Figure 40**, **Figure 41**).

Long-term trends. Long-term coral monitoring efforts have been conducted on the reef crest (3 – 4 m depth) and reef slope (6 – 7 m depth) of SJI, LAZ, Kusu Island, the Sisters' Islands and other southern islands in Singapore since the 1980s to the present day (Republic of Singapore Yacht Club et al. 1991, Guest et al. 2016, Chou unpublished data). Although no long-term monitoring data was found for the corals at Pulau Tekukor, it can be expected to exhibit similar trends due to its general proximity. These efforts showed that there had been a general decline in coral cover for the Southern Islands between the 1980s and 1990s (Guest et

Figure 40 Coral reefs at Kusu Island at dawn. Photo by Ria Tan.

al. 2016). From 1998 onwards, coral cover of reefs at shallow sites were found to recover rapidly from the initial declines due to anthropogenic disturbances and bleaching events, while reefs at deeper sites showed no signs of recovery (Guest et al. 2016).

Within the SJI-C, coral cover around SJI is thought to have been reduced by two thirds between 1991 and the early 2000s (Chou unpublished data) due to direct and indirect impacts of land reclamation and coastal development (Republic of Singapore Yacht Club et al. 1991, Chou unpublished data). For LAZ, its original coastlines before reclamation showed moderate coral cover (Chou unpublished data). However, due to the reclamation works to combine Seringat, Kias and Lazarus Island (original area), those coral reefs were lost. In more recent years, the extensive seawall constructed around Seringat and Kias have shown promise as potential sites for the recruitment and re-colonisation of coral communities and associated biodiversity (Ng et al. 2012, Chou et al. 2017, Taira et al. 2017, Toh et al. 2017). Coral communities were also found to have naturally colonised along the causeway that links SJI and LAZ (Yeo S., Lee Y. L. pers. comms. 2019).

Figure 41 Coral reefs at SJI. Photo by Ria Tan.

Biodiversity and significance. A total of 74 coral species have been recorded around SJI, i.e. ~30% of all coral species found in Singapore (**Figure 44**) (Huang et al. 2009). Kusu Island, the Sisters' Islands and LAZ had 91, 57 and 55 recorded species respectively (Huang et al. 2009). A recent study by Wong et al. (2018) found the reefs around Sisters' Islands hosted the highest coral species diversity based on species richness among the southern islands, followed by SJI and the other islands. However, based on the Simpson's index, the differences in diversity among the southern islands were minimal (Wong et al. 2018). Coral communities in Singapore mostly comprise of stress tolerant and generalist species common in turbid and heavily sedimented waters (Dikou and van Woesik 2006, Guest et al. 2016). Stress tolerant species are slow growing, have high fecundity, long-lived and relatively less susceptible to thermal stress (Darling et al. 2012). While generalist species are highly tolerant to environmental stress, they exhibit more rapid growth (Darling et al. 2012).

Hard coral communities on seawalls have previously been reported for located in islands in the south, which includes the Southern Islands, to amount to 17 genera (Ng et al. 2012). These results indicate that seawalls can serve as a novel habitat for corals by providing suitable substrates for the recruitment and growth of corals (Ng et al. 2012). Furthermore, as the seawalls surrounding northern LAZ were only constructed in the early 2000s, this natural establishment of corals within the last one to two decades further indicate the location's suitability (i.e. hydrodynamics, availability of larval supply) for corals (Tay et al. 2012). As natural reefs are increasingly degraded and seawalls now form Singapore's dominant coastline type, Ng et al. (2012) suggested that with the right designs, seawalls can be utilized for the recolonisation of corals and reef communities and can serve as cost-effective forms of artificial reefs.

Among the reefs in the Southern Islands, reefs with high conservation value were identified. These reefs are either mostly undisturbed by direct land reclamation effects and other anthropogenic stressors, or experienced disturbances but still exhibit high diversity. These are primarily reefs on the Sisters' Islands and the western coast and northern tip of SJI, which are considered relatively "undisturbed". Included also are sites that were utilized in coral restoration efforts, such as the coral transplant sites at seawalls of LAZ and the coral nurseries at LAZ and Kusu Island (Chou et al. 2017, Toh et al. 2017), where juveniles of the obligate corallivorous butterflyfish (*Chaetodon octofasciatus*) were sighted, indicating that the nurseries have the potential to rear corals but to also provide an alternate habitat for reef fauna (Taira et al. 2017) (**Figure 42**). The results of the coral restoration works are further elaborated below.

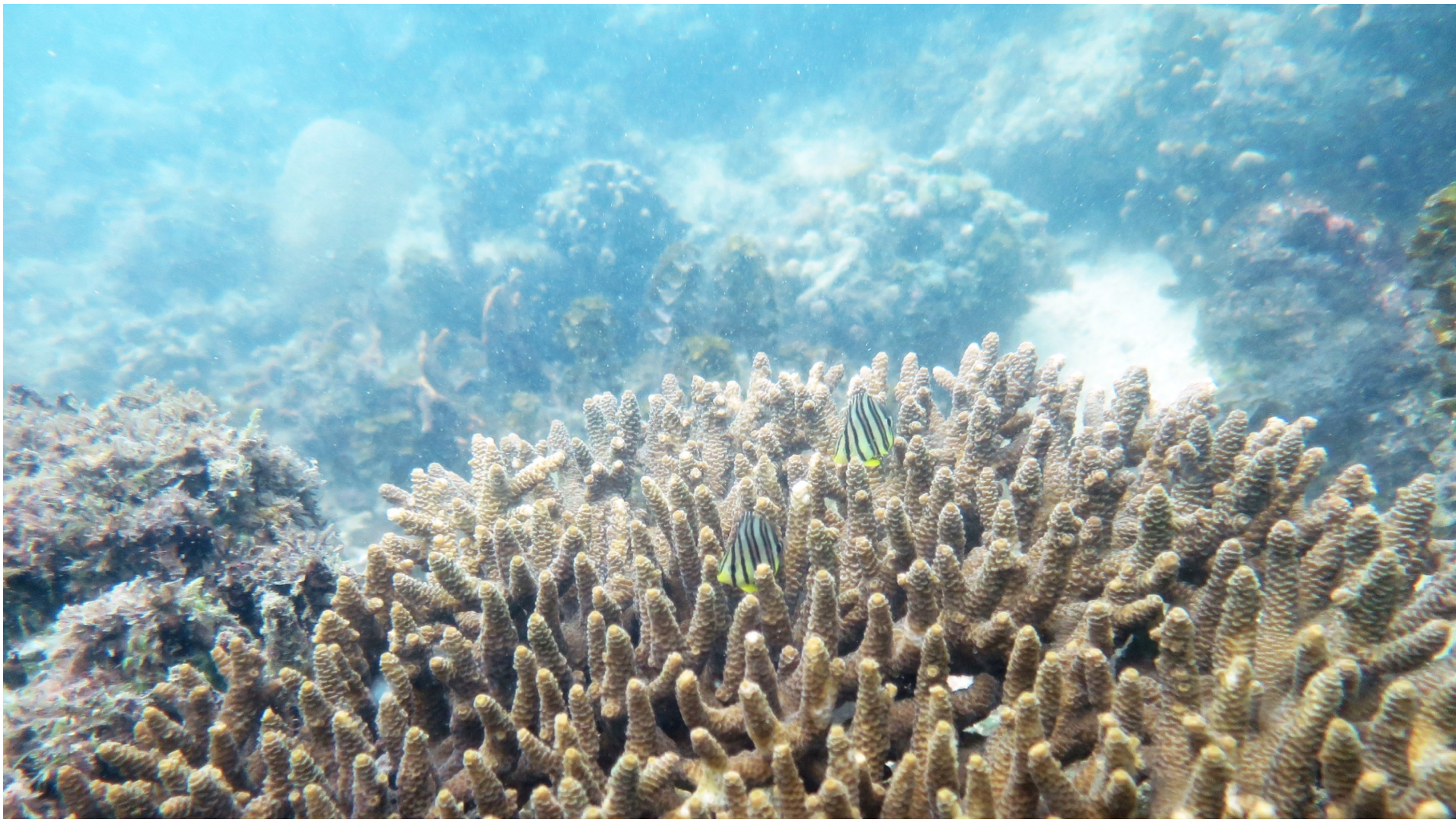


Figure 42 Obligate corallivorous butterflyfish (*Chaetodon octofasciatus*). Photo by Daisuke Taira.

These reefs are also home to a diverse fish community (Low and Chou 1992, Lieke and Myer 1994, Allen et al. 2008, Taira et al. 2017). In the Southern Islands, more than 100 coral reef fish species (Low and Chou 1992, Taira et al. 2017). The vast variety of fishes can be attributed to reef-building corals that serve as essential elements contributing to a complex habitat that provide a variety of niches for the fishes to occupy (Chong-Seng et al. 2012). Furthermore, some of these fishes contribute to the maintenance of reef health by feeding on algae (e.g. parrotfish and rabbitfish), thereby reducing competition between the corals and algae (Hughes et al. 2007, Green and Bellwood 2009).

Protected areas. The coral reefs surrounding the two Sisters Islands, along the western coasts of Pulau Tekukor and SJI are protected within the Sisters Island Marine Park (SIMP) boundary, Singapore's first marine park (NParks 2018). The marine park covers an area of about 40 hectares and was selected based on its ability to support various natural habitats (NParks 2018). As of 2017, the marine park is protected under the Parks and Trees Act, managed by the National Parks Board (NParks) (Wong 2017), making it illegal to fish, collect corals, or moor boats within the boundary without the prior approval by NParks (Wong 2017).

Enhancing biodiversity through restoration efforts. A number of reef restoration projects to promote coral establishment on Singapore's impacted reefs and artificial structures (e.g. seawalls) have been carried out since the 1990s (Loh et al. 2006, Ng et al. 2016, Toh et al. 2017, Ng et al. 2017).

One of the earliest large-scale reef restoration projects for Singapore was the deployment of Reef Enhancement Units (REUs) in 2001–2004 following the major redevelopment of the Southern Islands (Loh et al. 2006, Ng et al. 2016) (**Figure 44**). A total of seven plots were deployed around SJI, LAZ, Kusu Island, Sisters Islands, and Pulau Satumu (Raffles Lighthouse) (Loh et al. 2006). Recent surveys of the REUs found an almost two-fold increase in coral diversity since their deployment (Ng et al. 2017). These REUs were also observed to provide food and habitat soon after deployment, such as feeding and inhabitation by wrasses and damselfishes, and presence of fish eggs on interior walls (Loh et al. 2006), which persisted after a decade (Ng et al. 2017). Recent observations also reveal an increase in fish diversity, with representation from multi-niche specializations such as strict corallivores (i.e. fishes that feed on corals) (Ng et al. 2017). Asides from fishes, sessile animals such as anemones, bivalves and sponges were found to grow on the units as well, and mobile organisms such as crustaceans and cephalopods were also observed to interact with the units, indicating assimilation of the units with the reef environment (Ng et al. 2017).

Restoration efforts through coral transplantation have also been conducted in the subtidal areas along the seawalls around LAZ (Toh et al. 2017), which were found to be promising areas suitable for coral growth (Ng et al. 2012). The transplanted corals consisted of fragments from coral colonies salvaged from Sultan Shoal that would be impacted by coastal development (Toh et al. 2017). Following the transplantations, coral cover on the subtidal seawall section increased from 3% to 20.5%, and the species richness increased from two to eight genera (Toh et al. 2017). When done correctly, coral transplantation is an effective means to accelerate the re-establishment of corals by enhancing coral cover and diversity (Toh et al.

2017, Chou et al. 2017). From 2015 to 2016, a total of 904 coral fragments from 17 genera (*Acanthastrea, Echinopora, Favia, Favites, Goniopora, Hydnophora, Merulina, Mycedium, Pachyseris, Pavona, Pectinia, Platygyra, Pocillopora, Podabacia, Psammacora, Symphyllia* and *Turbinaria*) were transplanted to the seawalls at Lazarus East and Lazarus West, as well as the reef fringing Kusu Island, which generated a total restored area of 422 m^2 (150 m^2 degraded reef and 272 m^2 new reef) (Chou et al. 2017).

Two main factors that largely contributed to the successful restoration was the use of nurseries to propagate the coral colonies first before transplantation (Shafir et al. 2006, Ng and Chou 2014, dela Cruz et al. 2015, Toh et al. 2017) and the similar physico-chemical parameters of the waters of the nursery site and the donor site (Toh et al. 2017). Biodiversity were also enhanced at the coral nurseries (Afiq-Rosli et al. 2017, Taira et al. 2017), emphasizing the potential of these nursery sites for increasing biodiversity and the need to maintain good water quality around the SJI-C.

More recently, large-scale restoration projects were carried out through a collaboration between JTC Corporation (JTC) and the National Parks Board (NParks) (NParks 2018, Teh 2018a, Teh 2018b) (**Figure 44**). A total of eight purpose-built reef structures were installed in the waters off Small Sister's Island, within the Sisters' Islands Marine Park (SIMP) by the end of 2018 to form the JTC-NParks Reef Garden (NParks 2018). These reef structures are the largest in Singapore, making this Singapore's largest reef enhancement project (NParks 2018). The project had garnered the support of 11 donor companies from JTC's estates and developments contributing a total of $290,000 (NParks 2018, Teh 2018b) and is expected to contribute some 1,000m^2 of additional reef substrate to the Marine Park by 2030, supporting existing habitat enhancement and reef restoration efforts to conserve marine biodiversity (NParks 2018).

Figure 44 Marine biodiversity found in the waters around the Southern Islands. Photos by Marcus FC Ng and The Straits Times (2014).

Figure 43 Reef restoration projects carried out in the Southern Islands. (Top left) Reef Enhancement Units (REUs) with coral recruitment. (Bottom left) Coral fragments propagated in coral nurseries to be transplanted onto subtidal seawall. (Right) Singapore's largest reef structure being installed at the Sisters' Islands. Photos by Reef Ecology Lab and Ng (2019).

3.4.3 | Seagrass beds

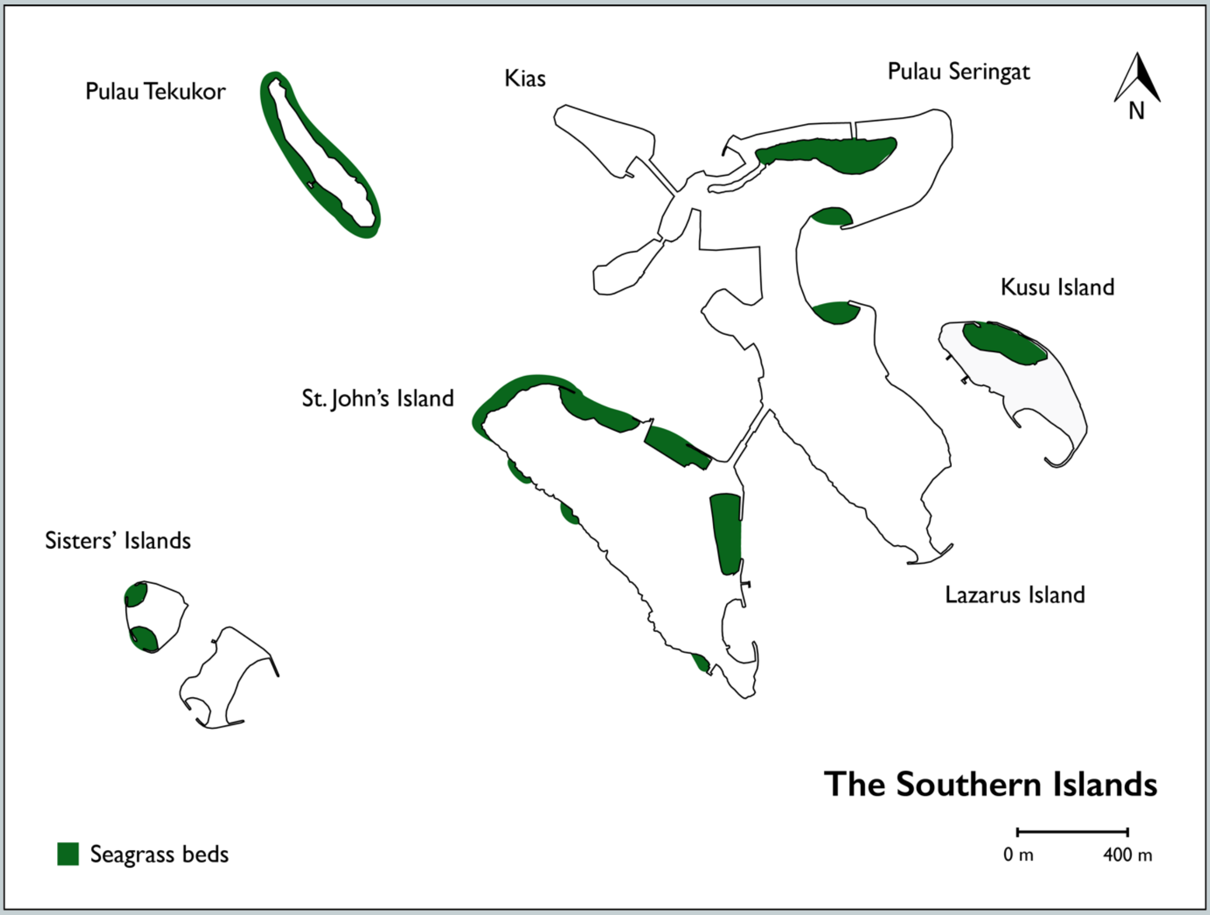


Figure 45 Distribution of seagrass beds in the Southern Islands (excluding Sentosa) (Lee unpublished data, Ow Y. X. pers. comms. 2019, WildSingapore).

Seagrass beds provide food and shelter for variety of marine organisms include marine snails, crabs, echinoderms, sea cucumbers and snapping shrimps (Tan et al. 2010). Juvenile fishes are also known to use seagrass beds as a nursery (Green and Short 2003, Nordlund et al. 2017).

Seagrasses are able to dominate a sizeable area and result in a seagrass meadow. While most of the seagrass populations found on the islands are beds (smaller and less dense compared to a meadow), notable beds at the southeastern part of SJI and southern part of the LAZ lagoon had relative high density and were diverse in seagrass species and faunal biodiversity (Ow Y. X. pers. comms. 2019). As such, there is relatively high conservation value particularly in these seagrass beds.

Biodiversity and significance. Seagrasses are marine flowering plants that grow submerged in shallow marine and estuarine environments and form meadows, which can be found in all continents except Antarctica (Hemminga & Duarte 2000, Green and Short 2003, Hogarth 2007). Seagrass beds can be found on all the Southern Islands, mostly in lagoons (**Figure 45**, **Figure 46**). There are 12 species of seagrass recorded in Singapore, seven of which have been observed in the SJI-C (Yaakub et al. 2013, Ow Y. X. pers. comms. 2019) (**Figure 47**). These seven species include the spoon seagrass (*Halophila ovalis*), *Halophila uninervis*, the ribbon seagrass (*Cymodocea rotundata*), *Cymodocea serrulata*, the noodle seagrass (*Syringodium isoetifolium*), the sickle seagrass (*Thalassia hemprichii*), the tape seagrass (*Enhalus acoroides*) (Noiraksar et al. 2012, Ow Y. X. pers. comms). Five seagrass species were found on SJI and LAZ (specifically at Bendera Bay and Eagle Bay), and two seagrass species have been reported for Pulau Tekukor (*H. ovalis* and *T. hemprichii*) and Kusu Island (*H. ovalis* and *E. acoroides*) (Yaakub et al. 2013). The seagrass biodiversity found ins Singapore are comparable to that found elsewhere in Southeast Asia, e.g. Cambodia, Malaysia, Thailand and Vietnam (Fortes et al. 2018).

Figure 46 Seagrass patch at SJI. Photo by Ria Tan.

Seagrass also forms one of the most productive ecosystems found globally, allowing them to sustain a considerable amount of biomass and diversity (Green and Short 2003). They also provide highly valuable ecosystem services, including nutrient cycling, sediment stabilisation, carbon sequestration and resources for communities as the key habitat in the life cycles of many marine species (Duarte 2002, Orth et al. 2006, Waycott et al. 2009, Fourqurean et al. 2012, Christianen et al. 2013). In addition, they hold vital ecological links, through nutrient exchange, to other estuarine and coastal ecosystems such as coral reefs and mangroves (Green and Short 2003, Hogarth 2007, Ooi et al. 2011, Nordlund et al. 2017). Furthermore, recent studies have also found that seagrass can play a role in mitigating ocean acidification (Ow et al. 2015, Ow et al. 2016).

Figure 47 (Left) Spoon seagrass (*Halophila ovalis)* found on the island. (Right) Flowering Tape seagrass (*Enhalus acoroides*) found on the island. Photos by Marcus FC Ng.

3.4.4 | Threats of the marine environment

The marine environment around Singapore's Southern Islands are increasingly exposed to multiple, concurrent stressors that further compromise the health and resilience of ecosystems. In addition to local-scale threats such as incessant coastal development, persistent high sedimentation and water turbidity as a result of coastal development, and discharges from shipping and industries, Singapore's marine environment face impacts from larger scale disturbances as a result of global climate change. For instance, during the El Niño phase of the

El Niño Southern Oscillation (ENSO) in 1988 and 2010, there was an anomalous spike in sea surface temperatures that resulted in mass coral bleaching on Singapore's reefs (Chou et al. 2012). In 1988, >90% of corals were bleached and up to 20% of corals in Singapore were unable to recover even after temperatures returned to normal levels (Dollar and Tribble 1993, Chou et al. 2012, De'ath et al. 2012, Guest et al. 2012). In the bleaching event in 2010, up to 10% mortality was documented (Guest et al. 2012). While there have been no similar records of the impacts of such warming events on seagrasses in Singapore, based on other studies, they are also expected to respond negatively with high temperatures causing reductions in productivity and growth (Collier et al. 2018).

A significant local threat that affects all marine habitats in Singapore is the high of sedimentation rates in our waters, which has exceeded the level that is ideal for tropical reefs (Rogers 1990, Todd et al. 2004, Dikou and van Woesik 2006, van Maren et al. 2014). The high levels of suspended sediment load in our waters are likely the product of the five decades of land reclamation and other coastal developments in Singapore (Chou 1988, Chou 1996, Rogers 1990, Todd et al. 2004, Chou 2006, Dikou and van Woesik 2006, van Maren et al. 2014). High levels of suspended sediments negatively affect the reproduction, recruitment, growth and survival of reef-building corals. High turbidity reduces the penetration of light required for photosynthesis by zooxanthellate corals, and have resulted in our local reefs being restricted to shallower water depths of less than ~8 m (Dikou and van Woesik 2006). The recovery rates of seagrasses from stresses are also influenced by turbid waters (Yaakub et al. 2014). Studies have found that long-term exposure to turbid waters can negatively impact the resilience of seagrass habitats and outweigh possible benefits gained from rising sea temperatures and ocean acidification (Ow et al. 2015, Ow et al. 2016). Leaf pigments in seagrasses have been found to be an indicator of light availability and salinity changes and can be used to monitor the habitats (Ali et al. 2018).

Seagrass habitats in Singapore are also threatened by excessive nutrient concentrations in the water column (de Jorge et al. 2002, Leoni et al. 2008, Ali et al. 2018). Ali et al. (2018) found that for *T. hemprichii* on SJI, leaf nutrient content, leaf morphology and epibiont biomass were greatly affected by increased nitrate and phosphorus concentrations. As there can be large variability in detected nutrient levels caused by localised hydrodynamics, monitoring of nutrients levels in the water column was also found to be an ineffective approach to determine impacts of localised nutrient enrichment (Ali et al. 2012). Instead, responses of the seagrass to monitor nutrient levels were needed (Ali et al. 2012).

In particularly for the habitat found on the western coast of SJI, disturbance caused by ship wakes generated by large ferries travelling along the Sisters' Fairway can have negative impacts on the reefs (Chou, Sam, Ng, Lee, Yeo pers. comms.).

Factors that threaten the health of ecologically significant habitats such as coral reefs and seagrass beds also threaten the persistence of biodiversity that depends on the occurrence of these habitats to survive. For example, should reef cover and health decline further, reef fish communities are also threatened by the loss of habitat areas (Low and Chou 1992, Bauman et al. 2017, Taira et al. 2017).

3.5 | Summary and conclusion

Before extensive reclamation and shoreline development, the Southern Islands' natural coastal environment consisted of coastal and mangrove vegetation with sections of cliffs, rocky headlands and beaches (Wong 1985, Tan et al. 2010). This is in stark contrast to what makes up Singapore's coastline today, which is dominated by artificial shoreline types (83%) and predominantly seawalls (63%) (Lai et al. 2015). (Lai et al. 2015). Most of the islands' natural terrestrial vegetation has been lost, and marine ecosystems affected by development works.

Yet, the variety of natural habitats found on the southern islands is immense. These habitats provide significant ecosystem services to the environment and to people. Furthermore, the persistence of each habitat affects adjacent habitats as well. These habitats ought to be conserved and protected. Effective management policies will be vital to ensure the continued health of these systems and retain what is left of our natural heritage and the softer landscapes of our coastlines (Turner and Yong 1999, Tan et al. 2010). Projects responding to the need of better understanding these habitats can already be observed, e.g. The Southern Islands Biodiversity Survey (SIBS) (Ng 2019).

Chapter 4

Our Cultural Heritage

Early documentation of China's expeditions to the South recorded the presence of Lazarus Island (LAZ) in Singapore, identified as '*Pi-pa-Hsu* (*yu*)', with 'Hsu' and 'Yu' meaning island and 'Pi-pa' likely a corruption of the local Malay name for the island, *Pelepah* (Mills 1979). Around the same time, in the 16th century, the name *Pulo Siquijan* began to appear in European maps such as in *Discripsao chorographica dos estreitos de Sincapura e Sabbam. ano*. 1604 (Chorographic Description of the Straits of Sincapura and Sabbam 1604 A.D). Singapore was spelt as *Sincapura* while St. John's Island (SJI) recorded as *Pulo Siquijan*. These indicate the importance of these two islands to navigators of the past.

Since then, the two islands have undergone many different changes, especially SJI, which was highly valued by the British. Other than the differences in evolution of functions, the islands also experienced numerous significant historical events and name-changes. This section aims to provide a deeper understanding of the origins of the island, the evolution of its key functions and notable stories collected from former islanders.

4.1 | Origins of the SJI-C

LAZ, Seringat Island and, to a lesser extent, SJI, were historically inhabited by Malays and *Orang Laut* ('sea people' whose lives heavily depended on the sea) originally from the Indonesian Riau Islands and Malaysia (Wurtzburg 1954). These Malays and *Orang Laut* were likely followers of the *Temenggong* (chief of security) of the Johor-Riau Empire who settled on the Singapore mainland in the 1800s (Wee 2001, Trocki 2007), though this cannot be verified.

In 1819, Stamford Raffles (on behalf of the British East India Company) decided to explore Singapore; this decision was likely influenced by early maps of the region and his failure to establish a port in the Carimon (Karimun) Islands of Indonesia as originally planned due to Dutch presence (Langdon and Guan 2010). On 28 January 1819, before landing on mainland Singapore's shores, Raffles and his fleet of eight ships anchored off the 'fine sandy beach' of SJI (Wurtzburg 1954). While no landing was made by the British, a group of island locals came on board to investigate, thus making SJI the first point of exploration.

4.1.1 | Toponymics of the island

As the two islands grew in importance, names for these two islands changed slightly based on their sizes or navigational orientation: for example, SJI was once referred to as *Pulau Sekijang Besar* (*besar* means big), *Pulau Sekijang Bendera*, St. John's No.1 and West St. John's. Similarly, LAZ once had the name *Pulau Sekijang Kechil* (*kechil* means small), *Pulau Sekijang Pelepah*, St. John's No. 2 and East St. John's (Reed 1864). Today, most former islanders still prefer to refer to the islands by their Malay names – *Sekijang Bendera* and *Sekijang Pelepah*.

Sekijang (alternatively spelt *sakijang*) is a combination of two Malay words, *seekor* ('one') and *kijang* ('deer'). Together, they form the word *sekijang* ('a deer'), possibly in reference to the mouse deer once commonly found on Singapore's main island, the Eurasian roe deer (*Capreolus capreolus*) brought over by the British, or the barking deer which is native to Singapore and found widely throughout Southeast Asia in the 1800s. Reported in *Berita Minggu* on 30 August 1981 (Minggu 1981), Encik Jaafar bin Hussein, the former *penghulu* (headman) of the islands related a story of two deer on the islands. Both initially inhabited one of the islands, but eventually split up so that each island had one deer, resulting with both islands carrying the name '*sekijang*'. However, there are no scientific records of deer on the island. Nonetheless, in 1906, there was a report of a Captain Stockley and Lieutenant Baring visiting St. John's Island to shoot two deer the British government had placed on the island 'some months ago' most probably for hunting purposes; the buck had become vicious and had to be culled (The Straits Times 1906). This was the only reference to deer on the island in the archives.

There is an alternative account regarding the origins of the name '*sekijang*' for the islands. The word could have also been derived from a type of fruit known as the *Irvingia malayana*, also known as the '*pauh kijang*' (the barking deer's mango) (NParks) or could refer to a 'climbing plant' or 'a deer's root' (Dewan Bahasa dan Pustaka dictionary). Most islanders, however, prefer to stand by the story of deer on the islands.

St. John's Island (*Pulau Sekijang Bendera*). St. John's Island was and is still known as *Pulau Sekijang Bendera* (*bendera* means 'flag'). The addition of the suffix '*bendera*' to the name was most likely due to the flags installed on the island when it was set aside as a quarantine station by the British in the 1800s. Between 1874 and 1973, St. John's Island was used as a Quarantine Station (see section 4.1.3.2) (**Figure 49**). In order to notify ships that there was a Quarantine Station in the vicinity, yellow or red flags - depending on the gravity of the situation - were flown from the station. According to former islanders, there were also flags on the water tanks built by the British to provide water to the island's new inhabitants. Similarly, before the island was called *Shèng Yue Hàn Dăo* (a direct translation of St. John's Island), the Chinese immigrants also called it *Kî-chiun-san* (*Qí Zhang Shan* in Mandarin) which means 'Flag Island'.

There are various accounts regarding how *Pulau Sekijang Bendera* eventually ended up with the name 'St. John's'. Wurtzburg (1945) and Savage and Yeoh (2013) referred to the colonial administrator John Crawfurd's notes which suggested that 'St. John' is actually a corruption of the word '*sekijang*' by the British. Crawfurd claims that when Raffles and his men arrived in Singapore in 1819 and anchored off St. John's Island, they asked the islanders for the island's name. They were told '*sekijang*', which they initially misheard as '*Sijang*', and then transcribed as 'St. John'.

Lazarus Island (*Pulau Sekijang Pelepah*). LAZ was known as *Pulau Sekijang Pelepah* ('*pelepah*' meaning 'palm frond' in Malay). Whilst the suffix '*pelepah*' could refer to the abundance of coconut trees found on the island; one former islander tells a different story. In his story, there were once two Indonesians, one of them named Ode La Kadim. Ode La Kadim was sitting under a tree when night fell, and the tide rose. At high tide, he observed many coconut leaves on the island falling and sinking into the sea and was subsequently inspired to name the island *Sekijang Pelepah*.

Later, *Pulau Sekijang Pelepah* gained the named Lazarus when an isolation hospital (*Lazarette*) was built on the eastern side of the island in the 1900s. While the quarantine station itself was on SJI, LAZ was where the more serious cases were located. In the old maps, there were indications of three cemeteries on the island. Two on the western side for the local inhabitants and one on the hill at the eastern side for immigrants who succumbed to their diseases. The former islanders of SJI and LAZ sometimes still refer to these islands by their Malay names.

4.2 | Key functions of SJI through the years

4.2.1 | Landmark for passing ships

Before the arrival of the British in 1819, only LAZ and Seringat Island had inhabitants. However, after the British arrived, SJI grew in importance, especially for the colonial newcomers. Due to SJI's strategic location along the Singapore Straits, Raffles also instructed Farquhar to select a reliable crew and supply them with canoes to inform passing ships about the new settlement, Singapore, as well as to install a signal flag mast.

4.2.2 | Quarantine station

After a severe cholera epidemic in 1873 that claimed the lives of 357 people, SJI was declared a quarantine centre in November 1874. This prompted Andrew Clarke, then the British Governor of Singapore, to approve a proposal made by Acting Master Attendant Henry Ellis to establish a lazarette on SJI (Makepeace et al. 1991, Lee 1978). The quarantine station was able to accommodate up to 6000 residents suspected of infection from smallpox, cholera, chicken pox, measles and other communicable diseases. The station's inhabitants hailed mainly from China and India, but there were also Muslim pilgrims returning from the Hajj in Mecca, as well as Japanese and Europeans steamship passengers (Nanyang Siang Pau 1928).

By 1935, the quarantine station at SJI had grown to become 'the largest quarantine station in the world' and was even compared to New York's Ellis Island and El Tor in Egypt. However, living conditions were poor due to deteriorating facilities, overcrowding and insufficient necessities. It was only after many protests and complaints from the Chinese Advisory Board in 1927 that further improvements to the quarantine station were made.

While SJI was the main quarantine station, the isolation hospital and cemetery for those who died from their diseases were set up on LAZ. The cemetery was initially planned for Kusu Island but the plan faced resistance by the Chinese community who deemed Kusu Island as an important pilgrimage site.

In addition to the dormitories, the quarantine complex consisted of a generator room, a post office, a storage warehouse as well as a disinfectant shed. Upon arrival, the newcomers were screened for diseases. They were then separated by gender to be sprayed with izal solution in the disinfection shed, before being led to their dormitories where >200 people would be squeezed within (The National Archives 1930). Their clothes would be sent to a laundry room near the top of the hill to be boiled. Social class played an important role in the ways in which the newcomers to Singapore were treated whilst at the Quarantine Station. While those from the first- and second-class cabins of incoming ships were subjected to quick checks, after which they were allowed to continue on to the mainland, and housed in better condition if they needed to be quarantined, others, especially those from the lower decks, had to stay for a few days or even up to a week or so (Teo 1983, Chiu 2003, Ng 2018). SJI remained a quarantine station even after Singapore gained independence (The Straits Times 1967, 1970). However, by the 1970s, due to the decline in mass migrations, preference in taking airplanes over ships into the region, improved hygiene conditions on ships and the advent of official health certification requirements from source countries (e.g China and India), the off-shore quarantine station was made redundant and subsequently closed on 14 January 1976.

4.2.3 | Political Detention Centre

Parts of the quarantine station were converted into a detention centre for political prisoners in 1948 (Morning Tribune 1948). In 1955, before Singapore gained independence, political detainees from the Malayan Communist Party and the Anti-British League were detained at St. John's Island. Some of the detainees who were detained there included well-known individuals such as Lim Chin Siong, Fong Swee Suan and Devan Nair, who later became Singapore's 3rd President in 1981. While the detainees were probably housed in the Quarantine Station dormitories, some of them were placed in other structures that were on the island then. For instance, one of our respondents reported that Devan Nair and a few others were detained in a building that once existed in the area near the entrance of the current St. John's Island National Marine Laboratory (SJINML).

4.2.4 | Opium Treatment Centre and other uses

From 1955 onwards, the Quarantine Station dormitories at SJI also functioned as an Opium Treatment Centre (OTC). At the OTC, residents were not only weaned off drugs, but also trained in various skills such as carpentry, tailoring and craft-making in order to prepare them to rejoin society as "productive and responsible citizens" upon their release (Nanyang Siang Pau 1953, The Straits Times 1954a, 1954b, 1955). Subsequently, the OTC expanded to take in addicts of other drugs as well and was thus renamed as the Drug Rehabilitation Centre (DRC). Ironically, many of the recovered addicts enjoyed the peaceful environment of the island and the friendly comrades so much so that they continued to use drugs. The OTC was closed in 1975 and the DRC was moved to the mainland, after which SJI and its environs became a place better known for recreation. Prior to this, however, during the second half of 1975, the centre acted as a temporary holding place for Vietnamese refugees fleeing war in their homeland (The Straits Times 1975).

4.2.5 | Holiday Camps

After the closure of the DRC, SJI was planned to become a recreational destination (together with LAZ and Seringat Island) to replace the lost beaches at Changi due to the expansion of Changi Airport (See Chapter 2 for more information). Sentosa Development Corporation (SDC) took over the administration and maintenance of the island and began the plans for holiday camp development though not all of them came to fruition. The only major construction done by SDC were the addition of some of the quarters for their staff.

4.2.6 | Japanese Occupation (Moongate)

SJI was not spared from World War II. During the start of the war, before the fall of Singapore in 1942, SJI was used as an internment centre for German, Russian, Italian and Japanese soldiers and civilians. While their actual quarters on the island was not explicitly recorded, it is possible that they were detained in the quarantine station's dormitories. One salient thing to note from this period was the establishment of the moongate (**Figure 48**).

The moongate consists of a circular archway, capped with a Chinese-inspired roof, a nicely designed foundation completed with small tiles depicting various images, such as fish, ship, doves, jellyfish and even a deer (which could possibly have paid homage to the name of the island '*sekijang*'). The origins of the moongate remains unknown. While newspaper accounts indicate that it was built by German prisoners during the Second World War, other accounts from our interviewees attributed it to their forefathers.

There was also a pagoda near this structure (**Figure 48**). While the pagoda is no longer there, the moongate is still in existence today, although it is not accessible to the public as it is located within a restricted area that falls under the jurisdiction of the Defence Science and Technology Agency (DSTA).

Photograph by Denise Chivers.

THE MOON GATE ON ST. JOHN'S ISLAND

(This was built by German civilian residents of pre-war Singapore who were interned on St. John's Island after the outbreak of war in 1939).

Figure 48 (Left) An image of the 'Moongate' taken in 1936 by Denise Chivers Photo by The Straits Times (1950). (Right) Pagoda located near the moongate structure. Photo by the National Archives of Singapore.

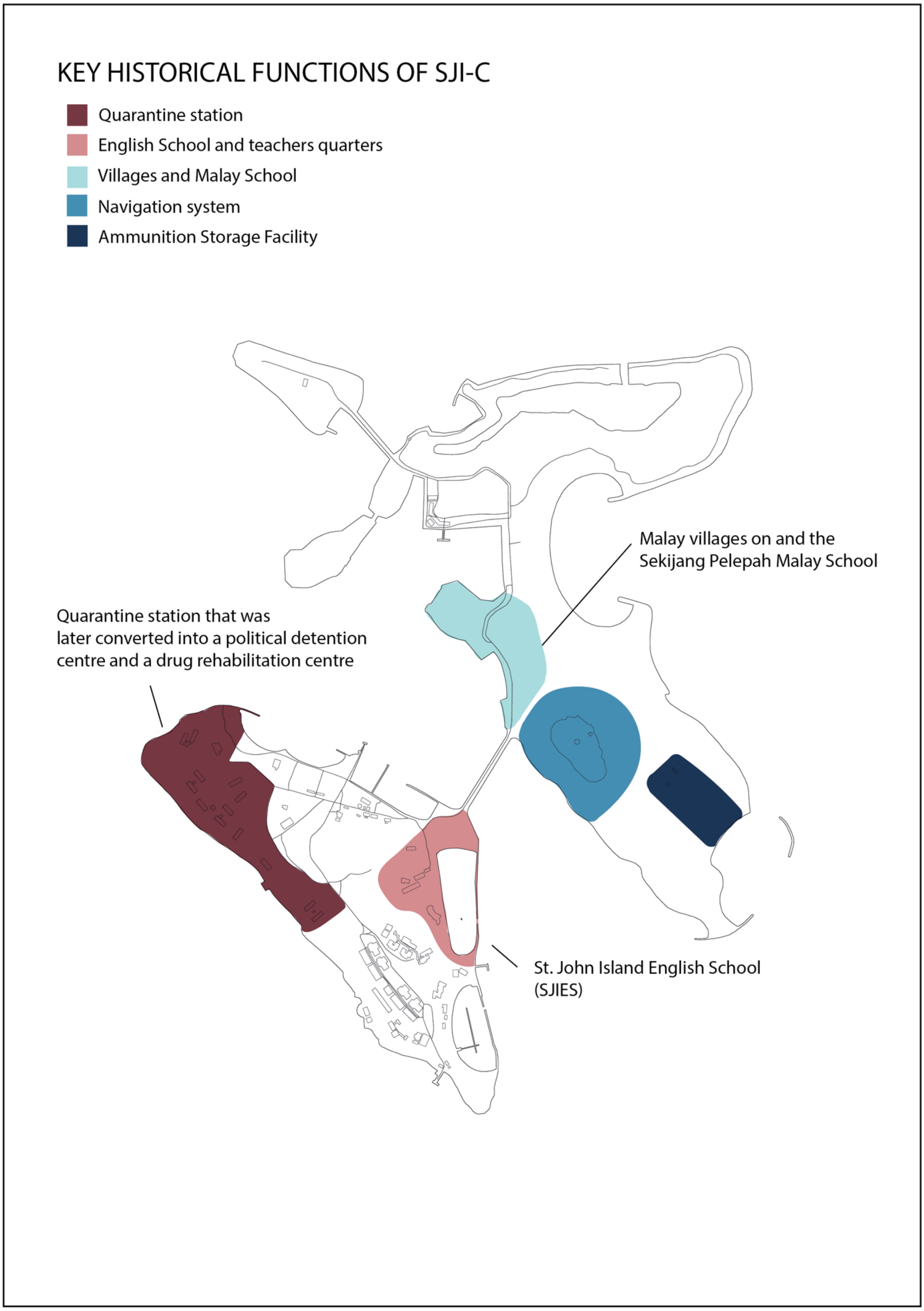


Figure 49 Map of the SJI-C showing areas of key historical functions.

4.3 | Key functions of Lazarus Island through the years

4.3.1 | A thriving village

As mentioned above, it was likely that LAZ was inhabited years before SJI was used by the British. The original inhabitants were mostly *Orang Laut* from Bugis or Java. These people eventually settled on the island and started to build stilt houses along the coastline. The village grew to about 44 houses and around 400 people by the 1960s.

According to former islanders, there were two villages on the island, one facing SJI, called Kampung *Cina* ('*cina*' means Chinese). It may be because a Chinese shopkeeper, Ah Soo, used to live there), and the other village faced the Straits of Singapore. Both villages were located on the northern tip of LAZ (original area). Other structures that used to be within the village on LAZ included a Malay cemetery, provision shops, at surau (small mosque), a community centre and a clinic (where the doctor came in only once a week). There were even public toilets that were built for the students and teachers of the Sekijang Pelepah Malay School. However, in the early 1970s, the villagers were made to dismantle their houses and relocate to the main island of Singapore as LAZ was set for development into a recreational island together with SJI and Seringat Island.

4.3.2 | Navigational Purposes

In 1961, a Visual Omni Range (VOR) was installed and on LAZ, coupled with a Master Attendants' Light. The VOR, restricted to the public, is the heart of Singapore's civil aviation navigational system, ensuring the safety of all aircraft coming into Singapore. The islanders of LAZ were once employed to operate and guard the facilities.

4.3.3 | Ammunition Storage Facility

Located on the southern tip of LAZ, where it is only accessible during low tide, there is a long forgotten former British ammunition dump which was later used by paint company ICI (Imperial Chemical Industries). Following independence, MINDEF reused it as an ammunition dump although this function was subsequently moved to Pulau Tekukor. Three out of these five structures are currently still intact, but the terrain was too treacherous to seek the other buildings (**Figure 50**). A fence surrounds these buildings and a water drainage pipe leads out into the sea. Before the former islanders were made to move to Singapore, some of them were employed as guards.

Figure 50 Structures from the ammunition dump, left forgotten. Photo by Asia Research Institute.

4.4 | Islanders way of life

Islanders on SJI and LAZ lived very differently despite being in close proximity. However, the islanders would cross over frequently for education or collection of supplies and other purposes. The majority of the population on SJI and LAZ were Malay, but their origins differed. For example, a number of Malay families on SJI moved there from mainland Singapore or Indonesia for work, whereas the majority of the Malays on LAZ were said to be descendants of the *Orang Laut* from Sambu, Bintan, and Batam islands.

Many SJI islanders eventually became employees of SDC. Staff quarters were built around the island. While some of these quarters were already demolished in the 1970s, some were still occupied until 2018 when asbestos was found on the islands. These buildings have since been barricaded and partially demolished.

Houses on LAZ were, on the other hand, built by the islanders themselves. They would creatively use materials from the island such as bamboo to build their stilt houses. Only two to three houses and the community centre were entirely built on land.

4.4.1 | Livelihood

Most of the residents on SJI were employed by the Maritime Port Authority or Ministry of Health as maintenance workers, cleaners, or groundskeepers, and their salaries ranged from only $1.50 to $4.00 per day. As the majority of working age residents on LAZ were fishermen, their incomes were dependent on their catch. The low salaries meant that they would sometimes run out of money before the month ends and would have to borrow money from each other. Islanders established a credit system with the provisions shops on both islands, where the shopkeepers allowed islanders to take the goods that they needed, trusting them to pay for it once they were able to.

The islanders of SJI and LAZ also sought other ways to supplement their incomes. For example, parents would send their children to Kusu Island, especially during the pilgrimage season, to beg for money or sell home-cooked food to pilgrims. The islanders would also sell souvenirs or offer *sampan* rides to LAZ and the Sister's Island for sightseeing at a small fee of ten to fifty cents.

Children from both islands would also make money by offering guided tours to Australian, American, and British tourists, showing them around the kampungs, selling them souvenirs such as necklaces and bracelets made of shells, or providing entertainment by diving into the water to collect coins thrown into the water by tourists. Young boys would sit by the jetty (**Figure 51**) and encourage tourists to "throw money" for which they would dive into the water to collect with their mouths.

Other sources of additional income came from the sale of food such as *nasi lemak* to the medical staff who worked on SJI. When electricity became more stable on SJI, families would use the island's power generator to make *air batu* (ice-lollies) and *ais kacang* flavoured with red bean and Milo, to sell to tourists and islanders on LAZ for five cents each.

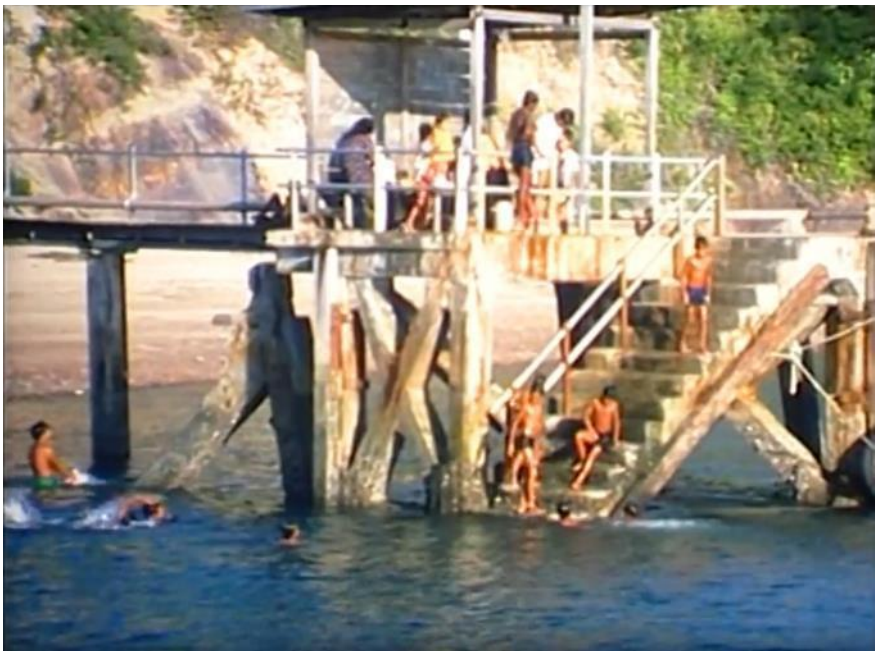


Figure 51 Photograph of boys jumping off the jetty taken by a tourist on island in 1975. Photo by Michael (2014).

4.4.2 | Education

There were two schools on the islands: St. John's Island English School (SJIES) on SJI that taught in English, and Sekolah Melayu Pulau Sekijang Pelepah (Sekijang Pelepah Malay School) on LAZ that used Malay as the medium of instruction. SJIES and the Malay school were built around 1946 when Mr. Wilton, the chairman of the Singapore Rural Board saw that it was dangerous for the islands' children to commute daily to Pulau Brani for school, especially when the currents were strong (The Straits Times 1946). Residents could choose which school their children attended. In order to get English education at SJIES, former islanders recalled having to take their own sampan to travel to SJI.

Those who attended SJIES described the institution as not being very big, with only one class per year group; each class comprising about 16 students. At one point, there were 122 students and 8 teachers (Berita Harian 1972). Teachers of SJIES either lived on the island in the Teacher's Quarters or would commute to the islands daily by ferry. The Teacher's Quarters are located at the top of the hill and was temporarily used as a dormitory for construction workers when asbestos was found on the island. Compared to SJIES, the cohort in the Malay-language school was even smaller. In 1972, just before the school closed, there were only 48 students. Teachers of the Malay school at LAZ lived on SJI in government-built quarters or commuted to the island. After finishing their primary schooling, students would attend secondary school on mainland Singapore by taking the ferry every day to Clifford Pier.

4.4.3 | Recreation

Swimming was a major part of island life. Depending on tidal conditions, male islanders would swim around their respective islands between the islands, with several individuals venturing as far as Pulau Jong. Their swimming abilities were renowned and well-demonstrated during inter-school competitions as they clinched many awards. Another favourite island pastime was football. Football matches against other island or mainland Singapore teams were held at the football field next to the jetty (Malaya Tribune 1947, The Straits Times 1970) (**Figure 52**).

Figure 52 Football field and mass toilets set up in 1998. Photo by Asia Research Institute.

Another sporting event the islanders regularly engaged in was 'Pesta 5S' (the 5S refers to the 5 islands that participated in the festival, all of which have names beginning with the letter 'S': *Sekijang Bendera/ Pelepah, Semakau, Sudong, Seking and Seraya*). The festival took place on Indonesia's National Day and islanders from the nearby Riau Islands, Indonesia, would also participate in the diving and snorkeling competitions or *kolek* (dinghy) and *jong* (small wooden sailboat) races (**Figure 53**).

Figure 53 Photograph of children playing with the *jong* at LAZ taken in 1971.

4.5 | Summary and conclusion

There is rich cultural heritage to be found on the SJI-C, from important historical key functions to stories of island life before Singapore became what it is today. The SJI-C's unique standpoint as a world unto its own, away from the mainland, creates a rare opportunity to experience the nation's history and heritage away from the hustle-bustle of our urban confines. To ensure the sustainable conservation of the islands' cultural heritage, the research team from the Department of Geography and Asia Research Institute, National University of Singapore proposed some recommendations.

The team suggested that a working committee be established, and for improvements to be carried out on amenities, facilities and activities on the island. The working committee should ideally consist of key island stakeholders who can regularly discuss strategies for the islands' development. These strategies should enable visitors to enjoy a more holistic island experience that incorporates both the islands' natural and cultural heritage. One component of these plans could include the rehabilitation and refurbishment of the islands' historical buildings for heritage and conservation education and outreach, providing both natural and historical information on the islands. Interpretive materials comprising local knowledge, history and folklore should be installed on salient structures, and walking trails created for guests to visit both historical and natural landmarks on clearly marked routes. These new attractions, once completed and shared with the general public on the mainland or on Sentosa, would help increase visitorship to the SJI-C and provide another meaningful layer to the islands' current attractions.

Another suggestion is to recreate traditional village houses on LAZ at the actual sites of villages past, complete with heritage information, traditional craft and fishing paraphernalia. The houses should be accurate representations of the lives of those who once lived on the islands; built on stilts, straddling both land and sea, and located on the beach near the LAZ jetty where the last village headman's house once was. Interpretive material and heritage information displayed at the site could illustrate the differences between the amenities and lives of those on LAZ and SJI before the islands were joined into a single entity. This heritage attraction should depict how people once lived, incorporating stories, photographs and collectibles from those who were actual residents of the islands. The ammunition dump on LAZ could also be restored and incorporated into historical guided tours that cover both these sites.

Chapter 5

Science, Research and Education

This chapter reviews marine science research facilities, notable research conducted and education activities on the SJI-C and surrounding area within the Southern Islands. This chapter also explores the concepts for marine research stations as vehicles for R&D, eco-innovation, science communication and environmental education.

5.1 | Research Facilities on SJI

SJI is currently home to two existing research facilities: 1) St. John's Island National Marine Laboratory (SJINML), a national facility for marine science research and education, and 2) Marine Aquaculture Centre (MAC), an offshore aquaculture R&D facility for the Singapore Food Agency (SFA) (See **Figure 3** for the location). SJINML began first as part of the Tropical Marine Science Institute, National University of Singapore (TMSI, NUS) – Singapore's first multi-disciplinary marine science institute set up in 1996 that supported strategic national needs. Coinciding needs for coastal facilities with direct access to clean, calm and deep coastal waters for both marine science (TMSI) and aquaculture (SFA) led to the co-location of these two research facilities on SJI (Taylor et al. 2017). Facilities construction began in 1998 and were completed by 2002–2003. Various parties (institutional and agencies) strongly supported the development of these offshore research facilities, including the Singapore Tourism Board's (STB; then Singapore Tourism and Promotion Board i.e. STPB) Southern Islands Development (Tan et al. 20120, Taylor et al. 2017). STB also saw an opportunity for public education in the Southern Islands through these facilities. The diverse coastal and marine ecosystems (See Chapter 3) found around SJI also presented much opportunity for environmental and biodiversity research and education.

5.1.1 | The St. John's Island National Marine Laboratory (SJINML)

Singapore has had a long history in marine biology research, with attempts at establishing an offshore marine research facility in Singapore that began in the 1950s (by the Zoology Department, University of Malaya in Singapore, for fish biology research) (Tan et al. 2012). It was not until 3 October 2002 that TMSI, NUS successfully established a facility on SJI that still stands today (**Figure 54**). This facility, now the St. John's Island National Marine Laboratory (SJINML) remains Singapore's first and only offshore marine science research facility established in recognition of the need for Singapore to better understand the waters that surrounds her limited land mass.

Figure 54 The St. John's Island National Marine Laboratory (SJINML), one of the three National Research Infrastructures (NRIs) and Singapore's only offshore marine laboratory. It was opened in 2002 and is located on the southern part of SJI. Photo by Rachel Oh.

Today, SJINML is a National Research Infrastructure (NRI), a scheme by the National Research Foundation (NRF) to develop important capabilities to drive collaborative, interdisciplinary R&D that support strategic national goals. Since its designation as NRI in 2016, SJINML (while still managed by NUS) is now a shared national facility open to all marine science researchers (local and international). As a NRI, the main goals of SJINML are to 1) enhance the quality of national marine science R&D, 2) conduct research of strategic significance relevant to national agencies, 3) catalyse collaborations that enhance strategic national and international research programmes, 4) increase high-impact research outputs in sustainability research, and 5) implement manpower training programs to support future needs in marine science.

Figure 55 Research facilities provided at SJINML. (Top row) Controlled environmental aquaria. (Bottom left) Outdoor "tanks". (Bottom right) Research vessel *Galaxea.* Photos by Rachel Oh and AsiaOne (2014).

Following major renovations recently completed in end-2019, SJINML now has the capacity to support and conduct a variety of multidisciplinary research, including climate change (controlled environment aquaria), microbial ecology (Biosafety Level 2 research aquaria and laboratories), sediment research (15 m current flume and sediment research laboratory), mariculture research (larval culture aquarium, indoor and outdoor "reef" tanks, sizeable aquaculture tanks), biogeochemistry (chemistry laboratories) and biodiversity research (bio-imaging facility and histology laboratory) (**Figure 55**).

5.1.2 | The Marine Aquaculture Centre (MAC)

The MAC was established in 2003 as part of SFA (then AVA) to build Singapore's expertise in aquaculture (specifically genetics, nutrition and health) (Tan et al. 2012, SFA website: https://www.sfa.gov.sg/) (**Figure 56**). The MAC is located at the southern part of the island, next to SJINML, and consists of 14 blocks over a footprint of about 1.8 ha. The area comprises purpose-built research facilities, incubation modules and other facilities including the seawater intake pump house that also supplies seawater to SJINML. Since the establishment of the MAC, important research in aquaculture and the marine sciences have been conducted

Figure 56 The Singapore Food Agency's Marine Aquaculture Centre (MAC) was established in 2003 to build Singapore's expertise in aquaculture (specifically genetics, nutrition and health). Photo by Rachel Oh.

at the island facility – including the successful breeding of the resilient and fast-growing St. John's sea bass (Chua et al. 2019, Teh et al. 2019). Brood stock for the St. John's sea bass is also currently housed at the MAC.

Research in tropical aquaculture at the MAC is conducted through partnerships and collaboration with academic institutions (e.g. NUS, Temasek Life Sciences Laboratory (TLL)) and industry. In addition to R&D, MAC also provides technical support to aquaculture farms in Singapore and promote the adoption of sustainable farming practices and technology. Furthermore, MAC also hosts learning journeys for schools, conducts practical sessions and mentor interns from polytechnics and universities.

Other projects by the MAC include improving the large-scale fry production technology (SFA: https://www.sfa.gov.sg/). The MAC had successfully transformed hatchery production from an extensive pond system (large footprint and vulnerable to weather changes) to an intensive indoor closed-loop production system (which allows for large scale production on smaller footprint and for more control of diseases and waste discharges). As such, this allows for a ten-fold improvement in the production of the Asian seabass and hatchery protocol developed for other key marine fish species: snapper, pompano and grouper. This production protocol has also been adopted by local hatcheries and nurseries.

See https://www.sfa.gov.sg/food-farming/aquaculture-services/marine-aquaculture-centre for more information on the MAC.

5.2 | Research at SJI-C

Over the years, SJINML and MAC have become more established and well-placed strategically in Southeast Asia to be focal points for marine science research and education, and aquaculture R&D (Tan et al. 2012). An extensive global network of academic and industry partners has been developed, and important research continues to be carried out at SJI-C (Tan et al. 2012). This section focuses on notable research and relevant research programmes conducted at SJI-C or facilitated by SJINML.

5.2.1 | Comprehensive Marine Biodiversity Survey (CMBS).

One of the landmark marine biodiversity research projects conducted in Singapore in recent years was the Comprehensive Marine Biodiversity Survey (CMBS) (Tan et al. 2015, Jaafar et al. 2018), the bulk of which was conducted at SJINML (formerly TMSI). The CMBS, led by the National Parks Board and the National University of Singapore from 2010–2015, was launched in response to recommendations put forth in the Singapore Blue Plan 2009, a proposal by civil society for the integrated and balanced conservation of Singapore's marine heritage (Hamid et al. 2009). The aim of CMBS was to conduct thorough biodiversity surveys and "stock-take" Singapore's coastal and marine areas, particularly poorly understood habitats in the north and south (Tan et al. 2015, Chou et al. 2019). The habitats that CMBS studied included intertidal mudflats, subtidal soft-bottom benthos and non-scleractinian components of coral reefs (Tan et al. 2015, Chou et al. 2019). There were reportedly more than 350 surveys conducted in the Johor and Singapore Straits (including areas around the SJI-C), at depths from 0 – 200 m (Jaafar et al. 2018). The CMBS was successfully executed by not only scientists (local and international), but also members from the government agencies, private corporations and the general public, this making it one of the largest marine science projects in Singapore to date (Chou et al. 2019).

From the CMBS, a total of 39 species new to science were described, 306 species new to Singapore was recorded, with two rediscoveries of species that have not been sighted in Singapore for over 50 years (Jaafar et al. 2018, Chou et al. 2019) (**Figure 57**). The biodiversity accounted for in this survey totalled more than 1,100 species. One of the notable findings include the discovery of deep-water populations hydroids, sponges, bivalves, crinoids and baskets found in Singapore's waters, that have not been observed in other parts of the region and form a unique and less seen part of our rich marine biodiversity (Jaafar et al. 2018) (**Figure 58**). Not only was the CMBS able to confirm Singapore's rich biodiversity and provide an understanding of the variety of unique marine habitats (not limited to coral reefs), but also showed that there is much more diversity in our local waters that have yet to be studied (Jaafar et al. 2018).

Figure 57 Photographs of scientists and volunteers collecting and processing biodiversity survey data as part of the Comprehensive Marine Biodiversity Survey. Top left photo by SJINML. Other photos by Marcus FC Ng.

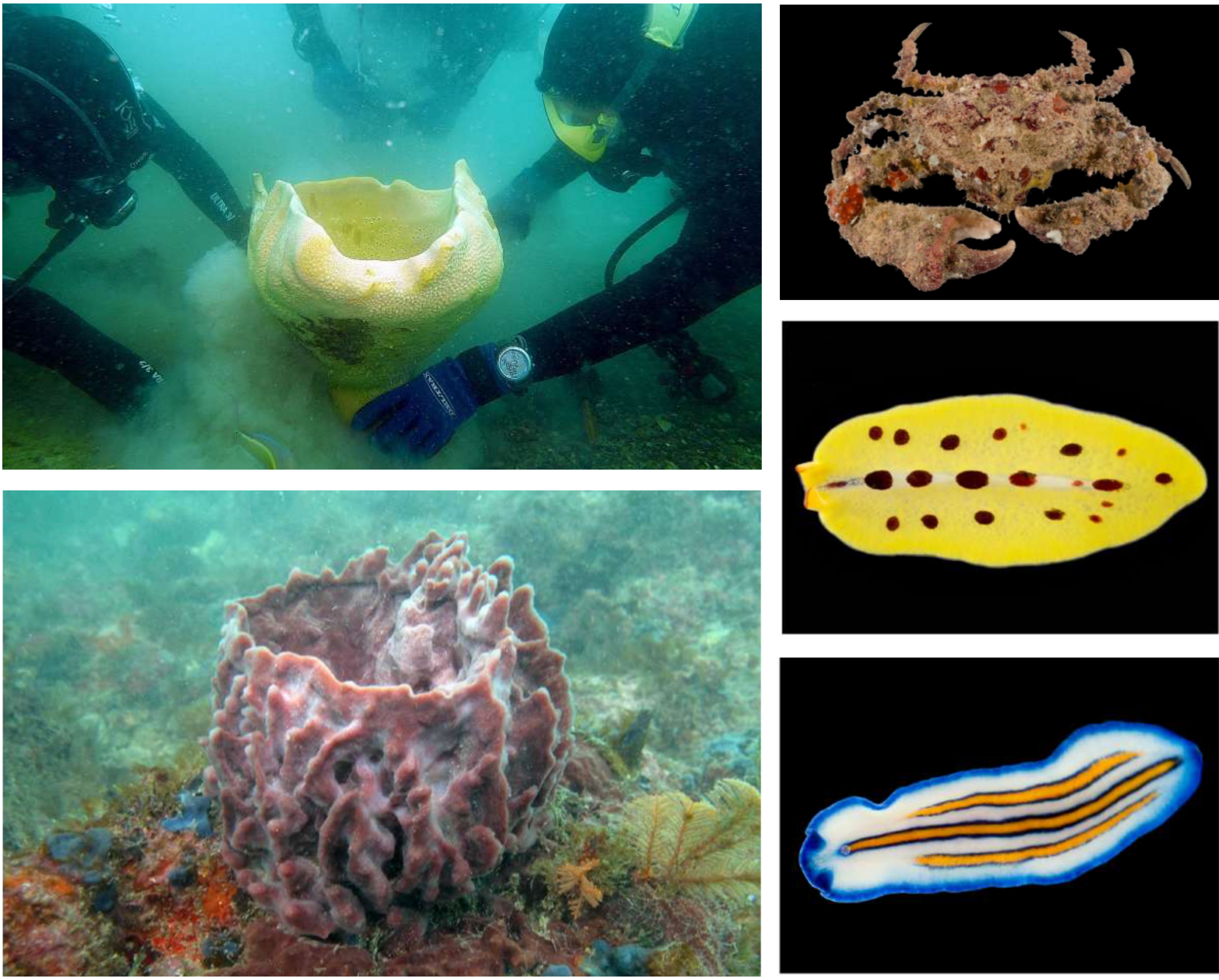


Figure 58 The Comprehensive Marine Biodiversity Survey resulted in two rediscoveries: (top left) Neptune's cup sponge (*Cliona patera*) (Photo obtained from Tan 2017) and (top right) Elbow crab (*Daldorfia horrida*) (Photo by NParks) after more than a century (Lim et al. 2012, Tan and Low 2013), as well as other discoveries (bottom left) *Xestospongia testudinaria* forms sponge gardens with high densities of associates including crinoids, hydroid *Monoserius pennarius*, protobranch bivalves, and basket star *Euryale aspera.* (Photo by Lim Swee Cheng) (middle right) *Pseudoceros* sp., a possible new species to science (Photo by Rene Ong). (Bottom right) *Eurylepta* sp., another possible new species to be described (Photo by Rene Ong).

5.2.2 | Mariculture Research

SJI is well-known as a site for the successful breeding of the St. John's seabass – commercialised by Allegro Aqua which supply the fry and fingerlings to farms in Singapore and around the region (Chua 2019). In addition, other successful mariculture research has also been conducted at SJI and SJINML. For example, giant clam mariculture feature prominently in SJINML's history. What started in 1998 when fifteen *Tridacna squamosa* broodstock were imported from Riau Indonesia, flourished into active research on the biology and behaviour of giant clams that put Singapore on the map as one of the leading experts in giant clam biology, conservation and mariculture (Neo and Todd 2012). The giant clam mariculture research was able to provide foundational understandings to produce large numbers of juvenile clams that were fit for restocking local reefs where natural recruitment was absent (Guest et al. 2008, Neo and Todd 2012) (**Figure 59**). In 2011, successful mariculture of giant clams at the SJINML aquarium facilities led to a project funded by NParks aimed at re-introducing this endangered species to Singapore's reefs (Neo and Todd 2012).

Figure 59 (Top left) Collected broodstock from selected reefs in Singapore. (Bottom left) Intertidal fieldwork. (Right) Holding area where clams rested on the secured fiberglass gratings. Photo by Giant Clam Research Team.

5.2.3 | Reef Enhancement and Restoration

There were two major research projects involving reef restoration efforts in the Southern Islands. The first was a project initiated by STB and NUS, and utilised artificial reefs structures known as Reef Enhancement Units (REUs) to promote reef rehabilitation. More than 100 REUs were deployed at seven reefs around SJI, LAZ, Sisters' Islands, Pulau Satumu (Raffles Lighthouse) and Kusu Island between 2001 and 2004 (Loh et al. 2006, Ng et al. 2016) (**Figure 60**). These units were customised to suit Singapore's reef environment. By providing suitable substratum, coral recruitment onto the REUs occurred within 6 months of deployment, at rates higher compared to those found on the natural reef. This was likely due to the REU design that reduced sediment accumulation, which would have impeded settlement (Loh et al. 2006). Following a decade of deployment, the marine communities found on these REUs matured with significant coral growth with some sexually matured colonies) and an increase in reef fauna diversity (Ng et al. 2017). A diverse fish community, sessile animals and mobile organisms were observed to interact with the REUs, indicating assimilation of the units into the reef environment (Ng et al. 2017) (**Figure 60**). Given Singapore's highly sedimented waters, where loose rubble dominates reef substrates (Chou 2006, Tun 2012), enhancing biodiversity using artificial substrates present a viable management strategy to increase the ecological value of the reefs around the SJI-C and the rest of the Southern Islands (Chou 2011, Ng et al. 2016, Ng et al. 2017).

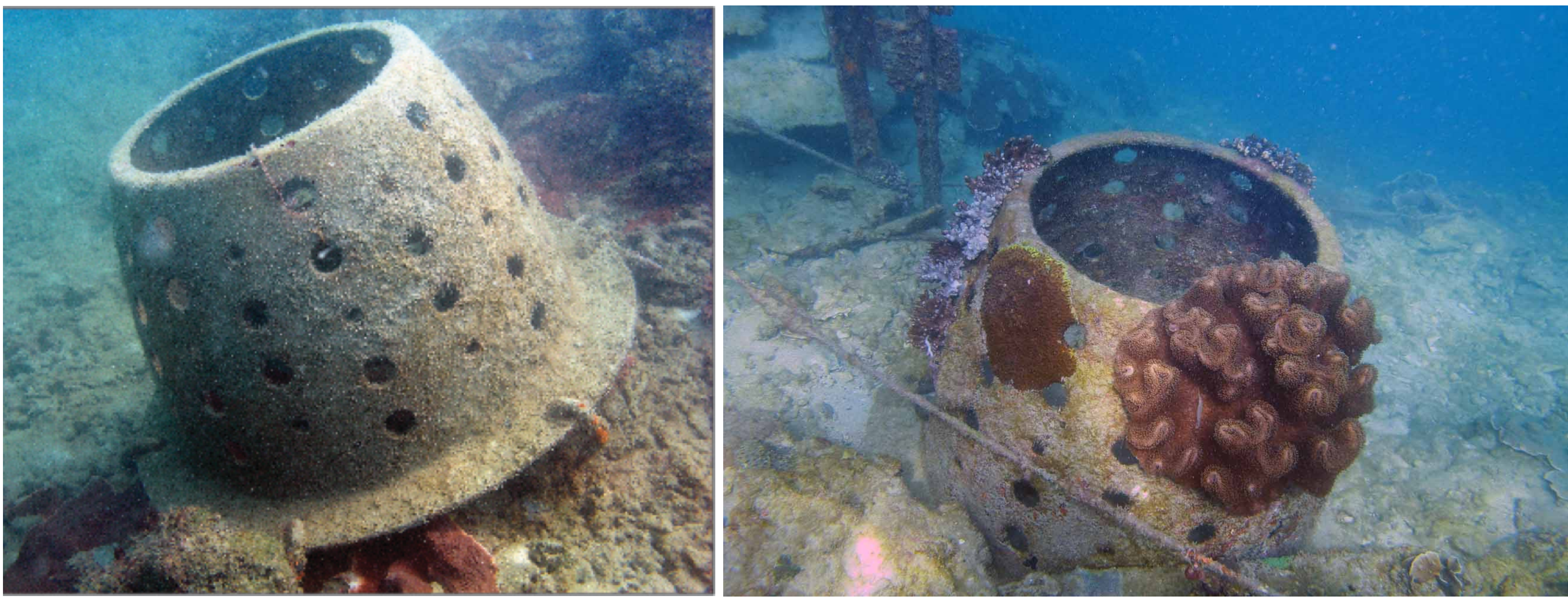


Figure 60 Reef Enhancement Units (REUs) were deployed to promote reef rehabilitation. (Left) REU when first deployed in 2002 and (Right) REU after sixteen years in 2018. Photo by Reef Ecology Lab.

The second key reef enhancement project involved transplanting corals transplants to initiate colonisation in degraded and non-reef areas (e.g. seawalls) by TMSI and the Marine Port Authority of Singapore (MPA) (**Figure 61**). Corals were translocated from to-be-reclaimed Sultan Shoal reefs and were reared in *in-situ* coral nurseries established around LAZ prior to transplantation. During the 4-year project that began in 2014, a total of 1251 fragments from 22 genera were translocated to the *in-situ* nurseries and approximately 900 fragments were eventually transplanted to LAZ and Kusu Island with an overall survival rate of over 80%. Through this project, a total area of 422 m^2 of reef was restored, comprising 272 m^2 of new reef created at LAZ and 150 m^2 from the degraded reef in Kusu Island (Chou et al. 2017). The coral nurseries established around LAZ were also found to host a variety of reef-associated biodiversity such as pufferfish, cuttlefish and juvenile butterflyfish for shelter and food (Taira et al. 2017).

Figure 61 (Top left) Coral fragments propagated in coral nurseries. (Top right) Coral transplants on granite boulders of the subtidal seawall. (Bottom left) *Podobacia* transplants after three years. (Bottom right) *Platygyra* transplants after three years. Photo by Reef Ecology Lab.

5.2.4 | Alien invasive species and fouling

With the seawater pump and aquaria system, Tan et al. (2012) noted successful attempts at culturing 'a myriad of marine plants and animals, from microalgae, seagrass to sponges, corals, giant clams and seahorse' that has been beneficial to the variety of research projects that were conducted at the laboratory. The aquaria system also provided the opportunity for scientists to conduct microcosm experiments, which would otherwise be challenging to achieve on mainland Singapore (Tan et al. 2012). Some key projects included examining the process of marine biofouling, which is of great interest to the maritime and shipping industry in Singapore, and worldwide (Tan et al. 2012). The project also gathered much support because of its relevance to cutting down the high costs to keep ship hulls clean and prevent the transfer of invasive species (Tan et al. 2012). Research conducted in collaboration with the United States Office of Naval Research have also resulted in SJINML being established as the world's leading laboratory for the research of marine fouling in tropical waters (Tan et al. 2012).

5.2.5 | Marine Science Research and Development Programme (MSRDP)

The Marine Science Research and Development Programme (MSRDP) was launched in 2016 by the National Research Foundation (NRF) and its primarily role is to 'integrate R&D in tropical marine science and promote active engagement of industry in the drive towards environmental and marine sustainability' (NRF: https://www.nrf.gov.sg/). The aims of MSRDP are to further marine science research in Singapore by utilising the rich marine biodiversity found in our local waters, developing research and innovation relevant to national goals, and build capabilities that can cater to the strategic needs of Singapore in the future. NRF invested S$25 million over five years in 2016 to projects that contribute to deepen our understanding of Singapore's marine systems (see list of projects funded at http://www.msrdp.sg/) The formation of SJINML as an NRF NRI was in parallel to MSRDP, and supports the MSRDP goals. See https://www.nrf.gov.sg/programmes/marine-science-r-d-programme/ for more information on the MSRDP.

5.2.6 | Marine Tidal Energy

Behera et al. (2012) conducted a study to explore the possibility for utilising the vortices and high current streams as well as tidal flow observed in the Singapore Strait as possible sources of clean renewable energy. The study used advanced numerical modelling of the hydrodynamics in the Singapore Strait to identify potential areas for placements of various types of technologies to harvest tidal energy. Their assessment of the tidal energy potential in the Singapore Strait suggested the conceptual possibility of locating tidal energy devices near St John's Island (**Figure 62**).

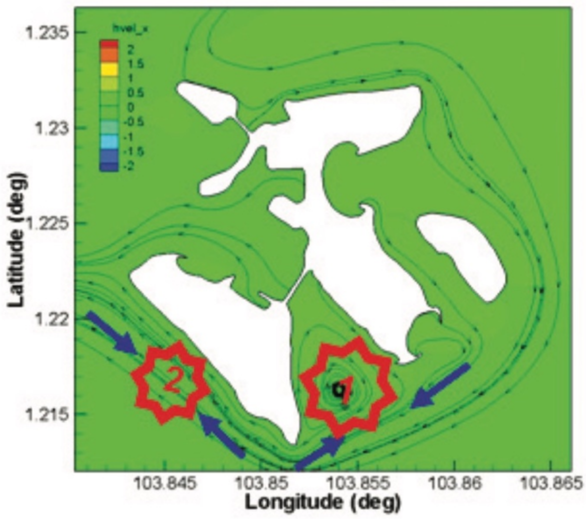


Figure 62 Possible locations (as indicated by numerals 1 and 2 enclosed in star outline) for installation of tidal energy devices between St John's Island and Lazarus Island, and off the southern coast of St John's Island (from Behera et al. 2012).

5.2.7 | Marine Environment Sensing Network (MESN).

The Marine Environment Sensing Network (MESN) is a proposal to establish three next-generation buoys for water quality monitoring and research, one of which is to be deployed in the waters around SJI. The MESN will provide platforms for 1) test-bedding of marine technologies and new sensing capabilities for research and development, 2) monitoring of baselines and key marine biogeochemistry and pollutants, and 3) data collection and data sharing to facilitate marine and climate science research and allow researchers and government managers to have greater freedom to actively contribute to and leverage on international environment networks. The need for MESN was first raised at the SJINML stakeholders' meeting in November 2018, and strongly supported by stakeholders (e.g. researchers, educators, industry) at the NRF MSRDP mid-term symposium in February 2019 and the December 2019 SJINML stakeholders' meeting. MESN is proposed to be developed through SJINML as part of the NRI, which would allow marine scientists and other stakeholders to access critical environment data required for the monitoring of Singapore's marine environment and research in climate and other long-term environmental changes.

5.2.8 | Natural Capital Singapore

National Capital Singapore (NCS) is a 3-year project "to assess the current status and health of Singapore's major ecosystems and quantify their economic and societal value" that began in 2018 (Natural Capital Singapore website: http://www.naturalcapital.sg/). The project was initiated in recognition of the importance of the natural environment in ensuring Singapore's economic pursuits and liveability, and the importance of fundamental information about natural habitats to assist in planning projects. This project serves to be the first assessment of Singapore's natural capital on a national scale and of a tropical, heavily urbanised country. It will also forecast potential changes in the capital and identify areas of trade-offs and synergies with Singapore's urban development in the future. NCS is developing a national carbon layer for Singapore, which includes carbon accounting of the marine ecosystems in the Southern Islands (including seagrass beds and tidal mudflats in the SJI-C) (Friess D. pers. comm. 2019). NCS also compiled published literature on Singapore's coastal and marine habitats available in online databases, which was used as a further indicator of scientific value of these habitats. Their study revealed SJI to be the fourth-most studied site in Singapore for coastal and marine research, and this was attributed in part to the presence of a marine station on SJI (Friess et al., In Review; Friess and Yando, pers. comm. 2019).

5.2.9 | Southern Islands Biodiversity Survey.

The Southern Islands Biodiversity Survey (SIBS) is a two-year-long project conducted by the National Parks Board (NParks) that began in October 2019 to survey the terrestrial (flora and fauna) and marine (intertidal and benthic) habitats of Singapore's Southern Islands (Ng 2019). This includes collating past literature and data from previous research such as the CMBS, as well as field surveys to fill the gaps in existing knowledge of the biodiversity in those areas (Ng 2019). Academics from fields such as biology, geology, and the social sciences are being involved in addition to NParks staff and volunteers (Tan J. pers. comms. 2019).

5.2.10 | Food sustainability for "30 by 30" target

Finance Minister Heng Swee Keat cited the St. John's sea bass produced by the MAC in his 2019 Budget Speech as an example of how the agriculture and food production sector was transforming (Chua 2019). In line with Singapore's "30 by 30" goal, a S$1 billion grant was allocated to help companies achieve high levels of local food production and be more competitive (Chua 2019). Research into development strategies to produce more competitive and sustainable local food choices, including those from aquaculture, contributes towards ensuring food security serves to be one of the national goals and is of high national importance.

5.2.11 | Potential knowledge gaps

Field stations such as SJINML are critical for addressing knowledge gaps pertaining not only to marine biodiversity and natural habitats, but are important for predicting future environmental trends, revealing historical environmental trends, developing long-term automated sensing, enhancing genomic understandings, conducting experiments as infrastructure, practicing science for sustainability and test bedding eco-innovation (Billick et al. 2013). In particular, field stations are crucial for climate change related research necessary to tackling the effects of climate change, such as sea level rise, the loss of blue carbon and ocean acidification. One such study conducted by Teh et al. (2010) examined the vulnerability of LAZ against rising sea levels when plans were proposed for it to be developed into a research. More of such studies are necessary for the future planning of Singapore's coastal landscape.

The Singapore Blue Plan 2018 also identified the need to establish formal planning regimes as part of the integrated urban coastal management framework (Jaafar et al. 2018). This was recommended especially so for ecologically sensitive areas. To do so, research exploring methods in management plans for the sustainable use of the marine environment and exploring assessments of natural habitats relevant to spatial planning and development should be conducted. These areas thus present potential knowledge gaps and research opportunities for SJINML.

Another knowledge gap would be in furthering understanding and exploration into aquaculture and mariculture. Given the facilities and aquarium available at the SJINML, research into aquaculture and mariculture are opportunities to fully utilise these resources. These studies can look into expanding the range of organisms cultured (aside from the giant clam), and also into the possibilities of food safe and sustainable options to contribute to Singapore's "30 by 30" goal.

5.3 | The SJI-C Education Landscape

5.3.1 | Scientific education and training

One of the main goals of SJINML as a NRI is to implement training programmes to support future needs in marine science. For this purpose, SJINML aims to develop an education programme that provide avenues for regular structured training in marine sciences targeted not only at students, educators and researchers but also professionals and industry partners. In the long term, the objective of the education programme is to raise the overall technical expertise both locally and regionally, in order to position SJINML as a focal point for marine science education in tropical Southeast Asia.

Conventional teaching material in marine science that are readily available were prepared based on temperate habitats and marine ecosystems that are less diverse or complex than the context presented in tropical Southeast Asia. As such, the SJINML education programme aims to employ open classroom field-based approaches to position training curricula based on local and regional context, in order to equip participants with relevant skill sets to address the respective challenges. A suite of education programmes will be developed specific to the needs and level of participants. In general, the training workshops will be broadly categorised into (1) introductory courses for general marine science education, (2) partnerships with Institutes of Higher Learning (IHLs) for field-based curriculum, (3) skills training for researchers, (4) professional workshops for environment managers and (5) international workshops for specialist training. Some examples of the workshops are:

- Introduction to Marine Biology (to be announced) - for general marine science education
- NUS Special Programme for Science Overnight Programme at SJINML (2019) - partnership with IHLs for field-based curriculum

- Seawater Quality Workshop (to be announced) - skills training for researchers
- Environmental Impact Assessment workshop (to be announced) - for environment managers
- SJINML-NMMBA Cnidarian Culture Workshop (July 2017) - international workshop for specialist training

Seminars. Networking between marine scientists and sharing of research projects has also been promoted at SJINML. Visiting researchers are encouraged to present their work in a seminar session hosted at SJINML. Two examples of the seminars conducted at SJINML in 2019 included: "Paradise Trashed: Sources and solutions to marine litter pollution in French Polynesia" by Scott Wilson from Macquarie University, and "Fate and Toxicology of Micro- and Nanoplastics in Real-World Scenarios" by Ana Isabel Caterino from Heriot-Watt University.

MSRDP EXPLORE programme. The SJINML provides internships to recipients under the EXPLORE programme to promote more scientific education as part of the Marine Science Research and Development Programme (MSRDP) by the National Research Foundation (NRF). Under this program, students have the opportunity to work directly with scientists at the SJINML and receive mentorship throughout their course of work. Education institutes partnered for the internships include students from various academic institutes from polytechnics, universities and research intuitions. In June 2019, SJINML (supported by the Lee Kong Chian Natural History Museum and The Singapore Institute of Biology) organised the Young Marine Scientist Symposium (YMSS) under the auspices of MSRDP EXPLORE programme (see http://sjinml.nus.edu.sg/young-marine-scientist-symposium/). The symposium served as a platform for students to share their research findings and aspirations for the marine environment. YMSS was attended by 136 participants the first marine science student symposium open to students from all institutions across Singapore.

5.3.2 | Educational engagement and outreach

Outreach programmes by SJINML. SJINML plays an active role in providing quality and research-based environmental outreach programmes to children of all ages and the general public. These programmes expose participants to the importance of marine science research in Singapore, the possibilities of marine exploration, and the currency of research conducted at the laboratory (Tan et al. 2012, Su, Seah pers. comms. 2019). Some participants also enjoyed the opportunity to join overnight camps at the institute to learn more about marine science (Tan et al. 2012).

From 2016 to 2020, the outreach and education team at SJINML also offered complimentary guided walks and workshops to the public as part of the Marine Conservation Programme in partnership with the Lee Kong Chian Natural History Museum, funded by the Jubilee Whale Fund. The guided walks typically provided lessons on the history of the island, natural heritage and cultural heritage found on the island, and the importance of marine conservation in Singapore. Along the walk, natural biodiversity and ecosystems were pointed out to the participants, providing a more engaging learning experience. These walks also provide the participants with an opportunity to visit the MPOEC at SJINML. At the workshops, marine conservation concepts aligning with those brought up during the walks were reiterated and the significance of the research conducted at SJINML were shared.

Self-guided walks with signboards by National Parks Board (NParks). NParks have installed signboards containing information about the history, terrestrial biodiversity, marine biodiversity and research landscape of SJI. Heritage trees were also marked out for visitors to view. The guide is available online at www.nparks.gov.sg.

Sisters' Islands Marine Park (SIMP) Marine Park Outreach and Education Centre (MPOEC). The SIMP MPOEC was opened in July 2015 and plays a role in raising awareness of Singapore's first and only marine park and the biodiversity in Singapore's waters (NParks 2019). A 3D diorama of dive trails and environmental specimens can be found in the centre to enhance the visitor experience (NParks 2019). To facilitate outreach activities, a seminar room and a teaching lab are also available for booking (NParks 2019).

Environmental education by the Friends of Marine Park (FMP) at Bendera Bay. The Bendera Bay refers to a lagoon on the southeastern side of SJI managed by a community stakeholder group known as the Friends of Marine Park under the National Parks Board (NParks) (**Figure 63**, **Figure 64**). This lagoon was named after the traditional name of SJI and houses a variety of habitats such as an extensive seagrass beds, coral communities, rocky shores, and mangroves. As this lagoon is currently still closed to the public, the environment education programmes planned at this lagoon have not commenced. The education work conducted at this lagoon will primarily aim to increase environmental awareness and encourage environmental stewardship amongst participants. More information on the perspectives of the community stakeholder group can be found in Chapter 6.

Figure 63 Bendera Bay located on the southeastern side of SJI is managed by community stakeholder Friends of Marine Park (FMP). The lagoon was named after the traditional name of SJI and will be used for environmental education and outreach in the future. The lagoon is home to a number of natural habitats, which include an extensive seagrass bed, coral communities, rocky shores and mangroves.

Figure 64 Natural habitats and biodiversity found at Bendera Bay. Photos by the Friends of Marine Park (FMP).

Kayaking tours by Kayakasia. Kayaking tours by Kayakasia offer a unique way to experience the island. The tour allows participants to kayak from Sentosa Island to SJI, providing the opportunity to see the other Southern Islands such as Pulau Tekukor and the Sisters' Islands on the way (Sam S. Q. pers. comms. 2019). On SJI, participants will be introduced to the history of the island, the biodiversity and the research and conservation efforts of the island (Sam S. Q. pers. comms. 2019). More information can be found online at www.kayakasia.org/Destinations/st-johns.

Heritage tours by Sentosa Development Corporation (SDC). In 2019, Sentosa Development Corporation (SDC) offered free heritage tours as part of Singapore's

Bicentennial (Tay 2019). These tours were aimed at providing an insight into the history of the Singapore Straits and the Southern Islands (Tay 2019). The guided tour begins at the Fort Siloso Skywalk in Sentosa Island where participants can experience a panoramic view, before boarding a boat to SJI for an exploration of the islands' history. Participants also have a stopover at Kusu Island to explore its cultural heritage. More information can be found online at www.sentosa.com.sg/en/things-to-do/events/singapore-bicentennial.

5.4 | Summary and Conclusion

It is evident that significant research and education has been conducted at the SJI-C, for which SJINML and MAC have played key roles. Marine laboratories have been the major drivers for fundamental research in environment and ocean science, and the presence of SJINML and MAC as offshore marine research facilities provides unique opportunities for research. They support access to research sites and resources (e.g. good supply of clean seawater) otherwise unattainable on mainland Singapore, and other essential services for marine scientists (e.g. aquarium and laboratory facilities within easy reach to study sites). As *de facto* education centres, marine field stations also provide unique opportunities for students (post-graduates, undergraduates, pre-university, polytechnic) to receive practical scientific training. Located in public spaces, these entities are also at the front line for communicating science to the general public, building industry linkages and facilitating integration of science into decision-making and realising policy. Coupled with the diversity of natural spaces present on the island (see Chapter 3), it is no surprise that SJI is a growing centre for marine science research and environmental education.

In the coming decades, Singapore will face a range of environmental and societal challenges including climate change and growing population needs. Science, research and education will be instrumental to our ability to navigate through environmental instability and resource vulnerability (Creed et al. 2018, Jaafar et al. 2018). Research brings about understanding of environmental risks and vulnerabilities, and education informs the changes in societal habits and paradigm shifts needed to effect long lasting changes. Science, research and education also form the basis for innovation that will help grow local enterprises, create good jobs and stimulate the economy. As Singapore aims towards greater resource resilience and a knowledge-based economy, marine science R&D and aquaculture are expected to play larger roles in the near future. Offshore research facilities such as the SJINML and the MAC provide strong on-the-ground presence and can be critical 'watchtowers' of the marine environment as well as active test-bed sites for eco-innovative solutions (Rockström et al. 2009, Billick et al. 2013). By stimulating demand for innovation through driving research and increasing awareness, and by helping translate the latest science into locally relevant action, marine research facilities such as SJINML can help empower Singapore to address climate change, sustainability and urban coastal living challenges for the long term.

Marine Stations: The Global Context

Summarised recommendations from the National Association of Marine Laboratories and Organization of Biological Field Stations (Billick et al. 2013).

There is a growing interest amongst not only scientists, but also local governments and international organisations to view marine stations as vital tools towards "a better understanding of coastal and ocean dynamics, revealing regional characteristics, and vulnerabilities". Given their proximity to the field and the resources and scientific expertise it houses, field stations are exceptionally effective in anticipating the occurrence of extreme weather changes and oceanic events, and in guiding action to 'natural events and potential climate change influences with minimal damage and cost. There is great potential of marine stations as centres of research and innovation.

To gain an understanding of the future possibilities for science and research for marine stations, a survey and a workshop with scientists and field station specialists were conducted in 2011 by the steering committee of the National Association of Marine Laboratories and Organization of Biological Field Stations.

Research. Key trends identified were the need for more collaborative research and for more climate-related studies. Increased collaboration beyond institutional boundaries through regional or international networks can enhance stewardship. It has also been found that sharing resources can greatly increase efficiency and could reduce or remove the need to invest in separate infrastructure, e.g. aquatic mesocosm infrastructure. Marine stations with monitoring capabilities to be "watchtowers for many of the planetary boundaries" and are well-positioned to conduct climate-related studies and environmental tipping points. Scientists can leverage of long-term datasets collected at/by field marine stations to develop and validate models, clarifying mechanisms through experimental investigations. Marine stations also serve as important test-bed sites for innovative climate solutions.

Education. Education provided at marine stations that caters to all (i.e. young scientists, students, citizens) is an unique opportunity. For young scientists in universities, exposure to field research can enhance education and inspire students more than typical university courses can. With residential facilities and mentorship by scientists based at the field station, students can immerse themselves in scientific learning that extends beyond the classroom. Such opportunities can increase both the student's understanding of scientific processes and the recruitment of students into science careers. The reach of field stations is wide and far-reaching as well – for example, the Organization for Tropical Studies, a consortium of universities and research institutions founded in the early 1960s, had enrolled more than 8,000 students of various levels in its courses at their three field stations based in Costa Rica. Field stations also have an important role to play in increasing environmental literacy and to provide opportunities for the public to directly engage with the field scientists, so as for the general public and decision makers to engage meaningfully with environmental issues of today.

Chapter 6

Stakeholders' perspectives

Stakeholder participation is fundamental for a successful integrated coastal management plan, especially when multiple sectoral needs are present (Cicin-Sain and Belfiore 2005, Chaniotis and Stead 2007, Gopnik et al. 2012, Hastings and Potts 2013, Potts et al. 2016, Creed et al. 2018, Buchan and Yates 2019). Involving stakeholders in the planning process has been shown to result in a deeper understanding of the social context of a plan (Yates and Schoeman 2012), better environmental decisions (Steele 2001, Reed 2008), greater compliance with proposed management plans (Innes 1996), early detection of conflicts in needs (Steele 2001, Pomeroy and Douvere 2008) and reduced cost of planning (Yates and Schoeman 2015). There have been numerous examples of successful stakeholder engagement in coastal and marine-related planning projects both locally and internationally. It has been used effectively in developing zoning plans for the Great Barrier Reef, Australia (Great Barrier Reef Marine Park Authority 2003); for devising climate and associated coastal change mitigation strategies in East Head, England (Creed et al. 2018); for planning offshore wind farms in Zhanghua, Taiwan (Zhang et al. 2017); and in the creation of Singapore's Sisters' Island Marine Park (Hastings et al. 2016). A diversity of voices included in participatory planning would greatly contribute to effective and sustainable coastal management (Buchan and Yates 2019).

The St. John's Island Complex (SJI-C) caters to the needs of a variety of stakeholder groups, and engaging stakeholders meaningfully to gather their views on the island complex is crucial for a more comprehensive review of the SJI-C (Gopnik et al. 2012). Surveys and focus group discussions were thus held with various stakeholder groups, primarily aimed at documenting opinions and feedback on the current uses (e.g. recreation, education, research) of the SJI-C, as well as their knowledge of and attitudes towards the islands. A variety of engagement methods were employed to cater to the diversity of stakeholders. We conducted a perception survey for public visitors, followed by a participatory mapping exercise with key stakeholder groups. A targeted survey on the perceptions and value of the Southern Islands to marine science and research was conducted by the SJINML during their Annual Stakeholder Meeting. This chapter presents the consolidated findings across all three engagements.

6.1 | Public and visitors perception survey

Visitors to the SJI-C form an important stakeholder group due to their large numbers on weekends and public holidays (Su T., Seah P. pers. comms. 2019, Singapore Island Cruise & Ferry Services pers. comms. 2019). Ferry operators were unable to provide exact visitor numbers due to confidentiality issues, but a report in The Straits Times (2019) cited an estimate of up to 200 visitors at the weekend (Tay 2019).

The perception survey represents the first detailed documentation of the SJI-C visitor profile, activities conducted on the islands, as well as visitors' knowledge and views of the islands. The survey aimed to gather information on the following:

1. Visitor profiles
    a. Citizenship, percentage tourists, gender, age group, ethnicity, working industry, annual income bracket

2. Experience on the islands
    a. How visitors found out about the islands
    b. Visitor regularity through frequency of visits
    c. Use of available transportation to islands
    d. Common activities conducted on the islands
    e. Significance of the islands (to respondents)
    f. Key issues faced by visitors

3. Knowledge of the islands
    a. Visitors' general knowledge of the islands
    b. Visitors' awareness of research facilities on the islands
    c. Frequency of visits to research facilities (if any)

4. Prospects for the islands
    a. Visitors' preferred key functions for the islands
    b. visitors' perspectives on change and improvements on the island

A total of 484 responses were gathered in the web-based perception survey between October and December 2019. Of 484 respondents, 426 (88%) were island complex visitors while 58 (12%) had never been to the islands. Of the 426 visitors, 296 (69%) of the surveys were conducted through face-to-face interviews during their visit on four weekends. Of the responses from those who had never been to the islands, all answers were considered in the analysis except in the calculation of visit frequency (2b), transportation mode used (2c) and key issues faced on the island (2f).

6.1.1 | Respondents' profile

Survey respondents were mostly Singaporean (69%), followed by long-term residents or working foreigners (approximately 21%) and lastly, tourists (10%) (**Figure 65 A and B**). This corresponds with estimates by boat operators that 70% of ferry users were Singaporean while the rest comprised foreign workers, expatriates and tourists (pers. comms.). They also reported that most of the guests were between 15 and 70 years old and typically visited the islands for a day trip; a small percentage visited to fish or camp overnight (pers. comms.).

The visitors surveyed also showed an even split between genders and a higher proportion of Chinese (69%) compared to Malay (5%) and Indians (6%) (**Figure 66 A and B**). The largest age group was of working adults between the ages of 20 and 44 (**Figure 67**). Despite the higher proportion of working adults, respondents' ages ranged from below 14 to above 60. This also corresponds with the age estimates provided by the boat operators above.

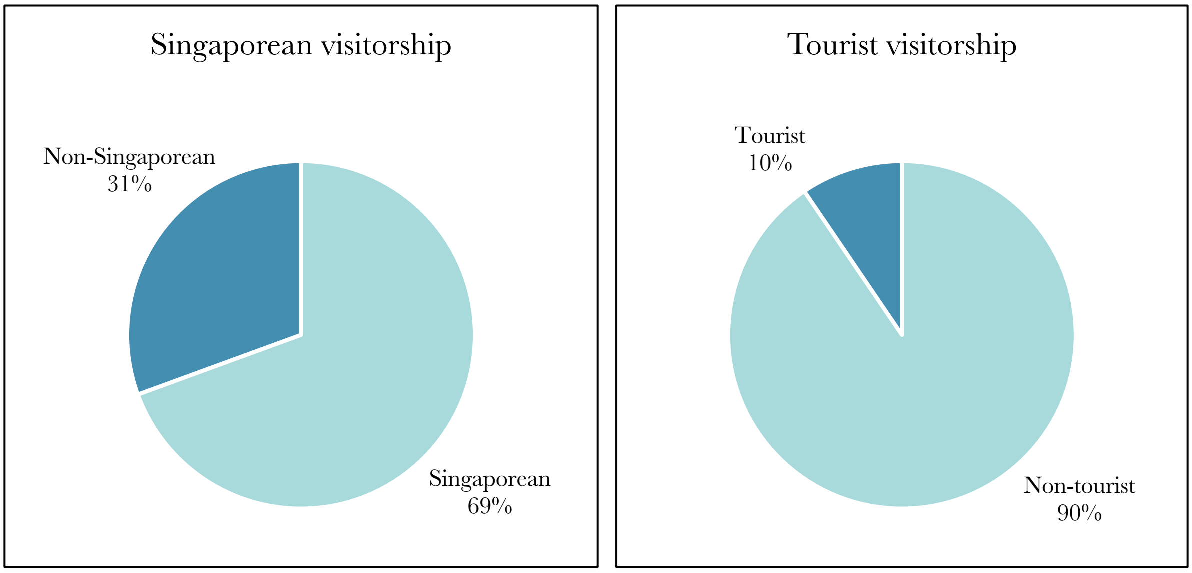


Figure 65 (**A**) Singaporeans and non-Singaporeans surveyed, (**B**) Tourists and non-tourists surveyed.

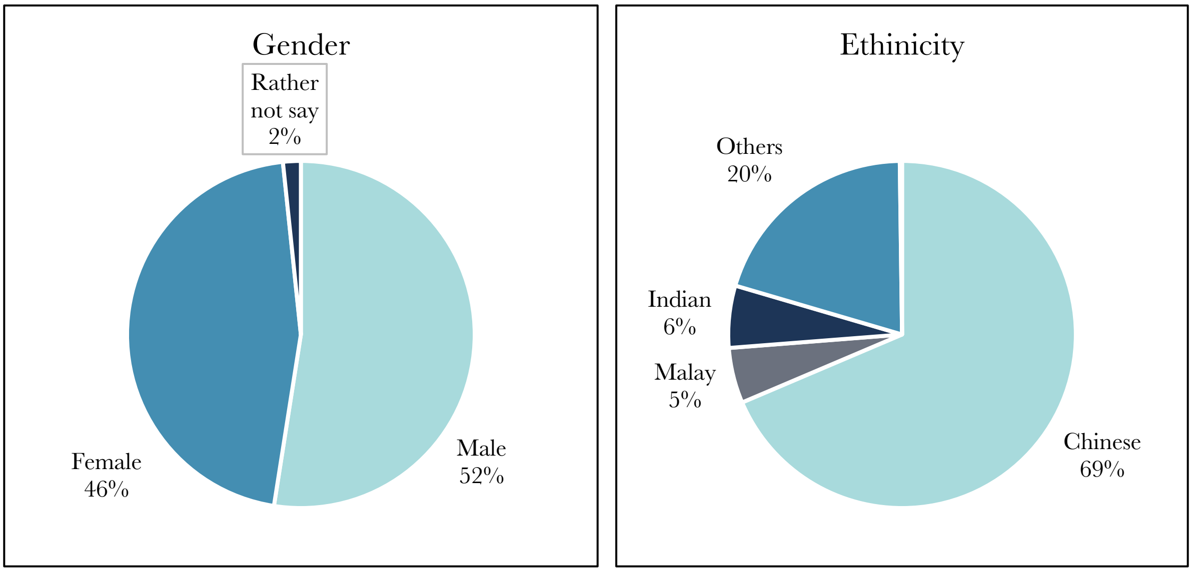


Figure 66 (**A**) Genders represented among respondents, (**B**) Ethnicity represented among respondents. The 'Others' category include Arab, Boyanese, British, Burmese, Danish, Eurasian, German, Hungarian, Indonesian, Irish, Japanese, Javanese, Korean, Nepalese, Philippines, Polish, Russian, Thai, Vietnamese ethnicities.

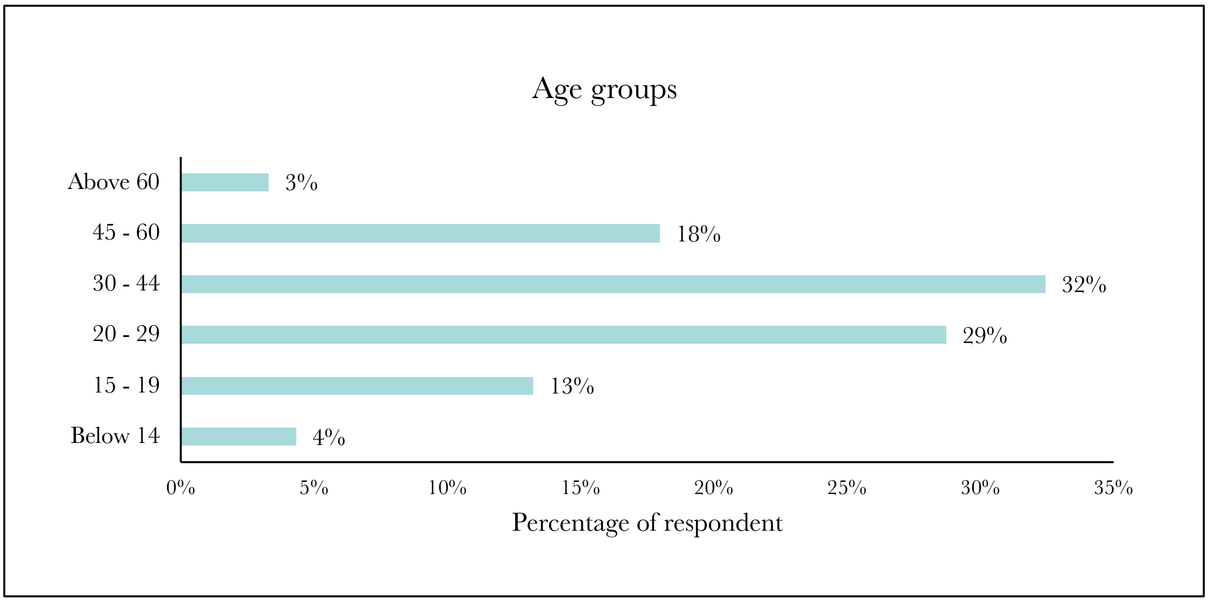


Figure 67 Respondents' age group.

Of those who responded to the survey, 67% were working professionals, 27% were students, and the remaining 6% were unemployed or retired individuals (**Figure 68**). Amongst the working professionals, individuals from Science and Research, and Education were the most common (**Figure 69**). This is probably due to the two research facilities and rich biodiversity on the islands. Respondents' incomes were relatively well-spread with a peak at '40 – 60 K' (12%) and at 'Less than 10K' (also at 12%) (**Figure 70**).

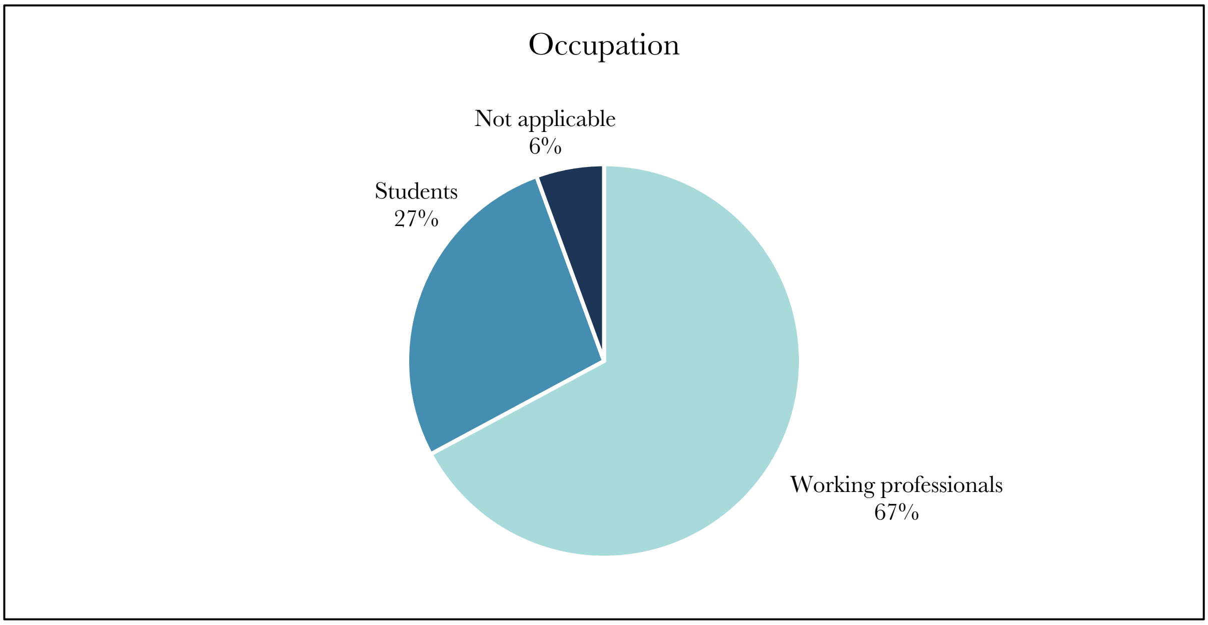


Figure 68 Breakdown of respondents' occupation.

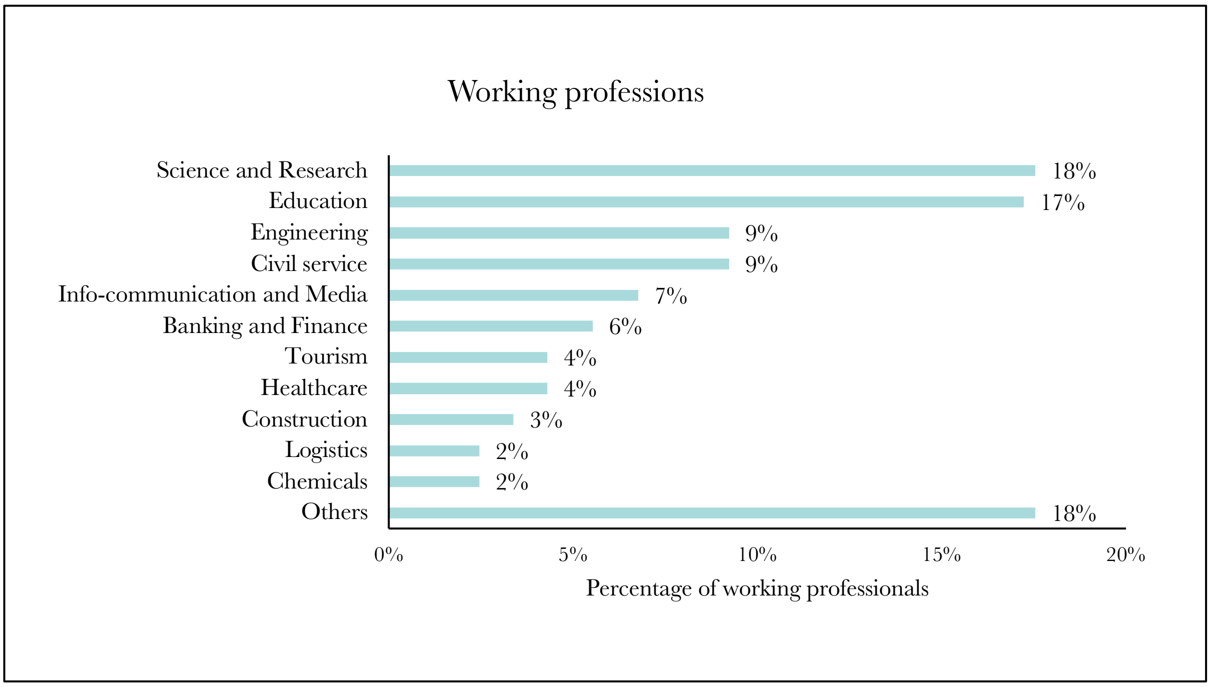


Figure 69 Breakdown of fields of work for respondents who declared that they were working professionals. Respondents who selected "Others" were asked to elaborate on their working profession and these include technology, non-profit, professional services, entertainment, editorial, operator, sports, design, communications consulting, factory, ship buildings, manufacturing, factory, homemaking, legal, transport, self-employed, social service, creative.

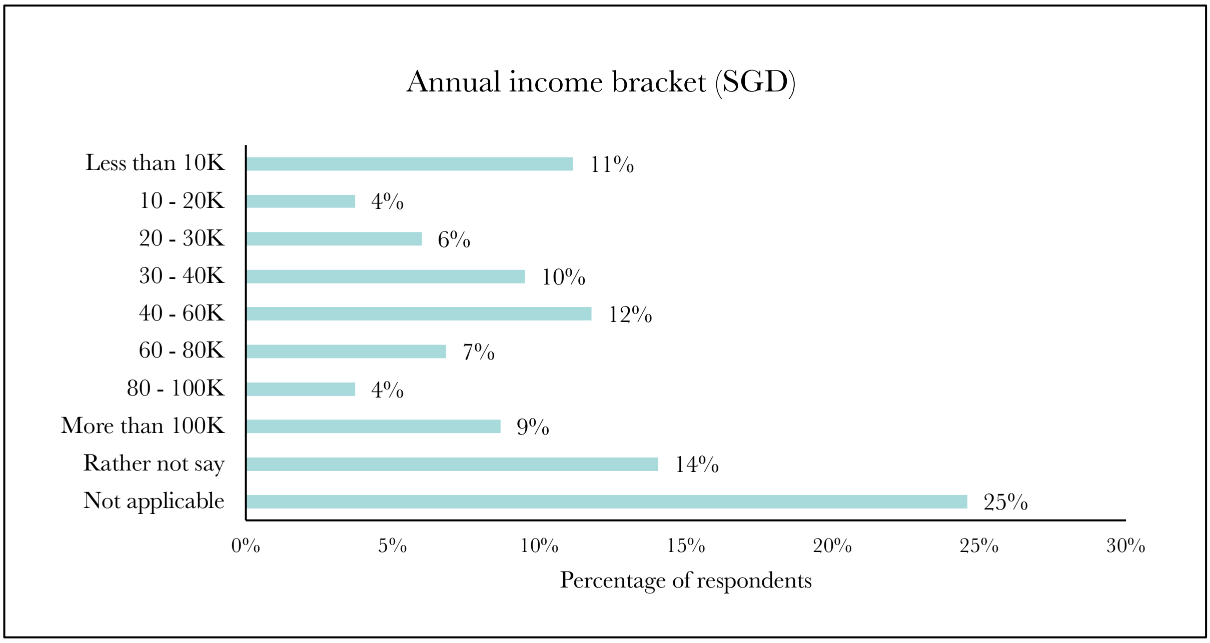


Figure 70 Respondents' declared income brackets.

6.1.2 | Experience of visiting the SJI-C

Most visitors were aware of the SJI-C through word-of-mouth, followed by social media, blog posts and government websites (mainly through the NParks and MOE websites) (**Figure 71**). Other more notable ways visitors gained awareness of the islands included school and work trips. In terms of the frequency of visits, first-time visitors were found to be the most common (52% of visitors), followed by yearly (26% of visitors), monthly (15% of visitors), and weekly and daily visitors (**Figure 72**). This means that first-time visitors constitute approximately half of a typical visitorship and regular visitors were more likely to be back yearly and monthly, rather than daily or weekly. The dominant transportation mode visitors relied on was the public ferry (75% of visitors) (**Figure 73**).

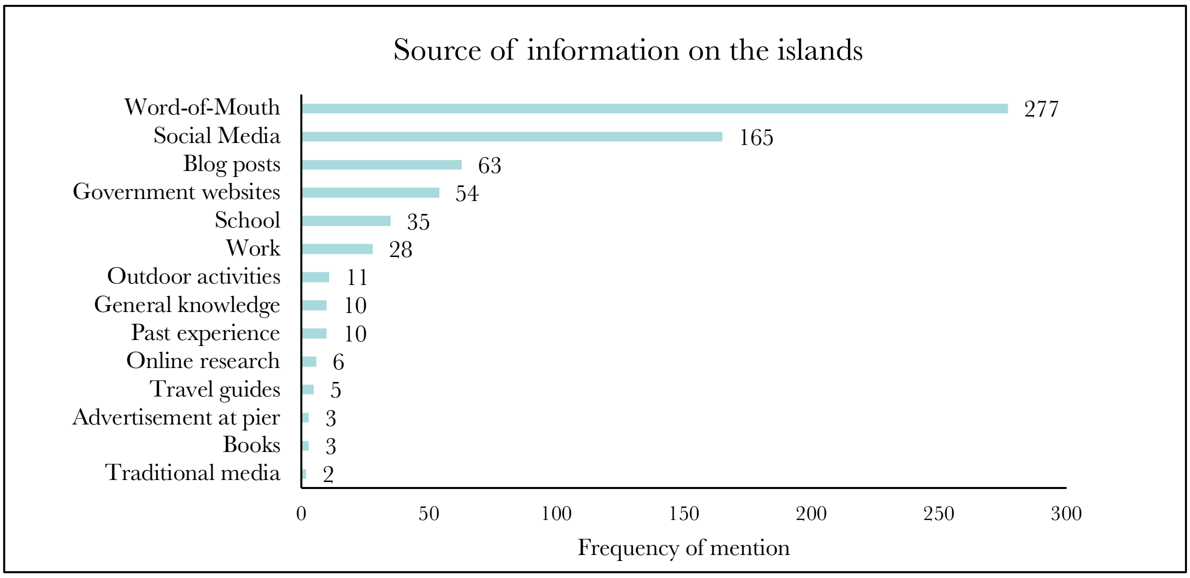


Figure 71 Visitors' sources of information on the islands.

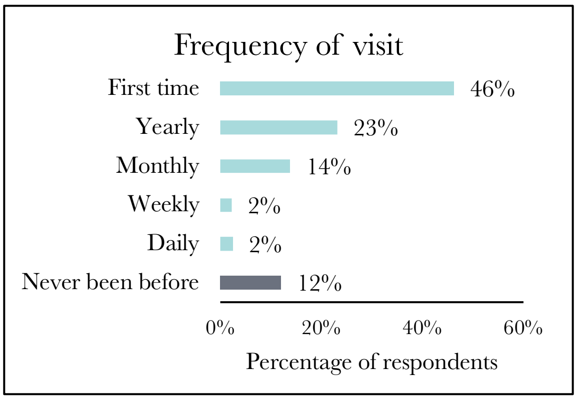


Figure 72 Frequency of visits to the islands.

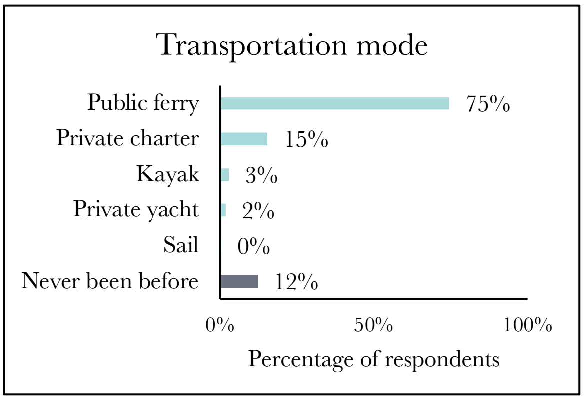


Figure 73 Visitors' transportation to the islands.

Activities on the island. Respondents were asked to share the activities they conducted on the island by selecting from a list of common activities or further elaborating if their activity was not included in the list. The most popular activity conducted or planned on the islands was nature walks (land and intertidal), which included both guided and non-guided self-exploratory walks (**Figure 74**). Other popular activities conducted include beach activities, picnics, visiting the MPOEC and camping/overnight stays. Observations of visitor behaviour during the survey period revealed that camping/overnight stays mostly took place on weekends, with the bungalow often occupied by families, and overnight camps often set up by friends, families, school groups or fishing/outdoor activities' groups. Overnight camps are less regular; approximately five to thirty tents were observed on any given weekend. Common overnight camping spots were observed include Eagle Bay and the east side of SJI just before the causeway. In addition to the activities discussed above, other notable activities included history/culture-related activities, scientific research (see Chapter 5), fishing and water sports (including freediving and SCUBA diving) (**Figure 74**).

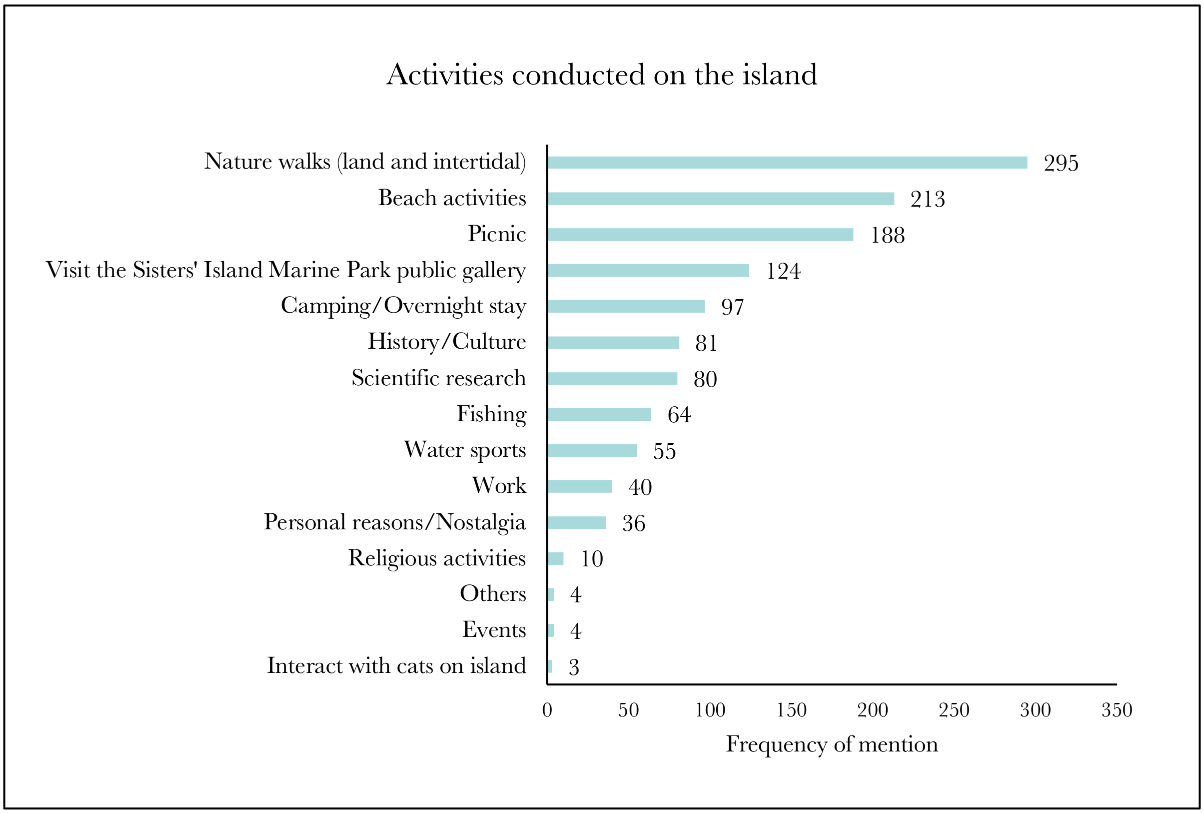


Figure 74 Activities conducted on the island by visitors. Respondents who are interested parties and have not visited the islands responded with activities that they were most looking forward to and would plan to do if they were to visit the islands.

Interviews with visiting recreational fishermen revealed that they highly valued the SJI-C. They often fished in the northeastern mangrove area for bait, and moved to the causeway (due to its high current and deeper waters) for bigger fish. These recreational fishermen reported that fishing sites like the causeway are not easily found elsewhere in Singapore, so they visit the islands more regularly for its unique fishing locations (**Figure 75**). This frequency of visits thus identified this group as a distinct stakeholder group amongst general visitors.

Visitors who participated in water sports also form an important stakeholder group. The verbal interviews revealed that this group mainly comprised kayakers and freedivers, as well as visitors from private yachts with water sports equipment such as kayaks, paddle boards or speedboats. Kayakers typically began their trips from the mainland, the St. John's Island swimming lagoon or Eagle Bay (**Figure 75**). Some of the kayakers also reported that they fish from their kayaks. Freedivers favoured deeper waters near the link bridge and typically visited monthly.

Although not reflected in the survey responses, camps and retreats such as meditation camps, religious retreats and company events have been observed on the islands in the past. These activities often take advantage of the islands' natural assets and low footfall to conduct their activities.

Figure 75 (Left) Visitors fishing at the causeway connecting SJI and LAZ. Photo by Rachel Oh. (Right) Kayaking groups land their kayaks at the SJI beach. Photo by Ria Tan.

Figure 76 Visitors' favourite aspects of the island as reported in the survey. (Top left) The causeway connecting the two islands. (Top right) The natural aspect of the islands. (Bottom) Eagle Bay at LAZ.

Favourite aspect of island. Respondents were asked to share their favourite aspect on the island through an open-ended question. These responses were then categorised based on their similarities. Based on the frequency of mention, the top four favourite aspects reported were specific locations on the islands, SJI-C's natural assets, the island ambience, and recreation (**Figure 76**, **Figure 77**) (see breakdown of favourite aspect categories in Appendix C.1). These aspects were mentioned in 203, 139, 76 and 74 responses respectively. Other notable favourite parts of the islands included research, such as the work conducted at SJINML and MAC; and marine education, which included educational tours and workshops, reef restoration efforts and interpretive material installed around the island and in the MPOEC.

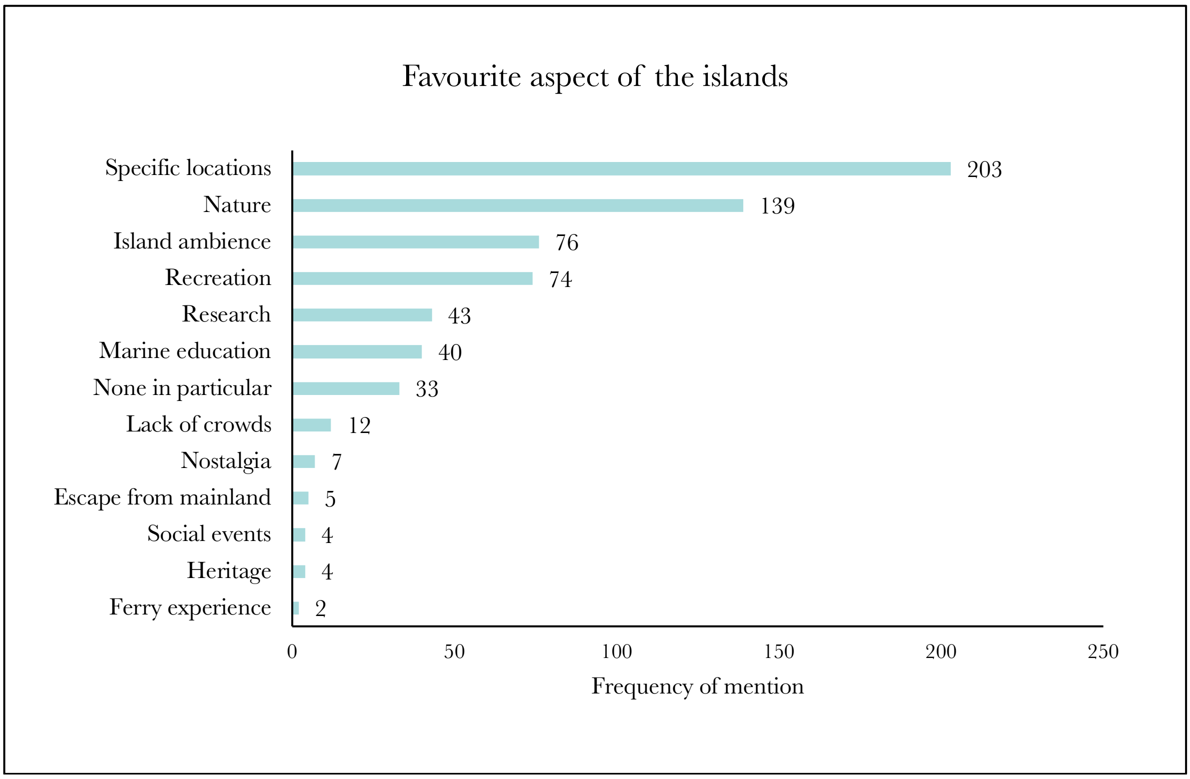


Figure 77 Favourite aspects of the island as reported by the respondents.

The most mentioned favourite aspect of the island was specific locations on SJI-C, with the most popular locations being beaches, especially Eagle Bay on LAZ. The causeway that connects the two islands was also highlighted as a popular favourite. These two options were commonly mentioned due to their picturesque quality and suitability for beach activities and fishing.

The second most mentioned favourite aspect was 'nature', which primarily included the serenity and peacefulness of the islands, as well as the islands' biodiversity and natural habitats. Others also highlighted the cats and geological features as contributors to the islands' natural assets.

The fourth most mentioned favourite aspect was 'recreation', which predominantly included nature walks and general exploring around the island. It also included relaxing, camping, fishing, swimming and intertidal walks.

Many respondents also mentioned through verbal interviews and in responding to the survey that it is difficult for them to pinpoint a particular favourite part of the island as most of them enjoy the island due to its overall charm. Although responses in this section were distilled into different categories as shown in **Figure 77**, it is important to note that most aspects complement the enjoyment of other aspects. For example, the enjoyment of 'nature' complements recreational activities such as nature walks. The distilled categories shown in the figure thus illustrate the many aspects that contribute to the SJI-C's overall charm.

Key concerns and issues. Respondents were asked to share if they faced any issues on the island through an open-ended question. These responses were then categorised based on their similarities. While 73% of visitors were satisfied with the SJI-C, roughly a quarter of visitors (27%) raised a number of issues about the islands. Of the concerns raised, amenities, transportation and infrastructure were most frequently mentioned, garnering 58, 53 and 7 responses respectively (**Figure 78**) (see breakdown of favourite aspect categories in Appendix C.2). However, the nature of these concerns varied.

Amenities referred to facilities that supported visitors' needs, such as toilets, water points, food and beverage options, shelters, signages, bins and the jetty. The most common complaint was the poor condition of toilets (e.g. faulty lights, low water pressure), and the sparse distribution of toilets on the island (i.e. too far and too few). Another common issue raised was the lack of food and beverage options, water points, bins, signages, shelters and a poorly designed jetty.

The most mentioned concern about transportation was the low frequency of ferry services. Other issues included strict regulations at the pier, high cost of ferry tickets, poorly maintained boats, long travelling time, insufficient travelling options, inadequate information on ferry services and high boat traffic. Concerns about poor telecommunications reliability such as internet access and stability were also raised during the face-to-face interviews with working professionals.

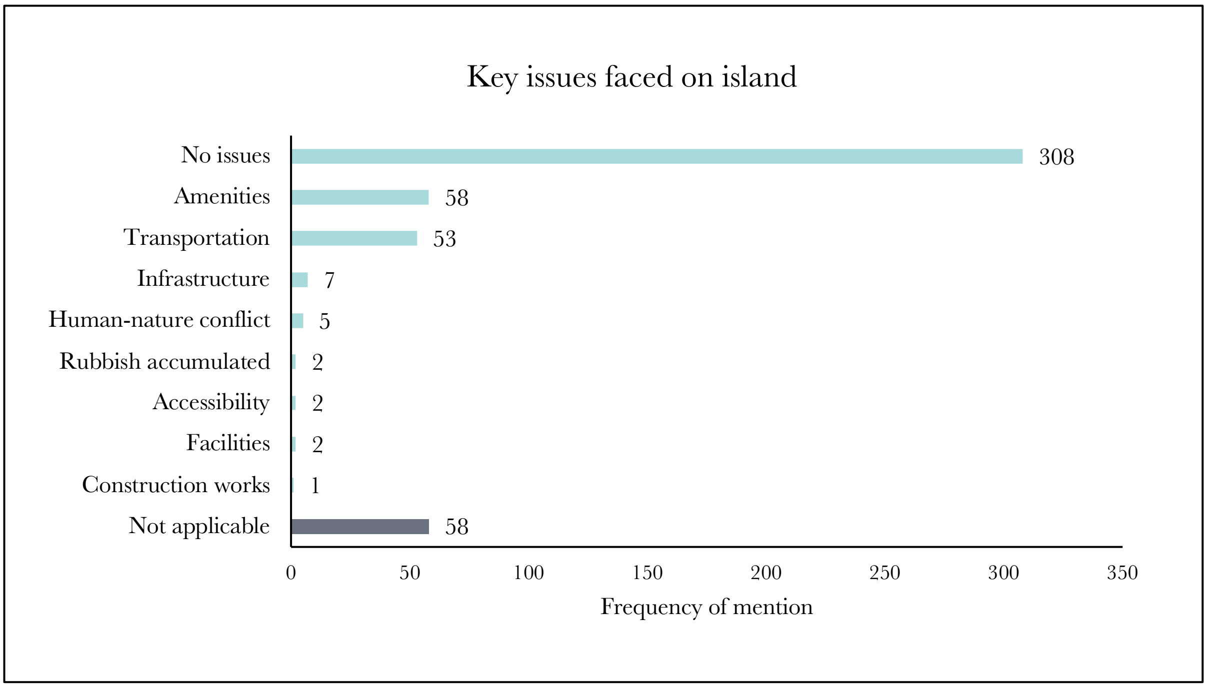


Figure 78 Key issues faced on the island by respondents. Respondents who have not been to the islands were listed as 'Not applicable'. Amenities referred to features on the island that supported the needs of visitors which included toilets, water points, food and beverage options, shelters, signages, bins and the jetty. Facilities referred to specialised feature on the island that catered to a specific purpose and it includes research and educational facilities and overnight stay facilities on the island.

6.1.3 | Knowledge of the SJI-C

The survey also assessed respondents' level of general knowledge about the islands' cultural history, ecological characteristics and research and educational facilities (**Figure 79** and **Table 2**). Most respondents were aware that SJI and LAZ are two separate islands despite the connecting bridge (78% of respondents). Most were also aware of SJI's historical role as a quarantine centre (55% of respondents) and that it is home to a number of natural habitats (53 % of respondents). However, awareness of the islands' cultural history was weak, with only 22% aware that there were once Malay villages on LAZ. Only a minority of the respondents noted that they were unaware of all the points listed as options in this question (12% of respondents).

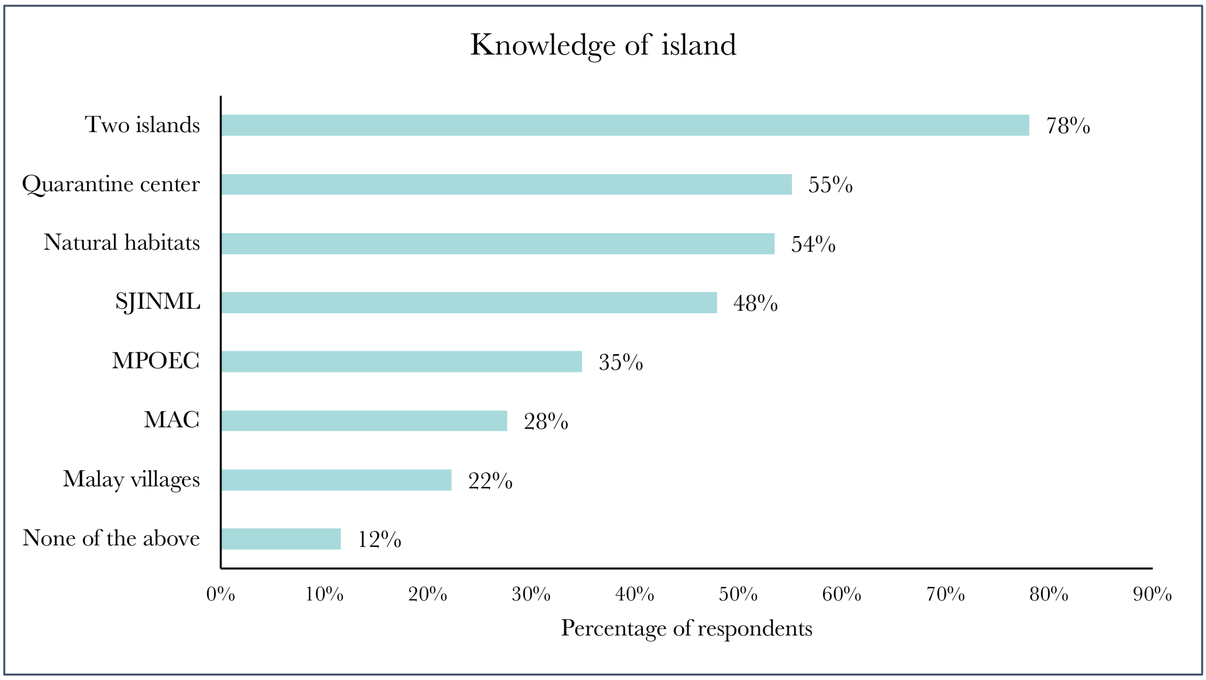


Figure 79 Graph showing respondents' breadth of general knowledge of the islands' past and present. Each bar in the graph indicates the percentage of respondents who were aware of the information given in the question. Further details are provided in Table 4 below.

Table 2 Legend for Figure 79.

Abbreviation	Statement
Two islands	St. John's Island and Lazarus Island are two different islands.
Quarantine centre	St. John's Island used to house a quarantine centre.
Natural habitats	St. John's Island houses a variety of natural habitats such as coral reefs, seagrass meadows, mangroves, rocky shores and coastal forests.
SJINML	St. John's Island houses a Marine Science National Research Infrastructure (St. John's Island National Marine Laboratory).
MPOEC	St. John's Island houses the Sisters' Island Marine Park public gallery and aquarium.
SFA MAC	St. John's Island houses the Singapore Food Authority's Marine Aquaculture Centre.
Malay villages	Lazarus Island was occupied by (predominantly Malay) villages in the past.

Respondents' awareness of the islands' research and educational facilities was moderate and varied between facilities. While most respondents did not visit the research and educational facilities, respondents were mostly aware of the presence of SJINML (48% of respondents), MPOEC (35% of respondents) and MAC (28% of respondents) (**Figure 79**). The level of awareness of the facilities also corresponded to the visitorship of these facilities (**Figure 80**). It is also important to note that some respondents were not sure which facility they were visiting (i.e. they were in the public gallery but did not know the name of the venue).

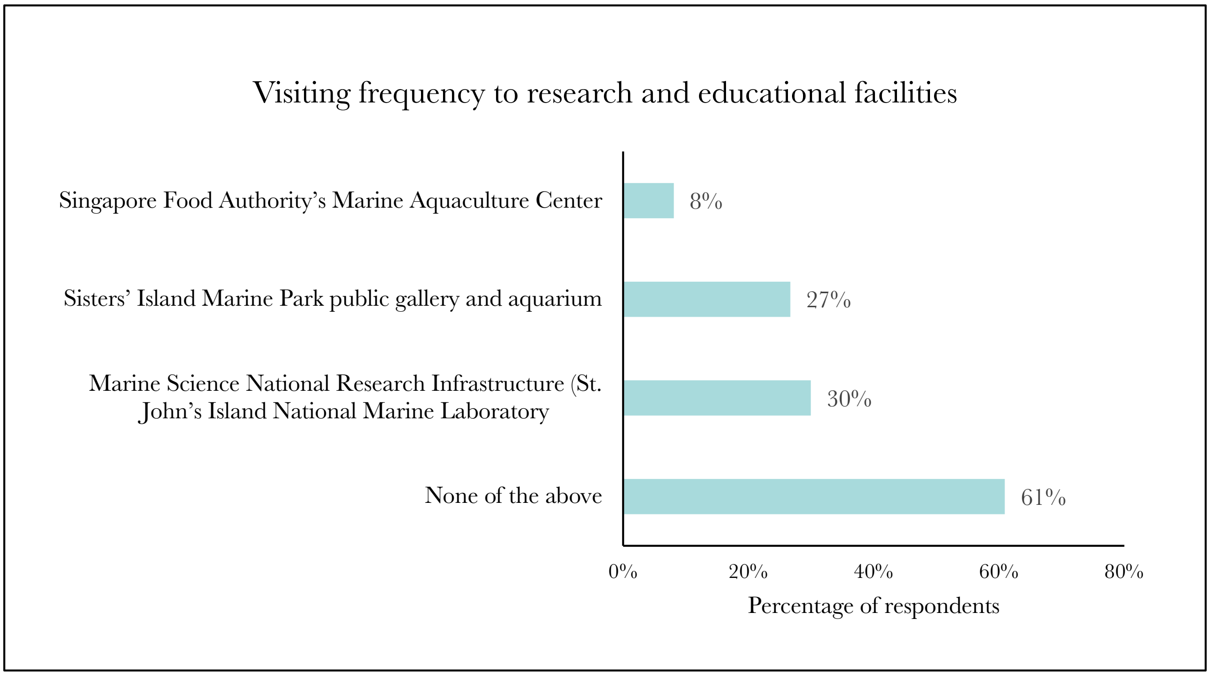


Figure 80 Visiting frequency to research and educational facilities.

6.1.4 | Perspectives on future of the SJI-C

Key functions of the island. Respondents were asked to rank key functions for the islands based on their preference from 1 to 7, with 1 being the most preferred and 7 being the least preferred. Rank scores were then calculated as a weighted sum function of the number of respondents and their ranked preference, with a higher rank score presenting a higher preference.

Based on the rank scores (**Figure 81**), Education (rank score of 2477) was the most highly preferred function, followed by Research (rank score of 2469), Nature Reserve (rank score of 2459), Tourism (rank score of 2154), Place of Worship (rank score of 1615), Residential (rank score of 1450) and Military (rank score of 1334). The importance given to 'Nature Reserve' was not unexpected as most visitors had reported that they enjoyed the islands' natural assets the most. Face-to-face interviews revealed that the Residential and Military functions were associated with restricted access to the islands, possibly contributing to their low rankings.

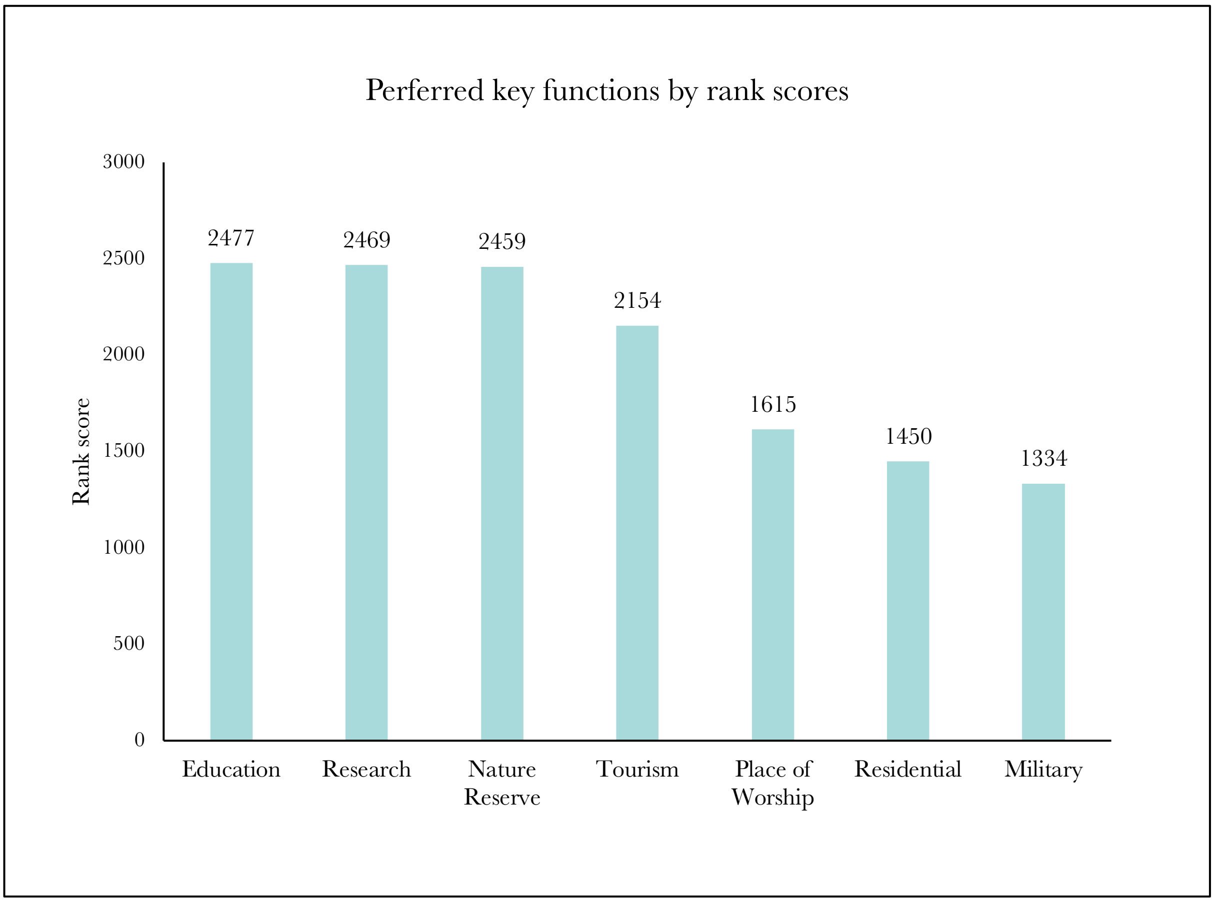


Figure 81 Preferred key functions of the island according to respondents arranged by summed rank. The key function with the highest summed rank is most preferred.

As there was a sizeable proportion of respondents working in science, research, and education (35%), as well as a large proportion of student respondents (27%), the ranked-sum of key functions were further broken down by profession to determine whether this resulted in a bias. All categories (students, respondents working in science, research or education, and respondents from other professions) showed consistent trends, with Education, Nature Reserve and Research still ranked the top three most preferred key functions, although their orders differed slightly (**Figure 82** and **Table 3**). This demonstrates that the high preference in these key functions were consistent regardless of professional background. The rankings of the four remaining key functions were also consistent across all profession categories.

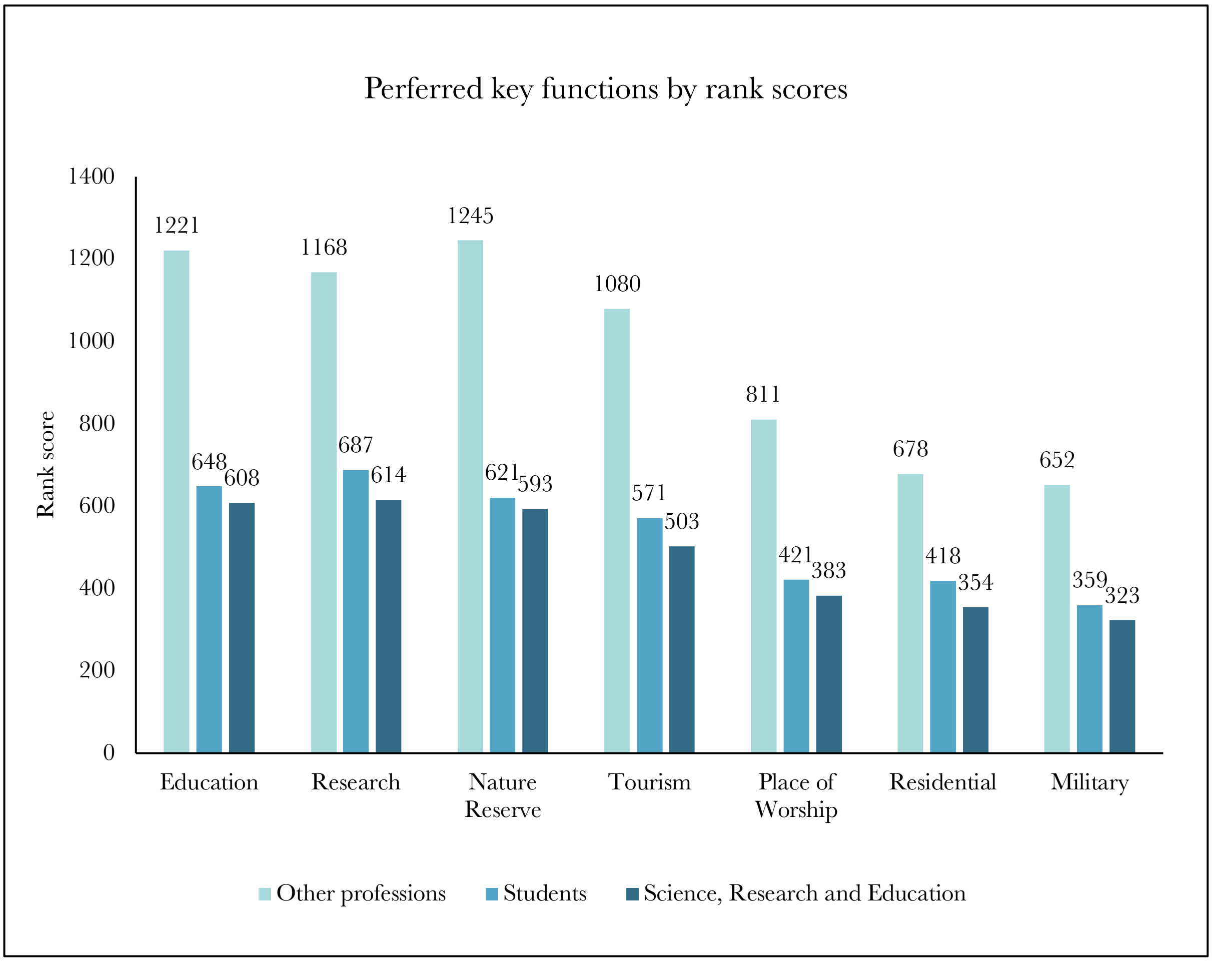


Figure 82 Preferred key functions of the island according to respondents from the "Other professions" category, respondents from the "Students" category and respondents from the "Science, Research and Education" category.

Table 3 Table comparing most preferred and least preferred key functions between all respondents, respondents from the "Other professions" category, respondents from the "Students" category and respondents from the "Science, Research and Education" category. The orange band highlights areas of disagreement while the yellow band highlights areas of agreement.

Category	All	Other professions	Students	Science, Research and Education
Most preferred	Education	Nature Reserve	Research	Research
	Research	Education	Education	Education
	Nature Reserve	Research	Nature Reserve	Nature Reserve
	Tourism	Tourism	Tourism	Tourism
	Place of Worship	Place of Worship	Place of Worship	Place of Worship
	Residential	Residential	Residential	Residential
Least preferred	Military	Military	Military	Military

Based on raw rankings (**Figure 83**), nature reserve received the most votes as a Rank 1 function (36% of all respondents), followed by Education (24%) and Research (20%). These three functions also received the highest number of Rank 2 assignments by respondents (Figure 77). Military was the least preferred function, with the greatest number of Rank 7 votes (35%), followed by Residential (15%) and Place of Worship (12%). Although 'Nature Reserve' received the most Rank 1 assignment, 11% of respondents also selected this function to be their least preferred function (Rank 7). Face-to-face interviews revealed that some respondents felt that gazettement of the islands as a whole for the purpose of a Nature Reserve would result in restricted access to the islands. Tourism is a moderate preference among most respondents, with a rank mode of Rank 4 (**Figure 83**).

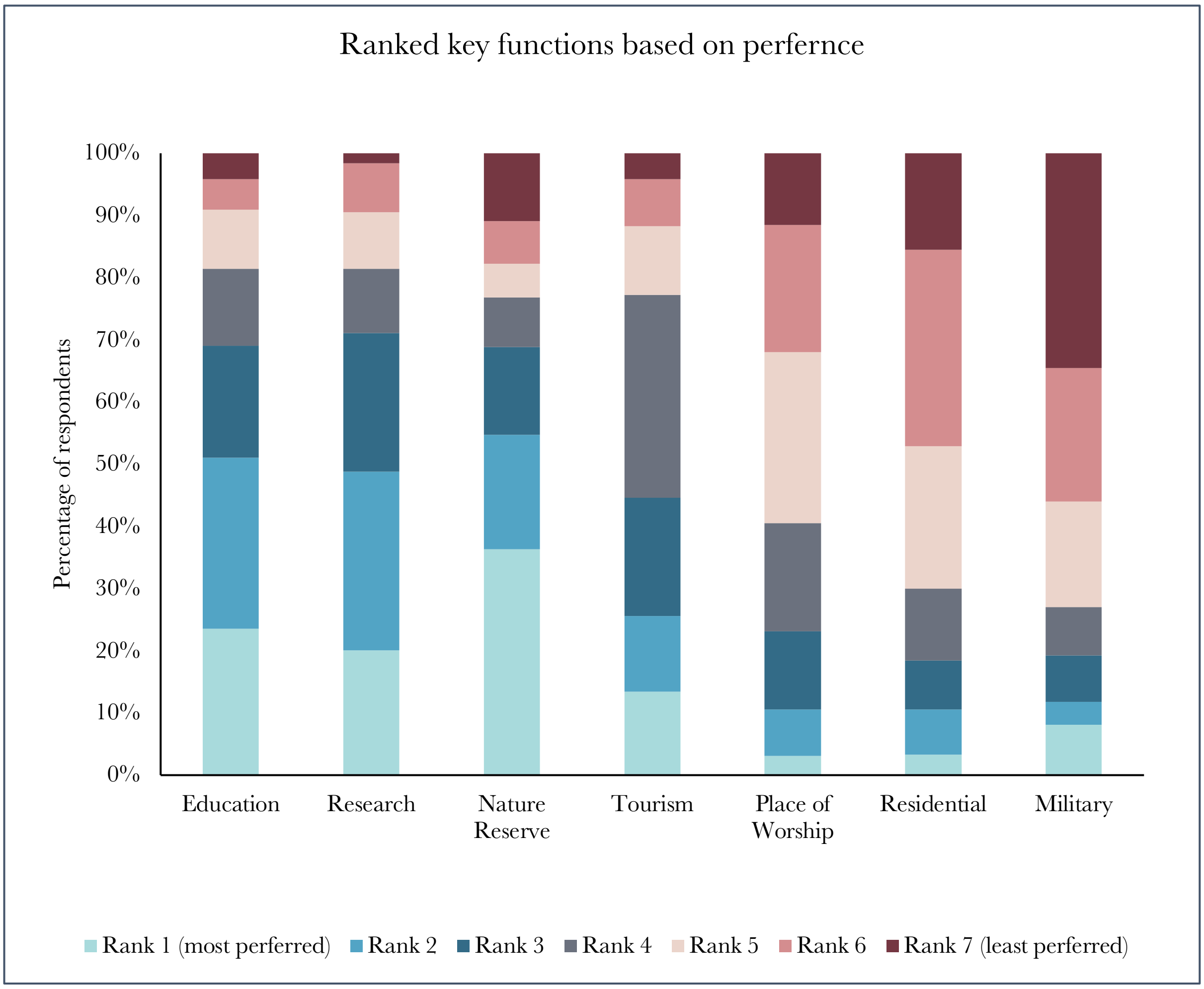


Figure 83 Breakdown of ranked key functions preferred by visitors. A rank of '7' is least preferred, and "1" is most preferred.

Change and improvements to the island. When asked if there should be change to the island, more than half (65%) responded that there should be no change while the remaining (35%) responded that there should be change. However, when asked what changes or improvements they would like to see, some respondents who responded 'No' to the question suggested improvements that they would like to see on the island. These included bringing back islanders or cats to the island or to address key issues faced on the islands (see Section 6.1.3), with a strong emphasis on the need to preserve the islands' natural aspects. These responses were thus modified from 'No' to 'Moderated' to accurately reflect the respondents' sentiments. After modification, more than half (54%) still responded that there should be no change on the islands and 11% were moderated as requesting some change.

Type of change and improvement. Respondents who responded that the islands needed change or improvements provided further details. Changes and improvements in amenities were the most frequently mentioned by respondents (**Figure 84**). This was followed by suggestions on island activities, transportation, infrastructure and environment (meaning that respondents wanted the natural environment to be maintained as is). Suggestions for island development were mentioned, but in lower frequencies, and included having more eco-friendly tourism opportunities and implementing leave-no-trace enforcement to combat the problem of trash on the island. Campaigns to raise awareness about the islands as an attraction were also suggested.

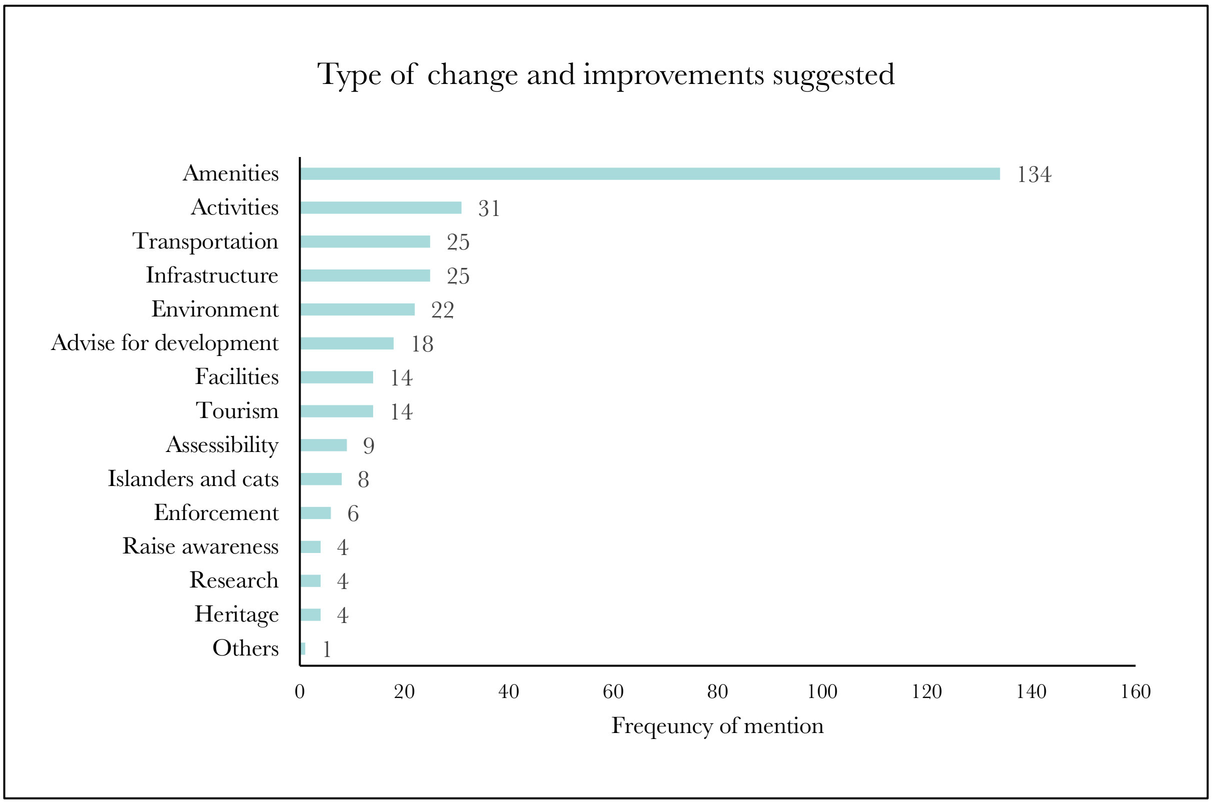


Figure 84 Types of changes and improvements suggested for the island. Amenities referred to features on the island that supported the needs of visitors which included toilets, water points, food and beverage options, shelters, signages, bins and the jetty. Facilities referred to specialised feature on the island that catered to a specific purpose and it includes research and educational facilities and overnight stay facilities on the island. Islanders and cats referred to bringing back the islanders and cats to the islands.

Suggestions to changes and improvements in amenities mostly included providing food and beverage options in the form of a food stall or vending machines. Other common suggestions addressed the key issues raised in an earlier section, such as to have better toilets, improved signage, more shelters, water points and rubbish bins. Installing a convenience stall on the island and starting waste recycling programs and having recycling bins were also suggested.

Respondents generally wanted more activities to be made available on the islands, in particular more nature and marine biodiversity walks. There were also suggestions for more overnight stay options and picnic spots. Other suggestions at much lower frequencies included having marine citizen science activities, heritage walks, snorkelling, virtual reality tours and helicopter tours.

The main improvement suggested with regards to transportation was to increase the frequency of ferry services. There were also suggestions for more varied transportation options to the islands, and reduction in price to be made for ferry tickets. Having buggies, e-scooters and other green transportation options on the islands were also raised. The main improvement suggested for infrastructure was for better telecommunication and network signals.

Suggestions to ensure the maintenance of the natural environment were also made, with suggestions for more protection, outreach and education programs and restoration being the most mentioned ideas. Others also proposed introducing more biodiversity, designing a coastal park and organising more nature park activities. Respondents mostly recommended preserving the islands' pristine nature, and to keep development and footfall at moderate levels, as well as to preserve the present coastlines and minimise reclamation.

A comparison between key issues raised in the earlier section with the types of changes and improvements suggested by respondents in this section can differentiate the unmet needs of visitors from their wants. The unmet needs of visitors dominantly include a better quality of amenities on the island to support the basic necessities of the visiting experience, as evidenced by being the top most mentioned key issue and the dominant type of change suggested. Better transportation systems and infrastructure are also the other unmet needs of visitors. In addition to their needs, the comparison shows that visitors want their favourite aspects of the island (nature and recreation) to be protected in future plans for the SJI-C, as well to improve the quality and diversity of these aspects.

6.2 | Participatory mapping with community stakeholders

Description of stakeholders. To get targeted opinions of community stakeholders with vested interest in SJI, we conducted a participatory mapping exercise with members of the Friends of the Marine Park (FMP). The FMP was formed to coordinate the community's efforts and participation in safeguarding the Sister's Island Marine Park, which includes parts of SJI (NParks 2017). The group is made up of representatives from a variety of stakeholder groups, including boaters, divers, scientists, recreational fishermen, kayakers, and education providers (NParks 2017). There are four main working groups in the FMP – scientific research, education, heritage and sea sports, and each group consists of individuals with the knowledge, experience or interest pertaining to the topic.

Results from mapping exercise. A participatory mapping exercise was conducted at a quarterly FMP meeting held at the Singapore Botanic Gardens on the 7th of November 2019. There were 36 number of representatives present. Stakeholders were asked to annotate blank maps of the SJI-C with zones suitable for various functions, such as but not limited to education, research, tourism development, residential, conservation, sea sports, fishing, aquaculture and military.

A total of six participatory maps were produced from the mapping exercise. Information from these maps generally covered zoning strategies for Environment Conservation and Education, Heritage Conservation and Education, Nature and Heritage Trails, Scientific Research, Sea Sports and Recreational and Fishing activities and was consolidated into the maps shown in **Figure 85 to Figure 90**.

For Environmental Conservation and Education, FMP members indicated separate areas for conservation and education mostly based on the ecological significance and quality of a habitat and its accessibility (**Figure 85**). For environmental conservation, pristine reefs on the western coast of SJI, which are also within the SIMP boundary, as well as the rocky shores and coastal forest on southern LAZ were marked. These areas are mostly inaccessible and thus, have not been heavily impacted by human disturbance and hold high ecological value. The natural rocky shores were considered especially important as they are rarely found on the mainland. For environmental education, SJI's swimming lagoon, which has a coral reef, a seagrass bed and a small rocky shore, was identified as it is easily accessible and suitable for intertidal walks.

Bendera Bay and the small mangrove patch adjacent to it were areas marked for the combined purpose of conservation and education. Bendera Bay is a lagoon on SJI's southwestern coast and is managed by NParks and the FMP to promote environmental awareness and stewardship (FMP). It contains a variety of habitat types such as sandy beaches, coral reefs, rocky shores and seawalls, as well as a very large and dense seagrass bed. The easy accessibility of the lagoon makes it a suitable location for environmental education in the form of guided walks. The bay houses a seagrass meadow, which has high conservation value due to its density, high biodiversity and sizeable area, and would be more suitable for conservation purposes. Similarly, the relatively untouched mangrove patch adjacent to the lagoon was deemed an ideal location for mangrove conservation (Su T. pers. comms. 2019). Some of the more accessible parts of the mangrove could potentially be used for short mangrove guided walks as well as clean-up activities.

Several locations were identified for Heritage Conservation and Education purposes (**Figure 86**). Historical buildings with high cultural significance, such as the old school on SJI, were identified for conservation. Others that were also easily accessible (e.g. former islanders' homes) were identified as possible visitor centres for education and outreach. Areas were also marked out for the sailing of traditional vessels, such as *kolek* and *jong*, which were chosen based on safety and environmental considerations. The group also suggested possible sites to recreate traditional houses on stilts based on the location of former Malay villages that used to be found on LAZ. Landmarks were also marked out along walking trails that showcased the nature and heritage aspects of SJI. These trails linked interesting landmarks, buildings with cultural significance, as well as areas of significant biodiversity interest and value (**Figure 87**).

Areas for coral restoration, aquaculture and mangroves were identified for scientific research (**Figure 88**). Coral restoration sites were selected due to the presence of existing Reef Enhancing Units (REUs), coral transplantation efforts, high coral cover, suitable environmental conditions, and low levels of disturbance. Aquaculture sites were also identified. The mangrove sites identified incorporated existing mangrove patches which currently have little research conducted on them.

Sites for sea sports, diving, freediving and kayaking were identified as shown in **Figure 89**. Most dive sites were chosen based on the islands' coral reef distribution and diver experience. Freediving and kayaking sites were based on existing common locations for freediving and past experiences. These sites were identified as possible sites for their safety and feasibility still needs to be further accessed.

Locations for recreation and fishing activities were annotated in **Figure 90**. The activities noted include fishing, tourism, nature and adventure camping, as well as general recreational activities. Fishing sites were selected based on key areas regular anglers already use. These areas have different environmental conditions, allowing for different types of fish to be caught. Tourism (e.g. resorts) was deemed suitable for the north of LAZ as the area is mostly reclaimed and vegetation there has already been affected by development. It is also far away from the main environmental conservation sites and will thus minimise pollution or disturbance to natural areas. Nature and adventure camps were marked out near the existing campsite due to currently available facilities and amenities. General recreational activities were mostly limited to Eagle Bay as it is well-known as a popular recreational ground for visitors.

This engagement session demonstrated that the zoning strategy recorded prioritised environmental conservation and education, as well as heritage conservation and education. The remaining areas that were not a priority for those functions were then assigned to other functions.

Who are the Friends of Marine Park (FMP)?

The Friends of Marine Park (FMP) Community consists of stakeholders from civil society, business, academia and government. The network encourages community members to collaborate for the long-term survival of life in our seas. It is built on trusting relationships that enable resource users to get involved in the planning, development, and management of the Sisters' Islands Marine Park. It facilitates activities that are mutually beneficial to the community and to the success of the nation's first marine park.

Members of the FMP community are made up mainly of representatives from various institutions, organisations and businesses that have expertise and interests in scientific research, education, natural and cultural heritages and sea sports. Individual volunteers of the Marine Park are members too. The network is administrated by the National Parks Board and supported by the Ministry of National Development.

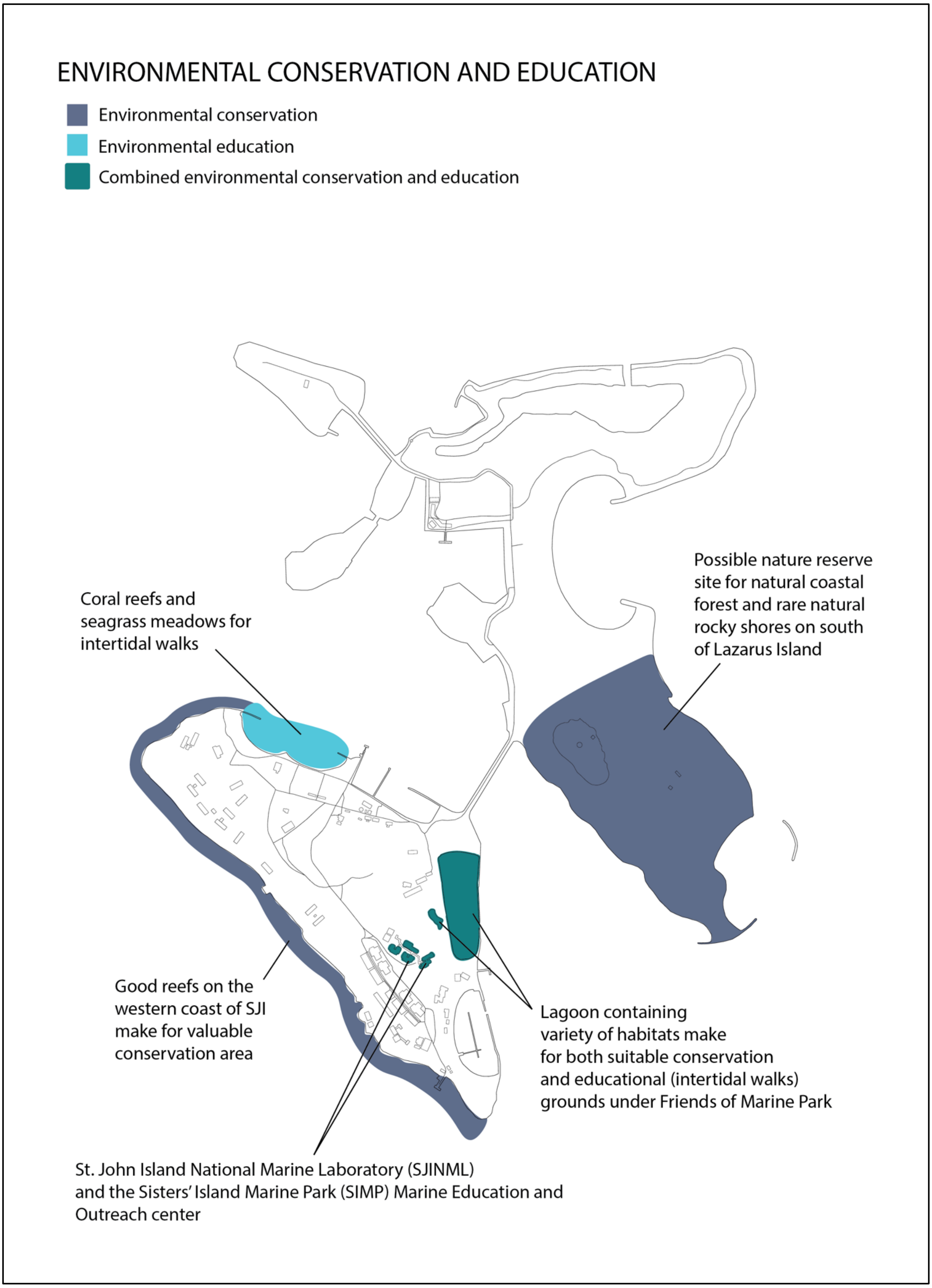


Figure 85 Consolidated map for Environmental Conservation and Education. Maps are consolidated from participatory maps produced from mapping exercise with the Friends of Marine Park.

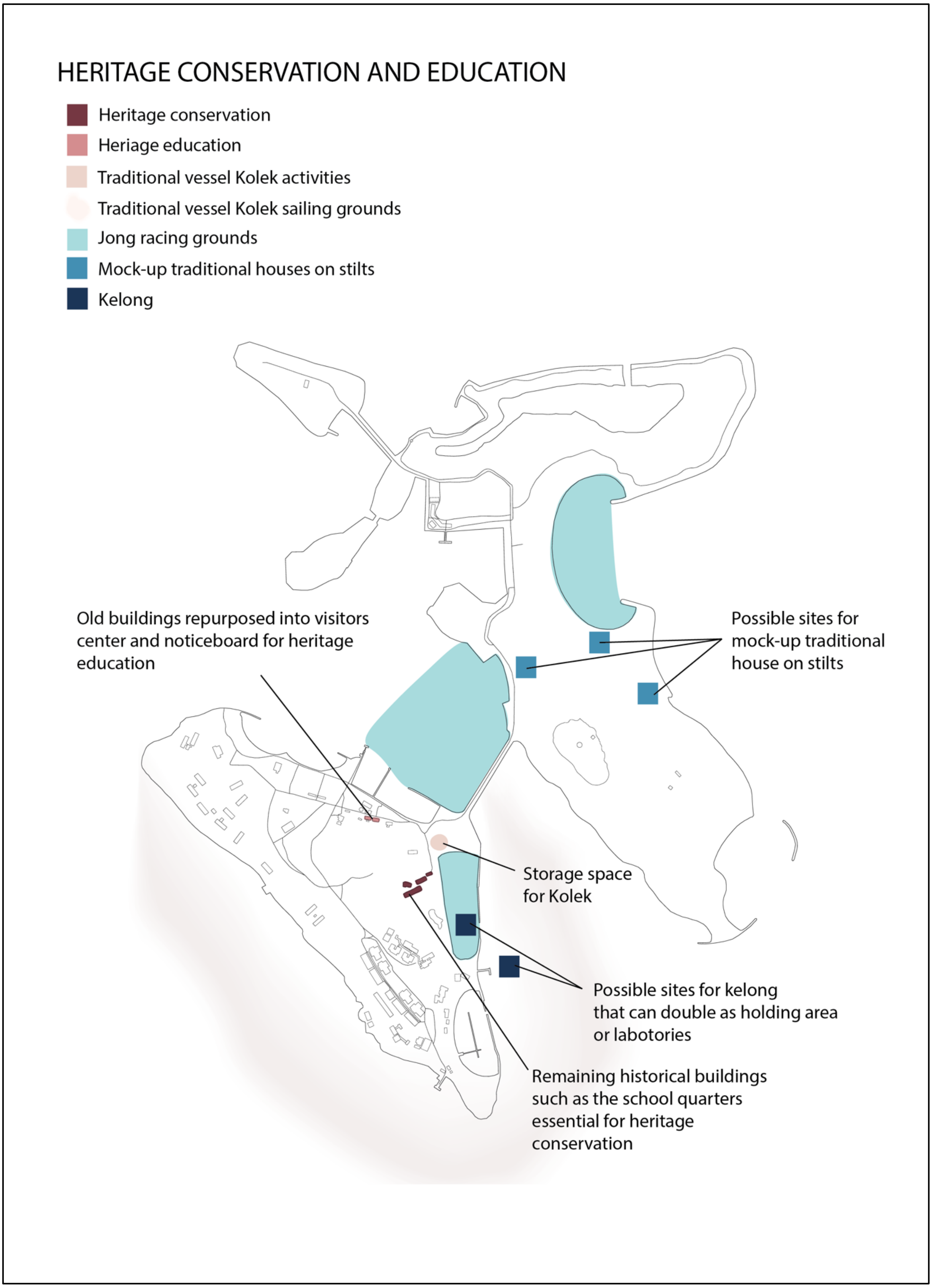


Figure 86 Consolidated map for Heritage Conservation and Education. Maps are consolidated from participatory maps produced from mapping exercise with the Friends of Marine Park.

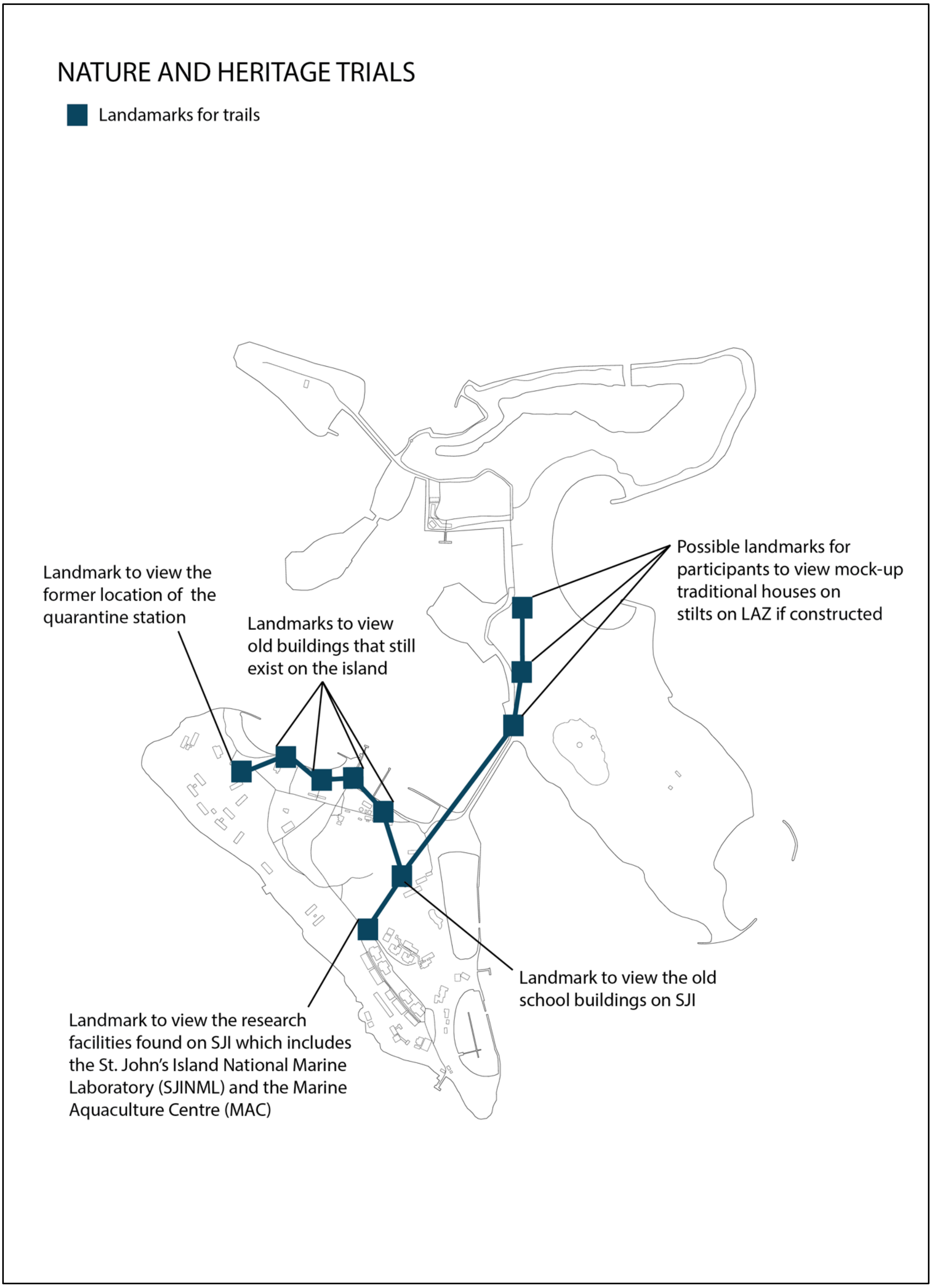


Figure 87 Consolidated map Nature/Heritage Trails. Maps are consolidated from participatory maps produced from mapping exercise with the Friends of Marine Park.

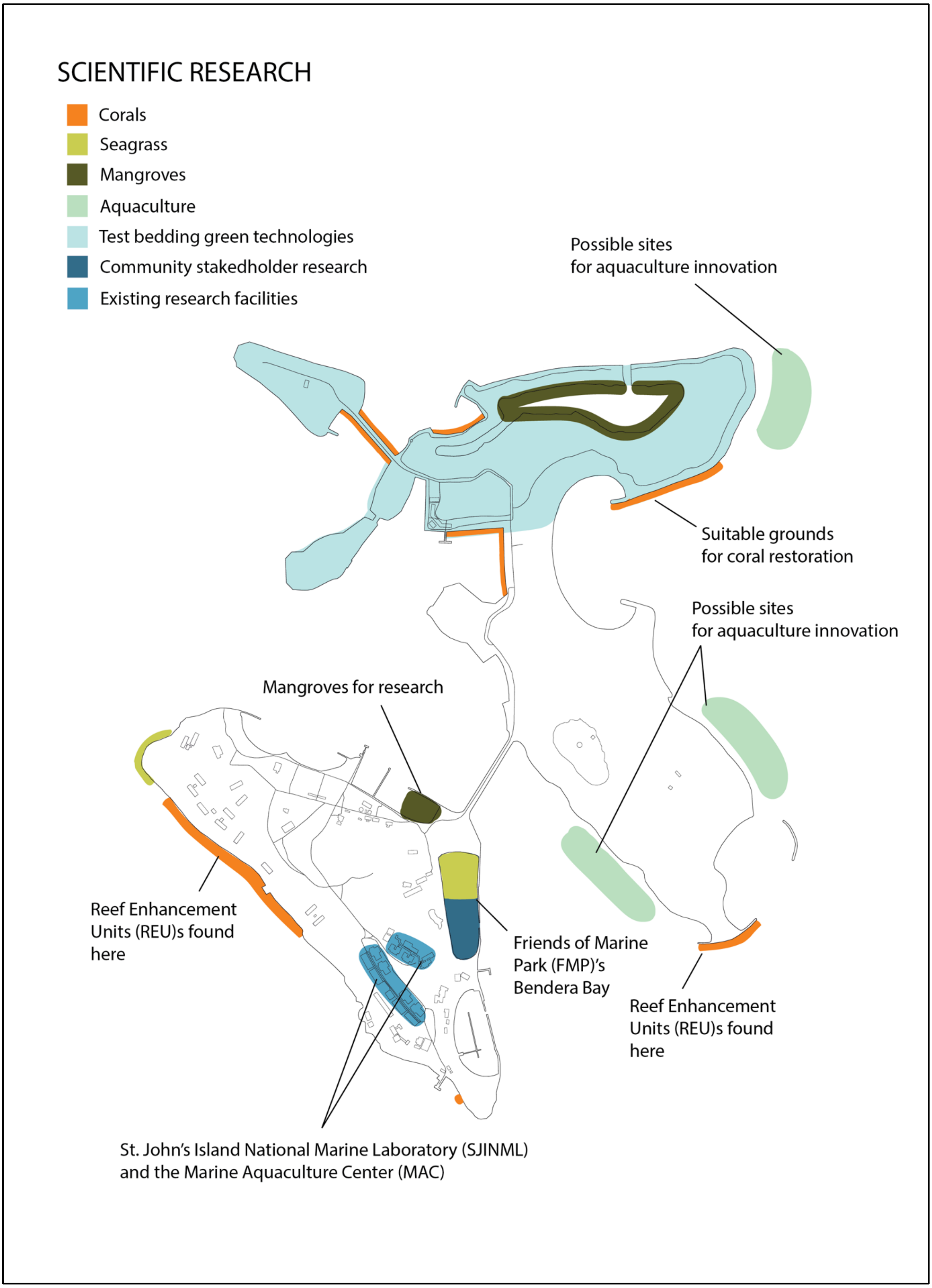


Figure 88 Consolidated map for Scientific Research. Maps are consolidated from participatory maps produced from mapping exercise with the Friends of Marine Park.

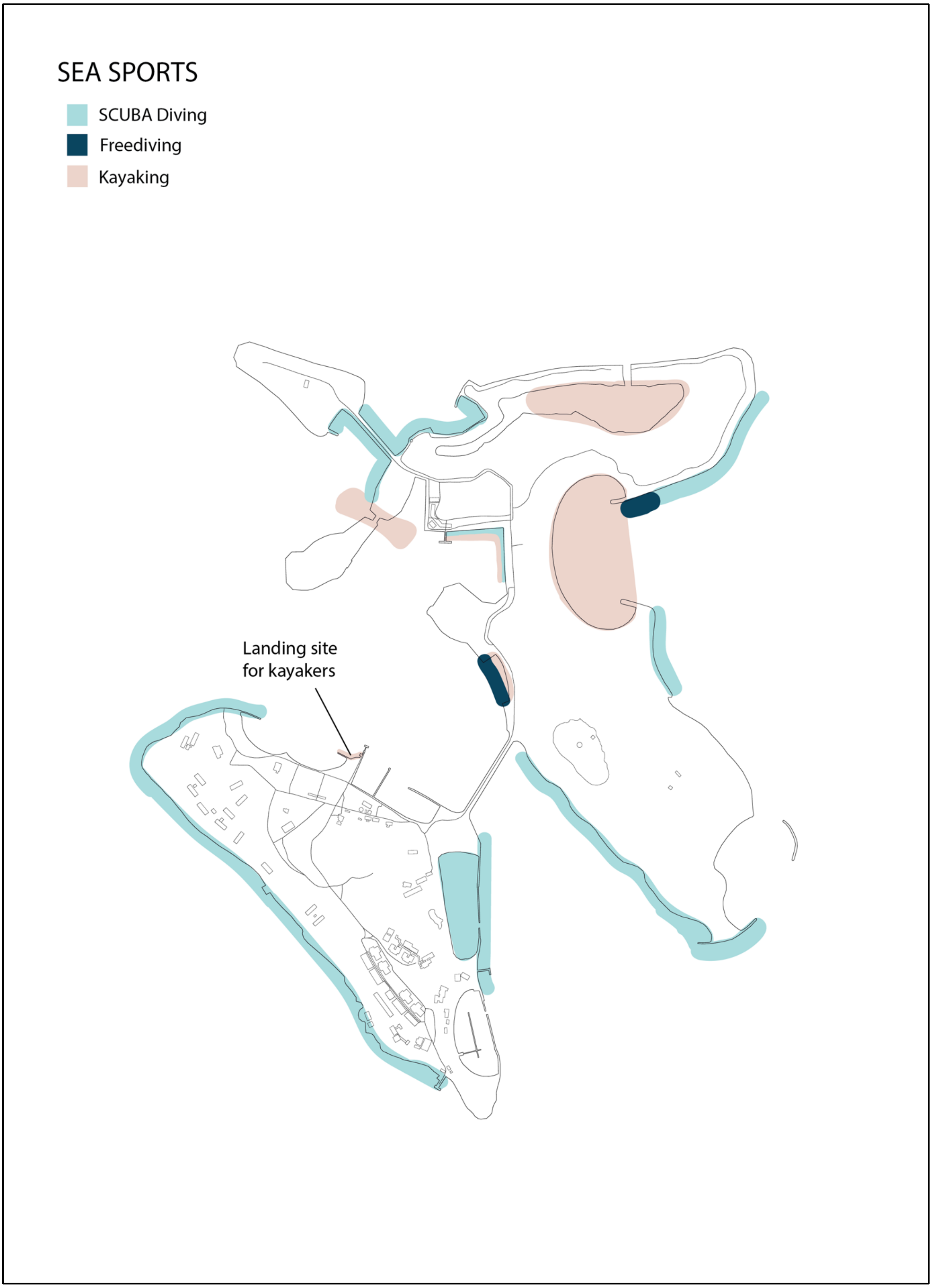


Figure 89 Consolidated map for Sea Sports. Maps are consolidated from participatory maps produced from mapping exercise with the Friends of Marine Park.

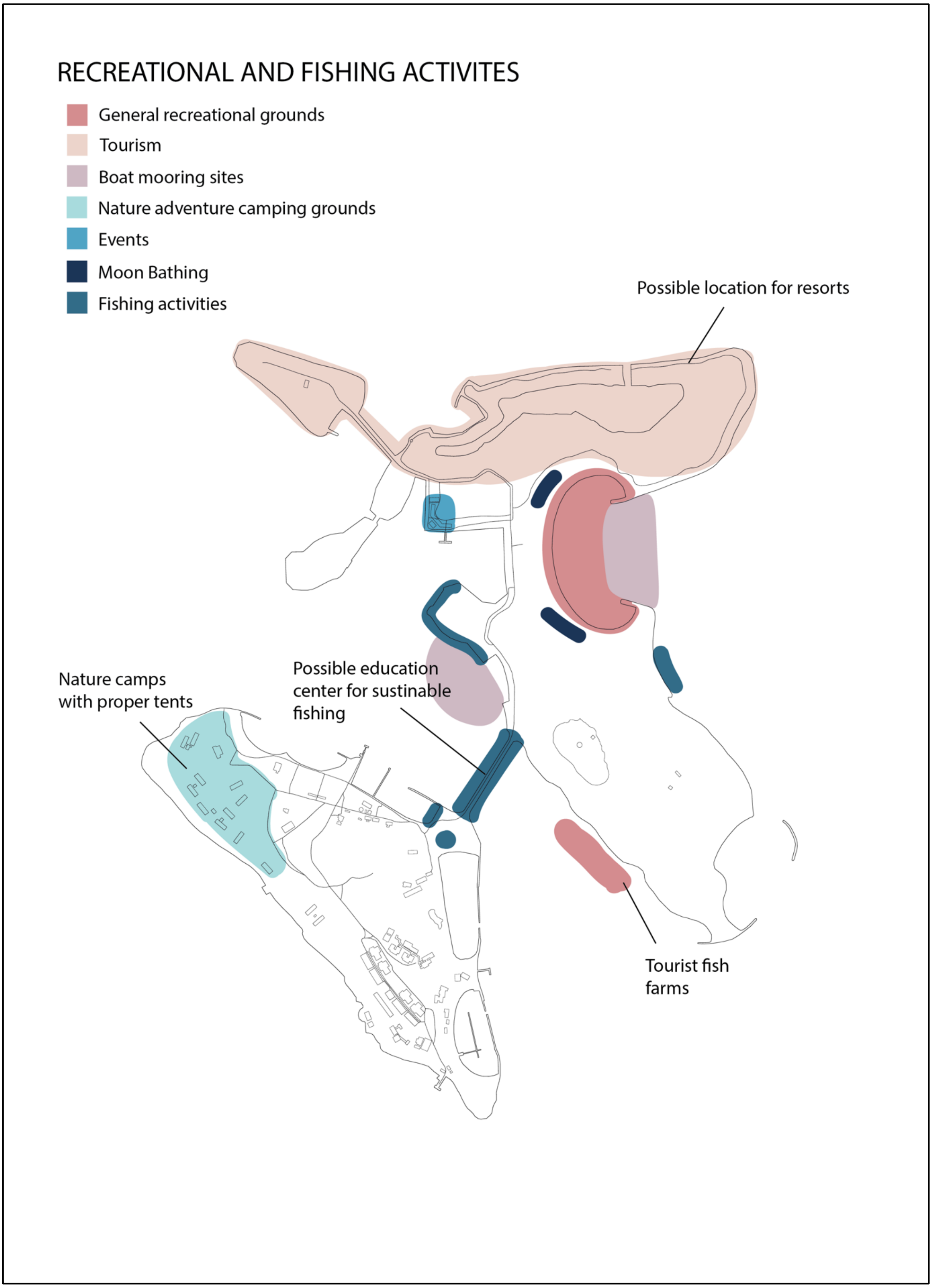


Figure 90 Consolidated map for Recreational and Fishing Activities. Maps are consolidated from participatory maps produced from mapping exercise with the Friends of Marine Park.

Voices of other community stakeholders:

The Singapore Blue Plan 2018

Recommendations for the islands by community stakeholders were proposed in the past in the Blue Plan 2018. The Blue Plan is a 'proposal for the conservation of marine ecosystems, prepared by members of Singapore society, and submitted to the Government for consideration. It was initiated by marine biologists with academics, volunteers, stakeholders, and concerned citizens. The Blue Plan synthesizes the current state of knowledge for marine environments, reviews relevant legislature and advocates comprehensive sustainable methods to manage this important ecosystem'.

History. Prior to the Blue Plan 2018, there were several other community-led proposals submitted to the government for the conservation of our local marine environments. In 1991, there was the Proposal for the Conservation of Coral Reefs in Singapore, which were then incorporated into the first Singapore Green Plan. In 2008, the International Year of the Reef, the first Blue Plan 2009 was submitted, which led to the Comprehensive Marine Biodiversity Survey (CMBS), a five-year large scale biodiversity survey that lasted from 2010 to 2015. The second iteration of the Blue Plan, the Blue Plan 2018, was able to gather the support of more partners and stronger scientific input and included relevant environmental legislation and polices.

Recommendations. The recommendations from the Blue Plan 2018 were aimed towards the sustainable conservation of coastal and marine systems in Singapore. They include the following:

1. Establish formal management systems for marine environments
2. Provide sustained funds for research initiatives and long term monitoring programmes
3. Enhance legislation to protect marine biodiversity and environment
4. Improve intra- and inter-agency coordination of public marine database
5. Protect remaining natural marine habitats from unnecessary biodiversity loss
6. Include topics on natural environmental into school syllabus and promote science communication

Particularly for the SJI, LAZ and Kusu Island, the Blue Plan 2018 also recommended for them to be designated as no-fishing areas in order to bolster the rehabilitation of corals in coral nurseries. The shorelines of these islands provide ideal sheltered areas for the growth of corals and have established as sites for coral nurseries.

6.3 | Research opportunities survey from marine science community stakeholders

Description of stakeholders. The marine science community stakeholders engaged were members and partners of the St. John's Island National Marine Laboratory (SJINML). This community include representatives from research, education, industries, government agencies and other relevant partners.

Research opportunities survey. The survey was held at the SJINML on the island during the Annual Stakeholders' Meeting on the 5th of December 2019. There were approximately 50 representatives at the meeting and a total of 29 responses were collected. Almost half of the responses collected were from the research community (48%), which were the dominant stakeholder group present (**Figure 91**). Representatives from industries (21%) and agencies (14%) formed the second and third largest group (**Figure 91**).

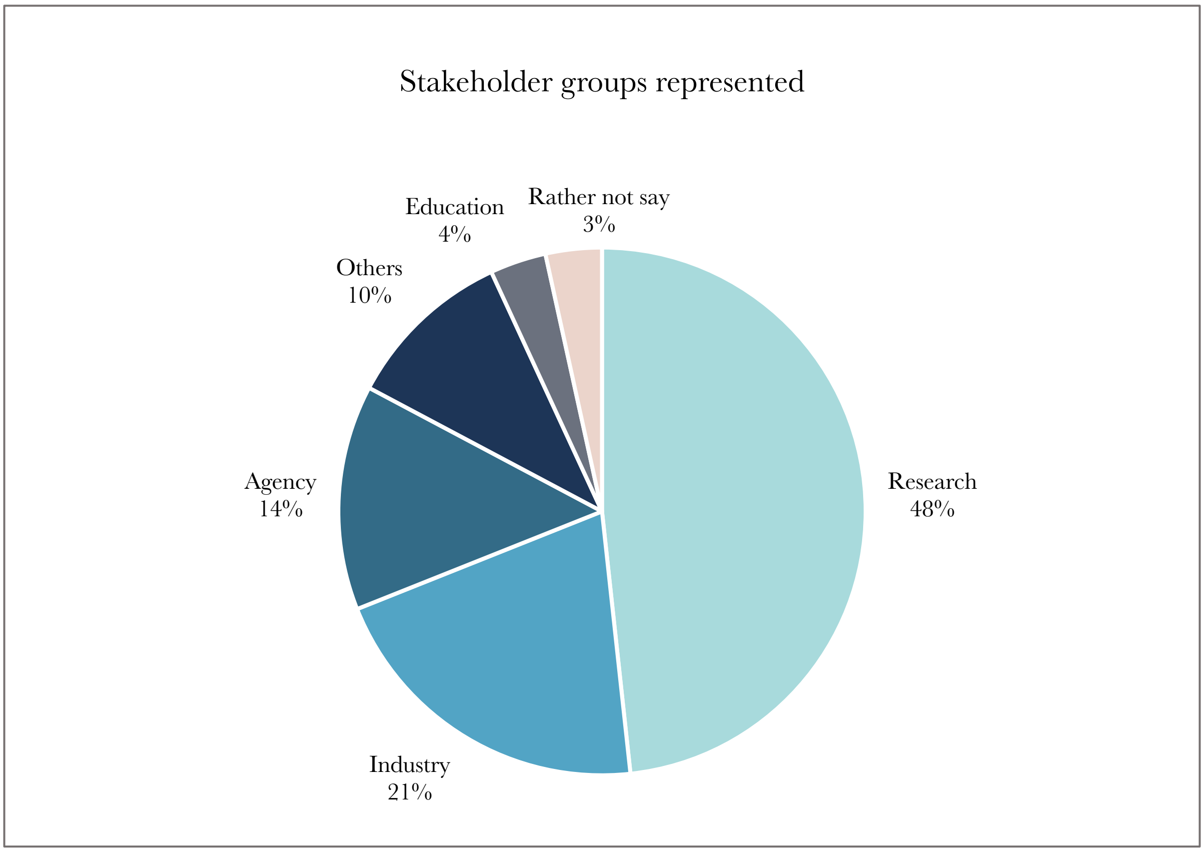


Figure 91 Breakdown of stakeholder groups surveyed during the SJINML Annual Stakeholders' Meeting.

Research opportunities. The respondents identified a number of possible research opportunities for the SJI-C in response to an open-ended question, which were then grouped into three tiers based on frequency of mention. The top tier included research in Biodiversity, Cultural History or Heritage and Geology; mentioned in 13, 12, and 12 responses respectively (**Figure 92**). In terms of biodiversity research, respondents recommended conducting a species inventory or census. For Cultural History or Heritage, aside from the research gaps mentioned in Chapter 4, respondents also suggested research on outreach strategies. Under the field of geology, respondents suggested geological mapping as an important study for the SJI-C. Respondents who identified natural history as a research opportunity also identified geological research to provide helping hands. These topics could be identified most strongly because they were presented at the beginning of the meeting.

Marine biology, climate change and ecology were topics identified in the next tier of suggestions. Climate change research were elaborated on to include sea level rise predictions, susceptibility to sea level rise, development resilience and prediction models for various natural habitats as well as in situ experiments to support those models.

Half of the respondents (55%) also identified the SJI-C coastal habitats as interesting areas for further research.

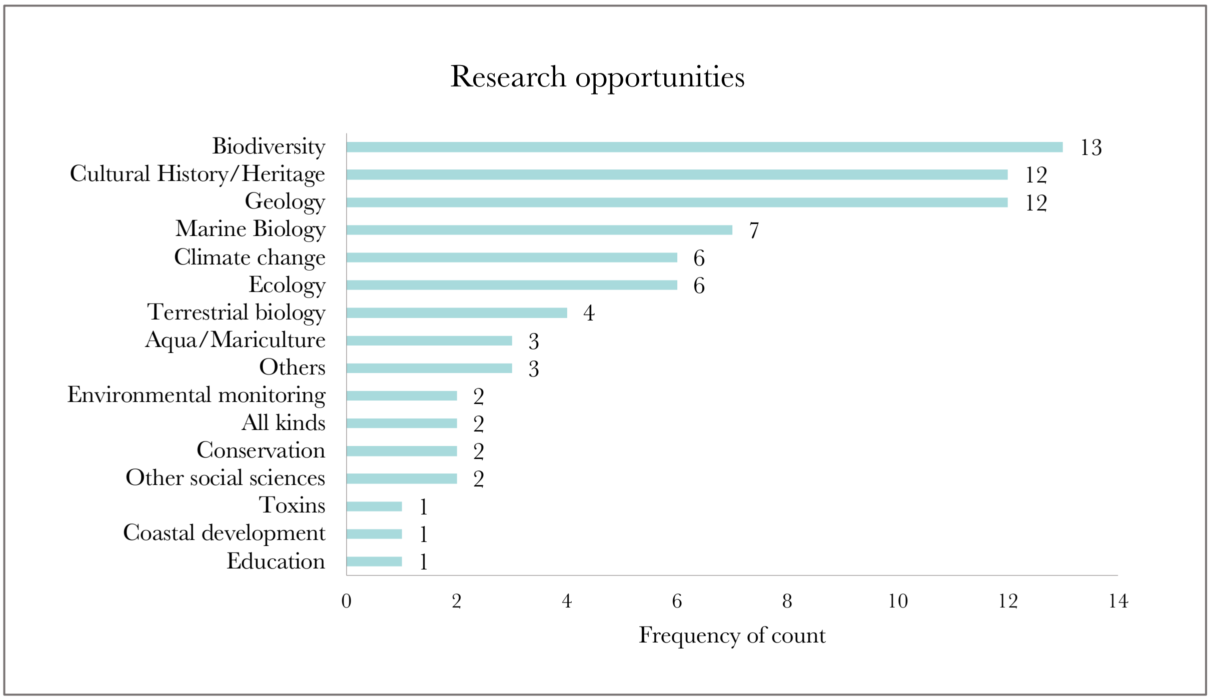


Figure 92 Graph showing research opportunities identified by stakeholders.

Activities compatible with research. Out of a list of activities, Conservation and Educations were identified to be most compatible with research, followed by both Aquaculture and Public recreation (**Figure 93**). Several respondents remarked that activities should be managed and have minimal pollution or disturbance to the natural environment in order to be compatible with research.

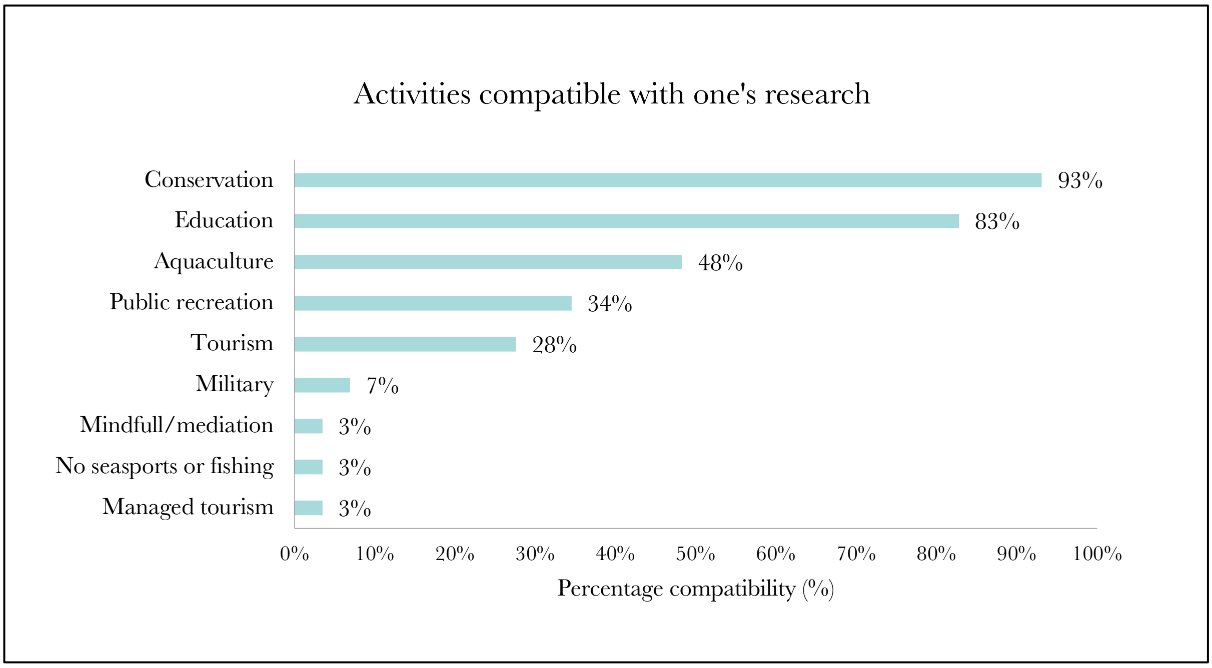


Figure 93 Graph showing activities identified by stakeholders to be compatible with research.

Research support. Facilities or programmes that would support research were also suggested; with education and outreach programs, and supporting amenities and facilities as the most common suggestions (**Figure 94**). Outreach and education programs included suggestions to develop more nature trails, cultural and historical trails, more facilities for educational purposes and supporting more student science projects. Supporting amenities and facilities were identified as important areas for improvement, including amenities such as toilets, food and beverage, shelter, the availability of power and internet connections, as well as better research accommodation or dormitories.

Respondents were also asked to consider the role SJINML should play in facilitating research in the Southern Islands (and in all other islands in southern Singapore) (**Figure 95**). Respondents noted that SJINML should provide support for research and researchers, as well as become a research hub known for having good infrastructure on an offshore location. This would include having state-of-the-art research and aquarium facilities, financial support and archival capabilities (for example, a depository for sediment cores). Mentorship for young researchers and communicating scientific research to the public through science-based camps were also cited as potential roles.

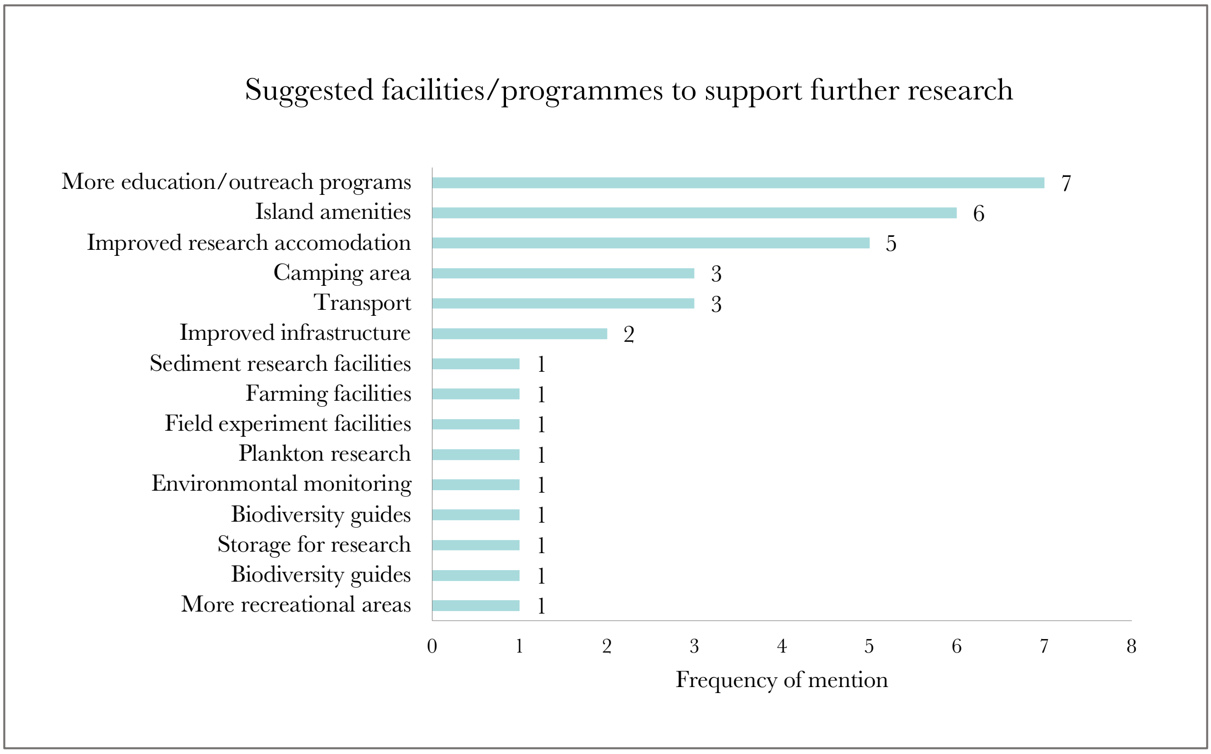


Figure 94 Graph showing improvements to support scientific research as suggested by stakeholders.

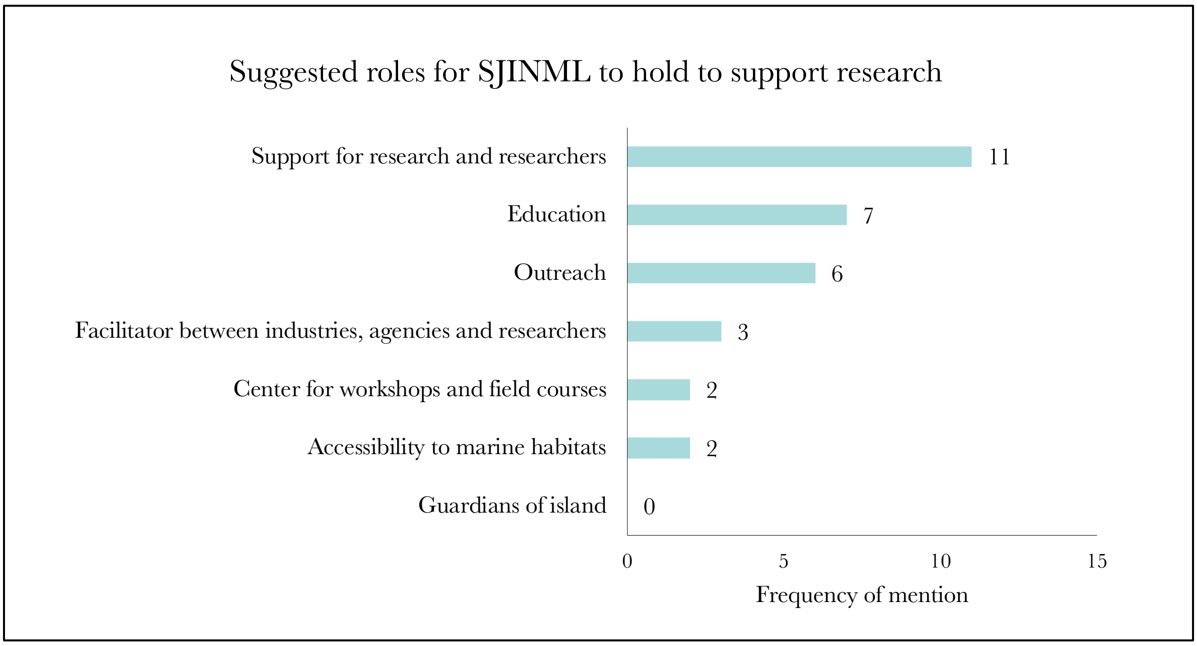


Figure 95 Suggested roles that SJINML could hold to support research in the Southern Islands.

6.4| Key findings

6.4.1 | Perception survey

1. **Profile of visitors.** Visitors to the island or those who intend to visit are mostly Singaporeans, long-term residents and working foreigners. Most are working professionals, with Education and Science and Research being prominent industries represented, as well as students.

2. **Regularity of visitors.** Half of the overall visitors are first timers, a quarter are annual visitors, less than a quarter are monthly visitors and the small remaining percentage are weekly or daily visitors.

3. **The island experience.** The dominant source of information on the island is through the word-of-mouth, and the dominant mode of transport to the SJI-C is the public ferry. The most common activity on the islands was nature walks (guided and non-guided). Other notable activities include beach activities and picnics, visiting the Sisters' Island public gallery, camping/overnight stays, fishing and water sports.

4. **Level of awareness.** Knowledge on the islands' cultural history and ecological characteristics is partial and good respectively. Knowledge of the islands' research and educational facilities correspond with its level of contact through visitors which in order of highest awareness is from SJINML, MPOEC and MAC.

5. **Significance of island to the respondent.** Most of the respondents reported that their favourite part of the SJI-C was its natural assets and rustic charm.

6. **Key issues.** While most visitors did not highlight any key issues on the island, a quarter of the respondents raised concerns related mainly to amenities, transportation and infrastructure. Amenities mostly include lack of toilets and food and beverage options; transportation mostly includes infrequent ferry timings; and infrastructure mostly included poor telecommunication and internet services.

7. **Key functions of the island.** Top three key functions for the island identified were Education, Research and Nature Reserve.

8. **Perspectives on change and improvements on the island.** More than half of the respondents did not see a need for change or improvements to the island. Some noted that there is a need for only a moderate level of change, related to improvements in amenities, activities, transportation and infrastructure. Environmentally-sensitive development was emphasised.

6.4.2 | Participatory mapping with community stakeholders

1. There were zoning strategies for Environment Conservation and Education, Heritage Conservation and Education, Nature and Heritage Trails, Scientific Research, Sea Sports and Recreational and Fishing activities were documented.

2. The zoning strategies mainly prioritised environmental conservation and education, as well as heritage conservation and education. Remaining areas that were not a priority to these functions were then assigned to other functions.

6.4.3 | Research opportunities survey with marine science community stakeholders

1. **Research opportunities.** Research on the biodiversity, geology and cultural history of the island were highlighted by most stakeholders. To enhance research, more education/outreach opportunities, better island amenities and improved research accommodations were suggested. Conservation and education activities were also identified as most compatible with scientific research.

2. **Role a of SJINML.** Most of the respondents suggested that SJINML provide support to research and researchers as well as become a centre for education and outreach. A notable role identified was to facilitate industry, agency and researcher engagement.

6.5 | Conclusion

There was an overwhelming consensus that the SJI-C's natural assets contribute greatly to the islands' charm. This was consistent between all responses from the general public, the FMP community and the marine science community. All groups stressed the need to ensure that the islands' natural habitats are preserved and protected due to its high ecological value and cultural importance, as well as for public enjoyment. The marine science community also raised the need for more biodiversity studies to be conducted in the Southern Islands. There is thus a need to incorporate conservation and environmental sensitivity in future plans for the area, and to ensure that any designation of the SJI-C, or part thereof, as a nature reserve will still enable the public to enjoy its charm and nature for the long term. Zoning plans can reference the maps created with the community stakeholders.

The importance of the role of the SJI-C in science, research and education was consistently expressed by stakeholder groups, independent of respondents' occupational background. The zoning maps support respondents' suggestions for the islands' role as a nature reserve or research and education hub. Input provided by the marine science community can also be used to guide future research in the Southern Islands. Despite the strong interest in having research as a key function for the islands, approximately half or less than half of the visitors surveyed were unaware of the research facilities already on the island and had not visited them before. There therefore needs to be improvements to signage and public outreach (among other aspects) to ensure increased footfall to the public areas of the available research facilities to enable increased public engagement and education.

Although the heritage value of the SJI-C was not emphasised by public stakeholders, this was probably due to a lack of public awareness. The stakeholder engagement sessions clearly identified the importance of research and education related to the cultural history of the islands. It is thus vital to incorporate the stakeholders' culture and heritage-related suggestions into the islands' future plans.

While it seemed to be the overarching view that there was no immediate need to bring large changes to the islands, improvements to address issues related to available amenities, transportation, recreational diversity and infrastructure (especially in relation to research facilities) are needed. Yet these improvements must be done without reducing the islands' charm and natural assets. Suggestions include more protection and restoration of the environment, and the implementation of "leave no trace" concept for waste disposal.

Chapter 7

Recommendations for the St. John's Island Complex

7.1 | Introduction

Singapore has always prided itself on being prepared for the future and leveraging on predicted trends to ensure continued progress as a society and nation. With the onset of climate change, the challenges Singapore will face in the coming decades will be vastly different from the ones we have tackled before. As an island nation, we are vulnerable to sea level rise and our imported food supply can easily be disrupted by extreme weather like droughts, floods and other global crises, as can our energy needs. Coupled with the projected growth of our population and their standards of living, we need to be pro-active in addressing potential issues, delivering solutions and seizing any economic opportunities arising from the ability to cope with future threats.

It is now the opportune time to invest in environmental research, education and eco-innovative technology and solutions to help us improve national resilience against challenges in the long-term, and develop the capacity to export such expertise to our regional neighbours. The St. John's Island Complex (SJI-C, consisting of the merged St. John's, Lazarus, Seringat and Kias Islands) (**Figure 3, Figure 96**) in particular, is well-positioned to play a pivotal role in these future advances. It is home to two major research facilities that are at the forefront of marine research in Singapore – the SJINML and the MAC, which leverage on the good water quality found around the islands. The availability of underutilised space means that current research facilities and efforts can not only be easily expanded, but also accommodate new uses, including technology test-bedding. With its rich habitats and biodiversity, unique geological formations, and historical importance, the SJI-C is also an ideal location for nature and environmental education, which are keys to creating a populace that is aware of the environmental challenges that we will face in the future.

With careful and sensitive planning, the SJI-C can be transformed into not only a hub for eco-innovation, research, education and conservation, but also a mix-used space that improves the quality of living for Singaporeans. Following the review study of the SJI-C (encompassing natural, historical, and scientific aspects) as well as extensive public and stakeholder engagement, there is now solid foundation to map the future of the SJI-C.

This Chapter serves to outlines recommendations for the SJI-C to be transformed into a hub for marine science research, education and eco-innovation.

Figure 96 Map of the St. John's Island Complex (SJI-C), within the Southern Islands. Map illustrated by Cecilia Su.

7.2 | Vision Statement

To transform the St. John's Island Complex (SJI-C) into an "Island of Eco-innovation" for marine research R&D, sustainability and environment education, conservation and partnerships for Singapore's long-term environmental, socio-economic and resource resilience.

7.3 | Strategic Thrusts and Guiding Principles

Singapore prides herself as a maritime nation with a proud legacy as a major trading hub in Asia. Singapore's economic, cultural and linguistic connections worldwide are largely due to our political stability, trademark efficiency, highly qualified workforce, and openness to R&D and education. The seas that surround us not only enable our marine economy, but also provide important ecosystem services that contribute to our current and future needs as a small island nation (**Figure 97**).

The SJI Complex provides an ideal isolated space to test-bed emerging technologies and new initiatives (e.g. closed-loop mariculture, eco-coastal defences, zero-waste facilities), carry out educational programmes and conduct research on the marine environment. We put forth these four key pillars for the transformation of the SJI-C:

1. Hub for Marine Science R&D
2. Champion of Experiential and Environment Education
3. Beacon for Urban Coastal Solutions in a Multi-use Landscape
4. Bridge for Natural and Cultural Capitals

The recommendations are based on the results of the SJI-C review study, stakeholder surveys and engagement and the following core strategic national thrusts:

- Advancing marine science research and development as a differentiator for Singapore's marine economy
- Increasing national and regional human resources by increasing science and eco literacy, skills upgrading and lifelong learning

- Building climate change resilience and ensuring sustainable development of our built and natural environment
- Towards achieving greater food and water security
- Increasing greater energy resilience by sustainable energy supply
- Strengthening socio-ecological resilience in the face of future disruptions by conserving our natural and cultural capital

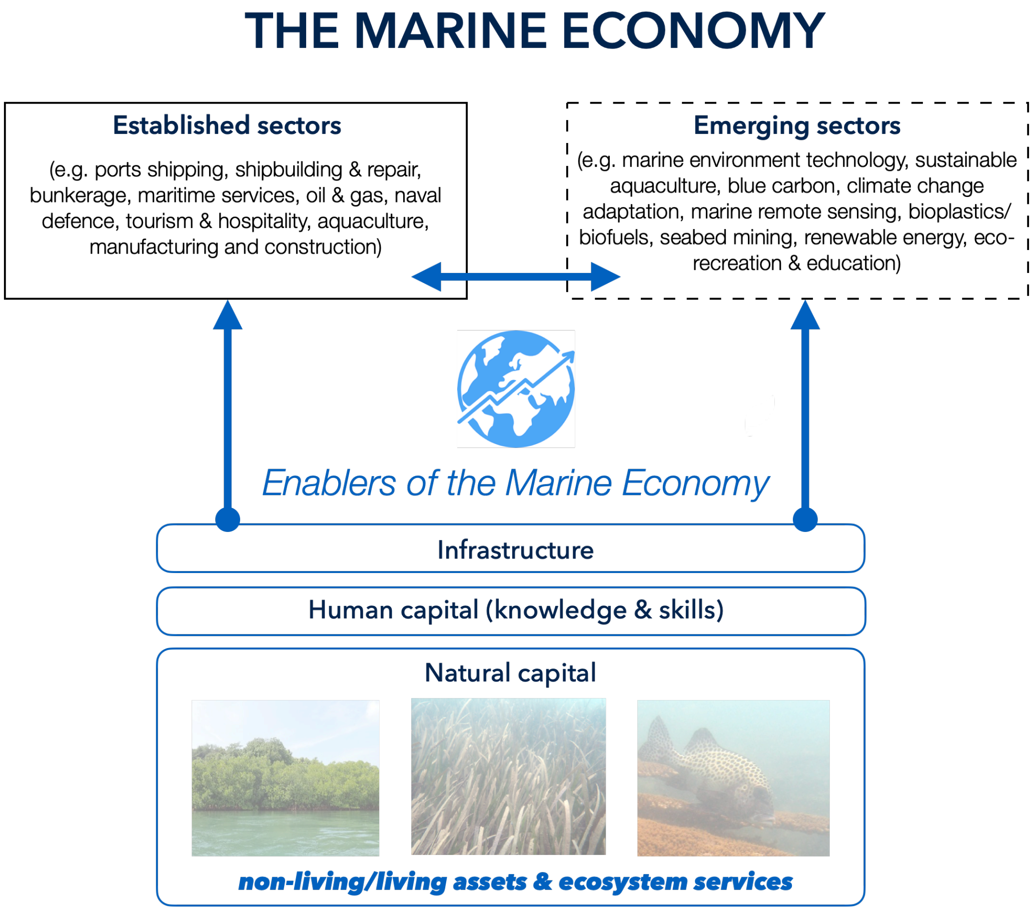


Figure 97 A snapshot of Singapore's marine economy.

Sustainability must be at the heart of any development to ensure the long-term viability of our limited resources. Any development for the transformation of the SJI-C must therefore be done in a manner that preserves the existing rustic nature, and rich natural and cultural capital that make the SJI-C unique. As such, we also propose the following guiding principles for transformation of the SJI-C:

1. All developments must be low impact and sensitive to the nature of the islands.
2. Encourage the use of eco-solutions to promote sustainability and consider the natural surroundings and native biodiversity of the islands.
3. Preserve the island heritage of the SJI-C, and conserve or rejuvenate important natural and historical sites/features.
4. Leverage on the educational value of the islands to cultivate responsible environmental stewardship

7.4 | The SJI-C as Islands of Eco-Innovation

The following Section outlines specific recommendations that will contribute towards the transformation of the SJI-C as a vibrant world-class hub for marine research R&D, sustainability and environment education, conservation and partnerships for Singapore's long-term environmental, socio-economic and resource resilience. The specific recommendations (A-Z) fall into each of the four key thrusts for the transformation of the SJI-C (see Section 7.3 | Strategic Thrusts and Guiding Principles). The summary of specific recommendations and the key research areas, key industry sectors and potential key agency stakeholders identified is presented in the **Appendix Table D 1**.

7.4.1 | Hub for marine science R&D

Research on the SJI-C was perceived favourably by the public and was consistently ranked as one of the top three preferred key functions of the island in the perception study conducted (**Figure 2**). This was possibly due to the presence of the two anchor research facilities on SJI, SJINML and MAC, which have a strong presence on the island since they were established in 2002–2003. This setting is an excellent opportunity to grow the SJI-C into an R&D hub with a focus on the rapidly expanding field of marine science. A marine science R&D hub also serves as a nursery and breeding ground for future innovators and game changers, and in shaping maritime and public policy (**Figure 98**). The specific recommendations A to G and their relevance to the SJI-C as a hub for marine science R&D are outlined below.

A) Coastal defence R&D

The low-lying areas of the SJI-C (see **Section 3.3.4 | Threats to the coastal environment**) could serve as a live site for R&D of novel coastal defence designs and other eco-innovative shoreline protection solutions for combating coastal inundation caused by sea level rise and increased storm surges. There is increasing consensus that a paradigm shift is needed in the way artificial structures are perceived and designed. Coastal defence structures will need to serve the dual purpose of reducing hazards as well as creating more liveable and sustainable coastal cities. The R&D into "blue-green" infrastructure will aid national efforts to develop long-term coastal protection strategies. With natural and modified coastlines, the SJI-C provides a microcosm of different environments that can be used for testing various coastal defence solutions.

B) Eco-innovation testbed

The self-contained and isolated nature of the SJI-C is ideal to testbed new innovative designs, technologies and approaches to coastal urban living with minimal disruption to the public. The SJI-C is therefore well-suited as a locale to support testing of blue-green innovations that utilise marine and coastal resources. There is also huge growth potential for marine technology R&D (e.g. remote sensing technologies for marine environment monitoring, aquaculture innovation, closed-loop systems, renewable energy). As a relatively blank canvas, the SJI-C can be a space to launch marquee projects that encourage collaboration between research, agencies and commercial partners.

C) Marine renewable energy

As Singapore looks towards renewable energy options, the SJI-C can also serve as a test-site for innovations in marine renewable energy. An earlier assessment published in 2012 identified two possible locations around the SJI-C for placements of various types of technologies to harvest tidal energy (see **Section 5.2.6 | Marine Tidal Energy**). As large areas of the SJI-C are yet to be connected to electrical service lines, there is opportunity as well as purposes for a combination of technologies to be tested and established as sources of renewable energy (e.g., tidal energy, wave, solar, biofuels) for use on the islands.

D) Marine Environment Sensing Network

Long-term, continuous monitoring of the marine environment provides the foundation for understanding the characteristics and vulnerabilities of our seas. Strong marine environment observing capabilities provide a core capacity for R&D that enables forward planning to maintain a healthy marine environment and overcome challenges of climate change. The SJI-C is located away from major coastal industries and its southerly position at the confluence of tidal streams between the South China Sea and Malacca Straits provides useful information of changes taking place regionally. Establishing an observatory for Singapore's marine environment around the SJI-C enables long-term monitoring that safeguards the health of our seas and value-adds marine science R&D. The Marine Environment Sensing Network (MESN) will contribute towards Singapore's marine monitoring efforts and raise capability for marine climate science research.

E) Nature-based solutions & Blue Carbon

Singapore is already experiencing the impacts of climate change—higher temperatures, rising sea levels and more unpredictable weather. Nature-based solutions that leverage on natural systems or biodiversity to address societal challenges are ways to build resilience in the face of these risks. With existing natural habitats which have high blue carbon value (e.g., seagrass meadows and mangroves; see **Chapter 3**), the SJI-C can serve as a demonstration site to showcase eco-innovation and trial strategies for nature-based climate change mitigation.

F) Eco-resilience

Biodiversity is needed to maintain ecosystem functioning, with the broad consensus that increasing the biodiversity of a system improves its ability to maintain and/or increase functionality. With diverse ecosystems (e.g., coral reefs, coastal forest, mangroves, seagrass beds, sandy and rocky shores) and a world-class offshore marine research facility (SJINML), the SJI-C can function as a "living laboratory" to attain better scientific understanding, formulate strategies and policies that enhance ecological resilience, conservation and management. The western coast of SJI forms part of the Sisters' Islands Marine Park. As part of the marine park, there is also opportunity for the SJI-C to serve as a living gene repository for Singapore's key marine biodiversity.

G) Marine science R&D, aquaculture innovation and partnerships

The SJI-C houses Singapore's only offshore National Research Infrastructure (NRI) for marine science R&D. Since 2016, SJINML has operated as an NRI that supports multi-disciplinary and multi-institution research. The SJI-C also houses Singapore Food Agency's (SFA) Marine Aquaculture Centre (MAC). Securing SJINML and MAC for posterity will encourage long-term investment and capacity building for marine science R&D and the development of sustainable aquaculture expertise in Singapore. These established core research facilities will play key roles in establishing the SJI-C as a hub for marine science R&D. Possible expansion of these facilities could include shared-use spaces for marine technology R&D and aquaculture innovation to address future national challenges while fostering synergy across disciplines. A world-class hub for marine science R&D also requires international research collaborations. Schemes to facilitate greater international cooperation and regional collaborations can be developed (e.g. joint research and projects that involve multi-national partners). Such efforts will help the SJI-C to become an internationally recognised hub for marine and environmental research/technology, drawing a global audience from both public and private sectors.

Figure 98 Proposed zone for marine science R&D on the SJI-C, and suggested locations for A) Coastal defense R&D, B) Eco-innovation test-bed, C) Marine renewable energy, D) Marine Environment Sensing Network, E) Nature-based solutions & Blue Carbon, F) Eco-resilience, G) Marine science and aquaculture R&D.

7.4.2 | Champion of experiential learning and environmental education

Improving environmental education and awareness is becoming increasingly essential to preparing our future generations for the imminent challenges of climate change. Studies have shown that connections with nature are important for promoting environmental behaviour. As such, exposing Singaporeans to our natural environment from a young age could lead to long-lasting behavioural changes and result in a more eco-conscious society. With its natural setting, rich history, and presence of scientific institutions, the SJI-C and the large Southern Islands group provides educational spaces for people of all backgrounds and ages – school children to university students to adults and professionals. It is well-positioned to play an important role in how we carry out environmental education in Singapore. This is supported by the fact that education was the highest ranked preferred function amongst respondents in the public perception survey. The SJI-C can serve as a nursery and breeding ground for future innovators, game changers and policymakers (**Figure 99**). The specific recommendations H to L and their relevance to the SJI-C as a champion of experiential learning and environmental education are outlined below.

H) Outdoor education

Field-based learning adds dimension for education to be authentic and holistic. Nature-based outdoor education can inculcate environmental stewardship in our next generation by increasing their awareness of nature and sensitivity to the environment beyond the city-scape. With an existing campsite (managed by SLA) on SJI, there is opportunity for the SJI-C to be another site for outdoor education. Current campsite facilities on SJI can be upgraded to support more outdoor and environment education.

I) Environmental education

Nestled in rich flora and fauna with multi-cultural history and the presence of scientific institutions and research facilities, the SJI-C provides an ideal space for marine science and environment education in an open classroom setting. The presence of a research facility on-site with learning spaces (e.g. SJINML) provide avenues for students to interact with scientists and be involved in active research that provide context for real-world problems. Co-curricular environment education programmes involving both local and international expertise can extend learning of content relevant to school syllabus. There is also opportunity for community-based environment education programmes with the Friends of the Marine Park community establishing a presence on the SJI-C through Bendera Bay, an NParks' managed area located next to DSTA and just behind SJINML (**Figure 99**).

J) Regional capacity building

With global development and technological advancement, the world experiences growth and shrinkage at the same time. Countries are intricately linked to each other, and border porosity promotes the transfer of not only valuable resources but also undesirable goods. This interconnectedness is epitomised in the marine environment. Focusing solely on local efforts to solve large-scale climate issues will be myopic. The regional and global contexts must be examined and assessed. As such, the capacity to put forth solutions should be raised and promoted. Informed decisions based on shared validated data will be key to providing a more comprehensive answer to the challenges of tomorrow. The SJI-C as a hub for marine science R&D can provide a rich platform for sharing skills, knowledge and build the international networks (in particular our regional neighbours) needed to take care of our shared environment.

K) Experiential learning

On-site experiences coupled with their digital immersion counterparts create a flexible learning environment. The SJI-C can provide on-site/place-based learning and immersive programmes that allow participants to experience the environment with their senses through formal & informal education. A virtual twin could be created for the SJI-C (natural habitats, research facilities) to aid in e-learning and digital education. A digital twin will also be useful for R&D and can benefit other efforts on the SJI-C (e.g. planning for R&D efforts).

L) Skills and professional development

The SJI-C can support training programmes in marine science and aquaculture for more technical skills and professional development. Curated specialised programmes will bring together experts and participants with relevant backgrounds and encourage opportunities for lifelong learning.

Figure 99 Proposed zone for experiential learning and environment education on the SJI-C, and suggested locations for H) Outdoor education, I) Environment education, J) Regional capacity building, K) Experiential learning, L) Skills & professional development.

7.4.3 | Beacon for urban coastal living in a multi-use landscape

The self-contained and isolated nature of the SJI-C opens up opportunities to test-bed new innovations and approaches to coastal urban living with minimal disruption to the public. The SJI-C can serve as a microcosm that integrates different environments and functions in a multi-use landscape to meet the varied needs of society and showcase Singapore's commitment to sustainable development (**Figure 100**). The specific recommendations M to L and their relevance to the SJI-C as a champion of experiential learning and environmental education are outlined below.

M) Eco-tourism and immersive experiences

By creating recreation, innovation and education programmes around key spaces in the SJI-C, the island can become a model of sustainable tourism in the region. There can be extended learning journeys from mainland Singapore and Sentosa, with the SJI-C providing "off-the-beaten-track" experiences for visitors looking to value-add their recreational activities (e.g. science in the outdoors, immersive tours). An example could be a Farm-to-Table (FTT) bistro to provide visitors with an authentic experience with minimal carbon footprint, or educational tours to learn more about the unique role that the SJI-C plays in marine research and conservation and food security (i.e. mariculture).

N) Closed-loop concepts

The SJI-C can serve as a test-bed site for closed loop concepts and novel technologies. In particular, the proximity to the sea makes it an ideal site to test blue-green innovations that utilise marine resources and are compatible with the sustainable use of the marine environment. Having the SJI-C as a dedicated test-site will be instrumental in helping build Singapore's expertise in the field and help showcase the future of urban coastal living. With visitation to the SJI-C by the public on the rise, the SJI-C can be used as a demonstration site to engage community and introduce new eco-innovative concepts and approaches to sustainable coastal urban living. An example is the concept of closed-loop dining, where food production, consumption and waste is combined with renewable energy generation (e.g. tidal energy, solar, bio-fuels), to create (as much as possible) a closed loop system that produces minimal waste. Compatible innovations can be tested alongside eco-resorts or net-to-plate/farm-to-fork restaurants that work with nearby mariculture farms and can serve as a proof-of-concept for implementation on larger scales.

O) Improved amenities (land and sea)

Improved amenities on the SJI-C will be needed to increase carrying capacity of the islands as the SJI-C encounters increased visitorship and transformed to accommodate expanded functions. Our public perception surveys revealed the need for improved general amenities like toilets, water dispensers, F&B options (possibly at the location of the original cafe on SJI), stronger network and communication connections. While the SJI-C is now served by power and water lines from mainland Singapore, there is also opportunity for use of off-the-grid renewable energy options. Improved amenities for visitors to the sea space around the SJI-C are also recommended. This should include buoys for boat moorings in popular anchorage sites, in particular those that have also identified harbouring sensitive habitats and/or high biodiversity (e.g. Eagle Bay with its lush seagrass meadows). The vertical seawalls constructed as part of earlier plans for LAZ was purpose-built to accommodate boat moorings. This could now be activated to allow recreational yachts access to the islands, and ease traffic at the two SJI-C public jetties. Specific areas can also be designated for specific activities such as SCUBA diving or freediving (**Figure 101**). As the sea space around the SJI-C become busier, accommodating shipping/sea transport, mariculture, conservation and different types of recreation (kayaking, boating, swimming, fishing/angling, diving, jet ski etc), designation of activity zones around the SJI-C may be crucial in reducing risks of unwanted accidents or conflicts, and ensuring safety at sea.

P) Improved transport links

As part of amenities, ferry links (e.g. Lazarus-Sentosa) to the SJI-C can be increased to facilitate transport to and fro Singapore mainland and Sentosa Island. In line with the general vision of the SJI-C as Islands of Eco-innovation and Singapore's goals for decarbonising public transport, there is prospect to replace or upgrade ferries to be powered by renewable energy (e.g. solar).

Q) Sustainable aquaculture

To address future food security challenges, aquaculture and mariculture research will become increasingly vital. With good water quality and good flushing, the SJI-C is well-suited to support sustainable mariculture that will add to Singapore's goals to produce 30% of its nutritional needs by 2030. Proximity to sensitive habitats nearby also provide important ecosystem services (e.g. nutrient cycling) that helps maintain good water quality in these waters. Given these conditions, there is potential to position the SJI-C as a hatchery hub to increase supply of fry to fish farms in Singapore and the region. A fish farm area has also been planned in the sea space between Lazarus and SJI (**Figure 100**), situated right in front of Bendera Bay (managed by NParks, Friends of the Marine Park) and in plain view of recreation goers to the island. The SJI-C can serve as a showcase for sustainable mariculture in a multi-use landscape – setting high industry standards for responsible aquaculture, demonstrating use of clean technologies and exposing the public (and corporate partners) to locally grown seafood. Better education and awareness are needed within Singapore to ensure that demand for locally grown foods can sustain local production. The Farm-to-Table (FTT) initiatives can link local farmers to local restaurateurs on the SJI-C or Sentosa, thereby helping increase appeal and appetite for local produce. These serve as a proof-of-concept for implementation on larger scales.

Figure 100 Proposed zone multi-use/commercial and recreation activities on the SJI-C, and suggested locations for M) Ecotourism and immersive experiences, N) Closed-loop systems test-bedding, O) Improved amenities, P) Improved transport links, Q) Sustainable aquaculture.

7.4.4 | Bridge for natural and cultural capitals: strengthening socio-ecological resilience

The SJI-C can serve as a focal point for community partnerships and appreciation for natural or built spaces to strengthen socio-ecological resilience and nurture a national identity based on a shared past and present. Intimate links exist between the SJI-C's history and its abundant surrounding coastal and marine natural heritage. It would be remiss for us not leverage on this wealth of natural and historical assets to create a bridge that brings communities together in a mixed landscape (**Figure 101**). Environmental problems are as well problems of society. Creating community partnerships and appreciation for our living spaces (natural or built, past and present) therefore strengthens socio-ecological resilience. As Singapore progresses, the rich marine biodiversity and maritime heritage the SJI-C holds contribute to contextualising the modern urbanised marine environment we currently live in, linking Singapore's history to its contemporary goals of being a leader in technology and science.

R) Forest restoration

There is visible soil erosion that threaten existing heritage trees (including 150 year-old Tembusu on SJI) and vegetated areas around the SJI-C, but especially so on SJI. Increasing pockets of forest and reducing clearings through forest restoration not only help reduce erosion, but can increase carbon storage capacity of vegetated areas. Forest restoration efforts are in line with Singapore's OneMillionTrees initiative. Heritage trees can also be a focal point of cultural exploration for visitors to the SJI-C.

S) Heritage & visitor centre

Old colonial buildings on SJI can be restored and re-purposed as the "Islands Heritage & Visitor Centre". Such a centre will celebrate the rich natural and cultural heritage of the islands while providing information for visitors to the island as well as key amenities to the public, including for safety and security. This space can also be used to showcase research & provide avenues for public education.

T) Community hall

To preserve Singapore's island heritage while creating spaces for communities to connect, the old St. John's Island English School (SJIES) can be restored and re-purposed as a multi-use community hall to bring stories, science and people together. This will encourage committed community participation that will contribute to the success of the SJI-C as a multi-use island complex.

U) Community activities

The SJI-C holds a wealth of natural and historical assets that belong in our heritage treasury that can be for shared use not just for today, but also for the future. The SJI-C can therefore serve as a focal point for community partnerships and strengthening national identity through a shared heritage. Some examples of community activities include traditional Jong and Kolek races contrasted against modern maritime seascape and traditional fishing practices vs. mariculture innovation can be showcased at the SJI-C, drawing links to the past and the present, bridging tradition and technology.

V) Historical features

Historical features on the SJI-C should be conserved where possible as part of our shared past and national identify. A prior historical study had identified historical sites for conservation or appropriate repurposing, including:

- Moon gate (within MINDEF compounds)
- Mosque
- Remaining platforms of former dormitories
- Former ammunition storage facility
- Grave on SJI that should be exhumed & relocated
- Old teacher's quarters

W) Artificial reefs

Artificial reefs, if properly constructed and managed, can augment biodiversity conservation efforts by creating additional refuge for marine life. Previous efforts that have established coral nurseries and deployed artificial substrates (e.g. Reef Enhancement Units) at the SJI-C have demonstrated success in enhancing marine biodiversity. The surrounding waters in the SJI-C can be used as a test-bed to innovate functional artificial reef structures that can stabilise loose rubbles and encourage marine life colonisation.

X) Coral reef conservation (Kusu Island)

The coral reefs fringing the eastern coast of Kusu Island is rich, diverse and unique. This site has been the focus for numerous reef research and restoration efforts in the more than past two decades, including sustained environmental and ecological monitoring efforts driven by researchers and citizen scientists (e.g. Reef Friends, BlueWater Volunteers). While National Parks Board Singapore (NParks) is currently conducting the Southern Islands Biodiversity Survey to identify areas for conservation, the Singapore Blue Plan 2018 did recommend elevated protection status for the reefs around Kusu Island on the basis of its biodiversity and functions as a living laboratory and observatory for coral reef research.

Y) Coastal forest conservation (Lazarus Island)

The coastal hill forest on Lazarus Island is a refuge for numerous nationally endangered trees, and is an ideal candidate for protection. This remnant patch is relatively untouched due to its isolation and serves as a rare example of coastal hill forests eco-systems which are increasingly rare on the mainland. This coastal forest also houses the former ammunition facility that is of historical interest and provides opportunities for merging natural and historical exploration.

Z) Natural rocky shore conservation (Lazarus Island)

Adjacent to the coastal hill forest on Lazarus Island is a relatively untouched stretch of natural rocky shore, which is a rare habitat on mainland Singapore that support high biodiversity and should be protected. With interesting and exposed geology, this small stretch of rocky shore on Lazarus island also has value as a site for environment and earth science education.

Figure 101 Proposed zone for natural and cultural heritage conservation, and suggested locations for R) Forest restoration S) Heritage and visitor centre, T) Community hall, U) Community activities, V) Conservation of historical features (see list in section below), W) Artificial reefs, X) Coral reef conservation (Kusu Island), Y) Lazarus Island coastal forest conservation, Z) Natural rocky shore conservation.

7.5 | Summary and Conclusion

How we choose to develop the SJI-C will affect how Singaporeans perceive and experience the island in the future. With various land reclamation efforts and fragmented use of the SJI-C in the past, much of the island has already been lost. However, the SJI-C remains a relatively blank canvas by contrast to mainland Singapore island, where efforts are ongoing to reset habits, promote sustainability and encourage environmental stewardship. It is paramount that future developments on the SJI-C are sensitive, but also maximise use and showcase Singapore as a world-leader in marine and environmental research/technology committed to sustainability.

With added structure, support and long-term planning, the SJI-C can be strategically transformed to as "Island of Eco-innovation" for marine research R&D, sustainability and environment education, conservation and partnerships that can cater to Singapore's long-term environmental, socio-economic and resource resilience needs. Leveraging on existing research facilities, mariculture efforts and tourism and recreation activities, the SJI-C can serve as a multi-use island complex that fits the varied needs of society.

Exercising prudence to maintain a multi-use strategy of the SJI-C will help safeguard longer-term optimised use of the island complex. Ensuring routes taken to realising shorter-term national objectives (e.g. 2030 strategies etc) are sustainable (environmentally, economically) will be critical in order to ensure that past effort and future goals are not penalised.

The potential role that the SJI-C can play in research, education and innovation goes beyond Singapore too. The SJI-C sits at the geographic centre of the SIJORI (Singapore-Johor-Riau) region, the fulcrum of an area already identified as having huge economic, social and political collaborative potential. The island complex is well-placed to be the heart of marine environment and food security research for the region, actively engaging with Singapore's neighbours to learn and benefit from regional expertise and resources for our own longevity and survival in an increasingly tumultuous world. With links to world-class research institutions, experts and educators, there are opportunities to transform the SJI-C into a hub where Singapore's research can be showcased to the region. We can demonstrate how coastal development can be balanced with nature and biodiversity, with innovative solutions and cutting-edge technologies, developed and tested right on the island. With tropical coastal cities rapidly developing all around the region, we need to seize the opportunity to set the standard for sustainable development, thereby ensuring the long-term sustainability of the seas that surround us all in the region. While exporting such expertise will undoubtedly benefit us economically, the soft power to be gained by positioning Singapore as a leading innovator in environmental solutions and technologies could potentially be far more valuable. A sustainably developed the SJI-C will also be a positive signal of Singapore's commitment to local and international environmental initiatives such as the United Nation's Sustainable Development Goals, the United Nation's Convention on Climate Change, the Aichi Biodiversity Targets, Singapore' Nature Conservation Masterplan and the Singapore Blue Plan.

In the coming decades, Singapore will face a range of environmental and societal challenges including climate change and growing population needs. Many of these require us to develop novel solutions in the present to avoid or minimise impacts in the future. The SJI-C presents an ideal opportunity to test these solutions, particularly in relation to eco-innovations and urban coastal management.

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Appendices

A. Perception Survey for the general public

Section 1: Personal data

1. Gender
   - ☐ Male
   - ☐ Female
   - ☐ Rather not say

2. Age
   - ☐ Below 14
   - ☐ 15-19
   - ☐ 20-29
   - ☐ 30-44
   - ☐ 45-56
   - ☐ Above 65

3. What is your ethnicity
   - ☐ Chinese
   - ☐ Malay
   - ☐ Indian
   - ☐ Other: ____________________

4. Which industry/field are you working in?
   - ☐ Banking and Finance
   - ☐ Chemicals
   - ☐ Civil service
   - ☐ Construction
   - ☐ Education
   - ☐ Engineering
   - ☐ Logistics

- ☐ Healthcare
- ☐ Info-communication and Media
- ☐ Science and Research
- ☐ Student
- ☐ Tourism
- ☐ Not applicable
- ☐ Other: ____________________

5. Annual income bracket (in SGD)
   - ☐ Less than 10K
   - ☐ 10 - 20K
   - ☐ 20 - 30K
   - ☐ 30 - 40K
   - ☐ 40 - 60K
   - ☐ 60 - 80K
   - ☐ 80 - 100K
   - ☐ More than 100K
   - ☐ Rather not say
   - ☐ Not applicable

6. Are you a Singaporean?
   - ☐ Yes
   - ☐ No

7. Are you a tourist?
   - ☐ Yes
   - ☐ No

Section 2: Your Southern Island Experience

8. How did you know about St. John's Island/Lazarus Island?
   You may choose more than one option.
   - ☐ Social Media (Facebook, Instagram, Twitter etc.)
   - ☐ Word-of-mouth from relatives and/or friends
   - ☐ Blog posts
   - ☐ Government websites (Please indicate which government board it was in the 'Other' option below.)
   - ☐ Other: ____________________

9. How often, on average, do you come to either or both of the islands?
    - ☐ Daily
    - ☐ Weekly
    - ☐ Monthly
    - ☐ Yearly
    - ☐ First time to the island at time of this survey
    - ☐ Never been before

10. How did you get to the islands?
    You may choose more than one option.
    - ☐ Public ferry
    - ☐ Private charter
    - ☐ Private yacht
    - ☐ Kayak
    - ☐ Never been before
    - ☐ Other: ___________________

11. Did you face any issues when you were going to/at the island(s)? If so, what are they?
    For example: transportation, services, infrastructure, amenities.

    ____

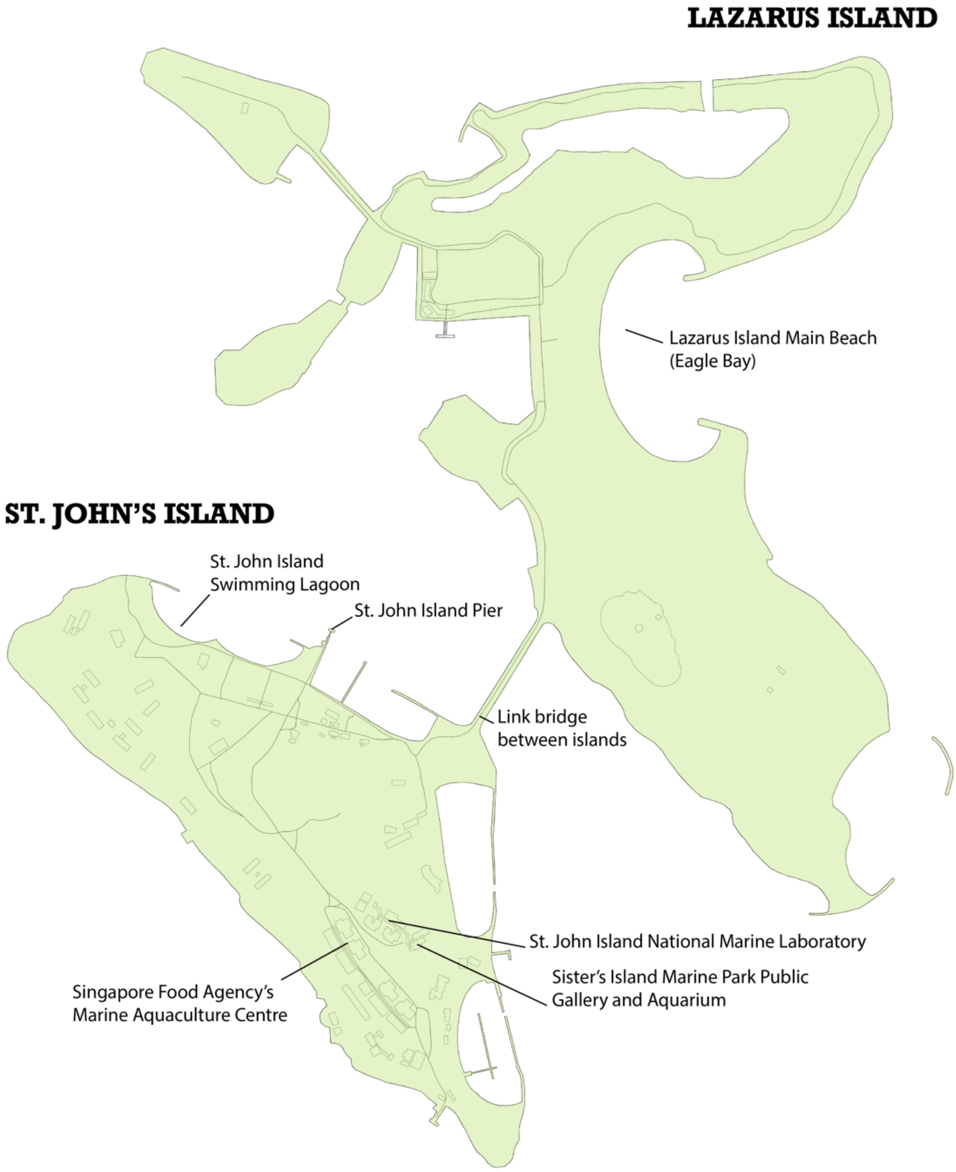
    ____

12. What are you planning to do or what have you done on the island before?
    You may choose more than one option.
    - ☐ Beach activities
    - ☐ Camping/Overnight stay
    - ☐ Fishing
    - ☐ History/Culture
    - ☐ Nature walks (land and intertidal)
    - ☐ Visit the Sisters' Island Marine Park public gallery and aquarium
    - ☐ Picnic
    - ☐ Religious activities
    - ☐ Scientific research
    - ☐ Water sports (including SCUBA diving and freediving)
    - ☐ Personal memories/reasons (Please elaborate in the 'Other' option below.)
    - ☐ For work (Please indicate the nature of your job in the 'Other' option below.)
    - ☐ Other: ___________________

13. What is your favourite part or experience on the islands? Why?
If you have not visited the islands, please answer with the part or experience you are most looking forward to. A map has been included below for your reference.

____

____



Section 3: Knowledge of the Southern Islands

14. Prior to this survey, did you know that St. John's Island and Lazarus Island are two different islands?
    - ☐ Yes
    - ☐ No

15. Prior to this survey, did you know the following:
    You may choose more than one option.
    - ☐ Lazarus Island was occupied by (predominantly Malay) villages in the past
    - ☐ St. John's Island used to house a quarantine center
    - ☐ St. John's Island houses a variety of natural habitats such as coral reefs, seagrass meadows, mangroves, rocky shores and coastal forests
    - ☐ St. John's Island houses a Marine Science National Research Infrastructure (St. John's Island National Marine Laboratory)
    - ☐ St. John's Island houses the Sisters' Island Marine Park public gallery and aquarium
    - ☐ St. John's Island houses the Singapore Food Authority's Marine Aquaculture Center
    - ☐ None of the above

16. Which of them have you visited before?
    You may choose more than one option.
    - ☐ Marine Science National Research Infrastructure (St. John's Island National Marine Laboratory
    - ☐ Sisters' Island Marine Park public gallery and aquarium
    - ☐ Singapore Food Authority's Marine Aquaculture Center
    - ☐ None of the above

Section 4: Future of St. John's Island/Lazarus Island

17. Please rank the following in order of preference to the key functions of the islands (1 being the most preferred function and 7 being the least preferred function).
    Only one number to be assigned to one option.

For example:		Your answer:	
Education:	___1___	Education:	________
Research:	___2___	Research:	________
Military:	___3___	Military:	________
Tourism:	___4___	Tourism:	________
Residential:	___5___	Residential:	________
Place of worship:	___6___	Place of worship:	________
Nature reserve:	___7___	Nature reserve:	________

18. In your opinion, should St. John's Island/Lazarus Island be changed in any way?
    - ☐ Yes
    - ☐ No

19. If yes, what sort of changes/improvements?
For example: transportation, services, infrastructure, amenities.

____

____

B. Research survey for marine science research community

1. What research can or should be conducted in the Southern Islands?

2. List habitats/mark areas in the Southern Islands (in particular the SJI Cluster) which you feel are scientifically interesting and merit further research (see maps).

3. What kinds of facilities should be developed in the Southern islands that will be useful to promote research and education?

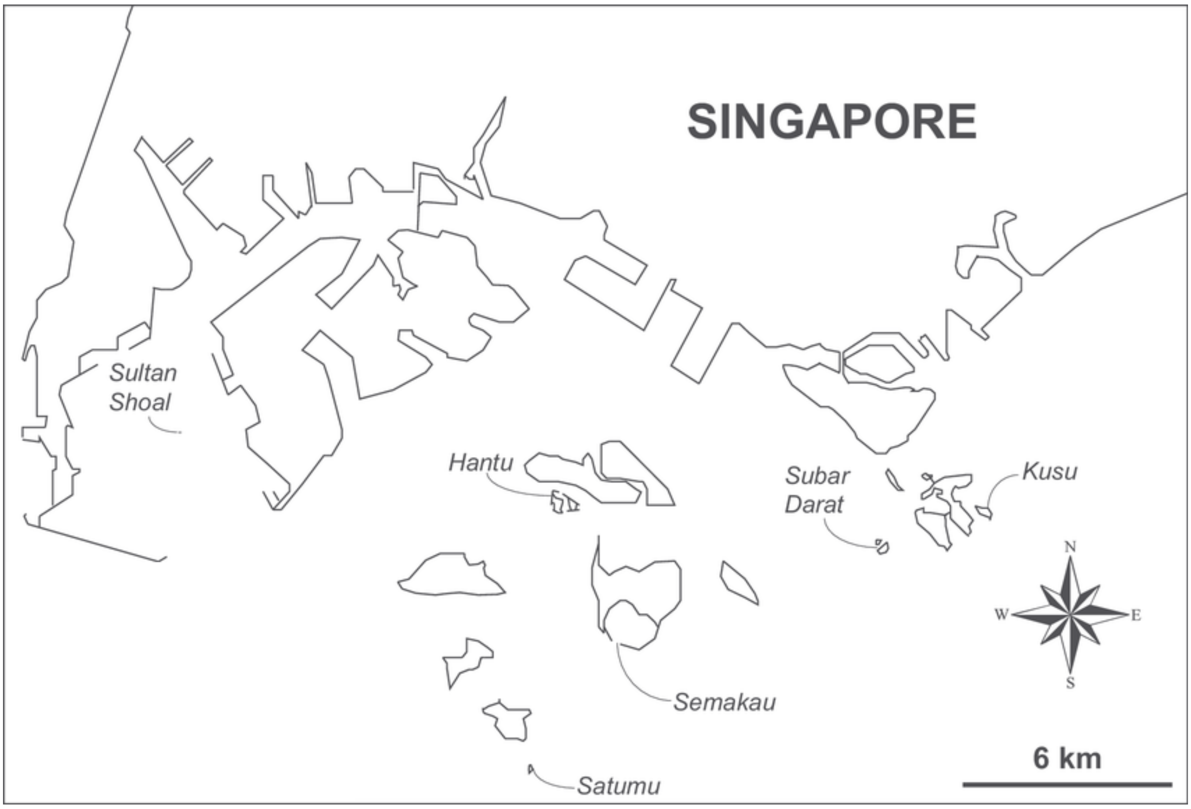
4. What role do you see SJINML playing to facilitate research in the Southern Islands?

5. What kinds of activities do you feel would be compatible with your research? (tick all that are relevant):

   - ☐ Education
   - ☐ Tourism (e.g. resorts)
   - ☐ Aquaculture
   - ☐ Military
   - ☐ Conservation
   - ☐ Public recreation (e.g. sea sport, fishing, diving, swimming)
   - ☐ Others: __________

Stakeholder:

☐ Research ☐ Industry ☐ Agency ☐ Others: _________


SINGAPORE
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Subar Darat
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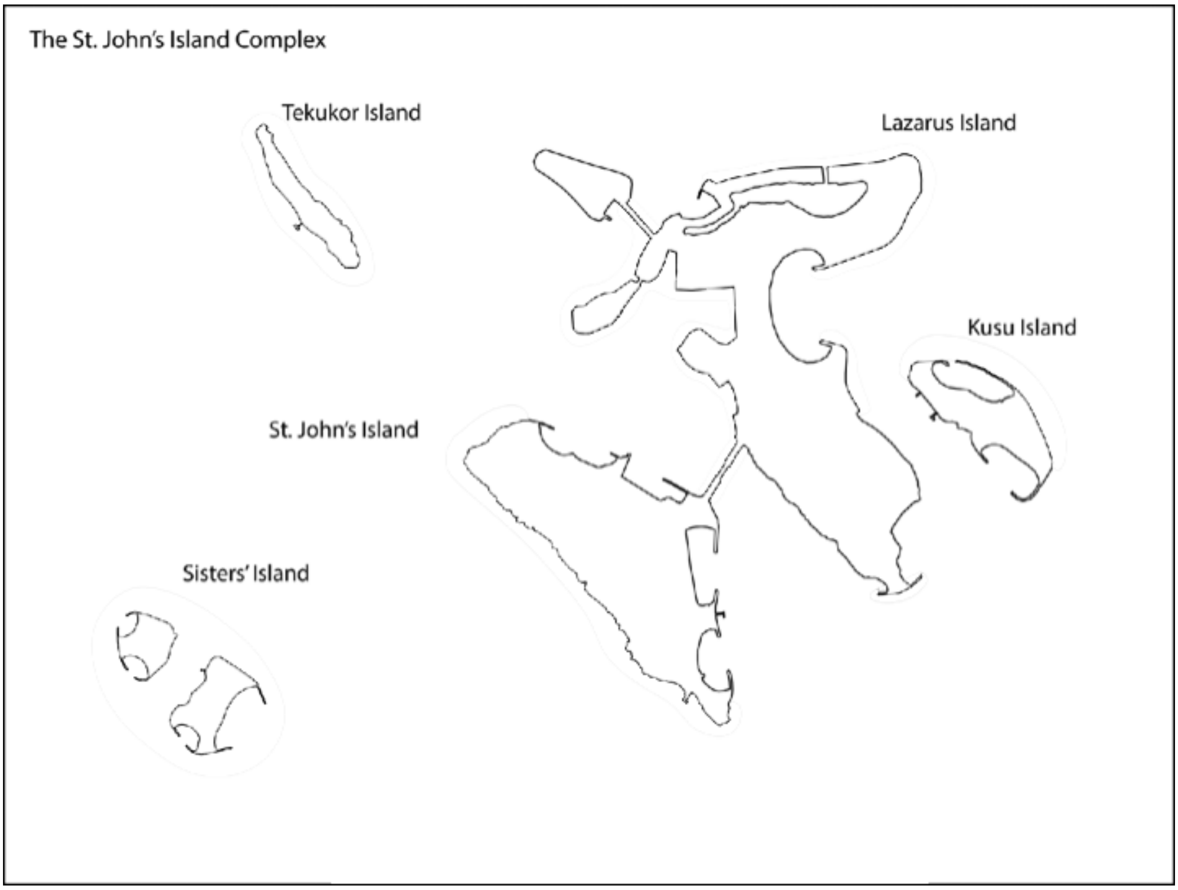
The St. John's Island Complex
Tekukor Island
Lazarus Island
Kusu Island
St. John's Island
Sisters' Island

C. Detailed proposed categories

Appendix Table C 1 Favourite aspect of the island

Favourite aspect (detailed)	Count
Location (eagle bay)	76
Location (beach)	45
Location (swimming lagoon)	34
Location (link bridge)	34
Location (coastline)	6
Location (seringat)	4
Location (jetty)	3
Location (highest point)	1
Natural aspect (serenity)	35
Natural aspect (biodiversity)	31
Natural aspect	28
Natural aspect (natural habitats)	15
Natural aspect (cats)	12
Natural aspect (clean waters)	11
Natural aspect (greenery)	3
Natural aspect (beach)	2
Natural aspect (night sky)	1
Natural aspect (geological features)	1
Recreational aspect (walks)	19
Recreational aspect (explore)	10
Recreational aspect (chill)	7
Recreational aspect (camping)	7
Recreational aspect (swimming)	7
Recreational aspect (fishing)	7
Recreational aspect (intertidal walks)	6
Recreational aspect	4
Recreational aspect (diving)	2
Recreational aspect (kayaking)	1
Recreational aspect (freediving)	1
Recreational aspect (snorkeling)	1
Recreational aspect (picnic)	1

Appendix Table C 2 Key Concerns and issues

Key concerns and issues (detailed)	Count
Amenities (toilets)	21
Amenities (f&b)	13
Amenities	11
Amenities (water points)	5
Amenities (bins)	4
Amenities (signages)	5
Amenities (shelters)	3
Amenities (jetty)	1
Transportation	14
Transportation (infrequent timings)	18
Transportation (bumpy rides)	9
Transportation (pier)	5
Transportation (cost)	2
Transportation (boats)	2
Transportation (travelling time)	1
Transportation (insufficient modes)	1
Transportation (information)	2
Transportation (boat traffic)	1
Infrastructure	4
Infrastructure (telcom)	3

Appendix Table C 3 Type of Changefor the island

Type of change for the island (detailed)	Count
Amenities (food and beverages)	38
Amenities	22
Amenities (toilets)	17
Amenities (toilets)	17
Amenities (convenience store)	9
Amenities (shelters)	8
Amenities (waste and recycling)	7
Amenities (water point)	7
Amenities (signages)	4
Amenities (bins)	3
Amenities (sustainable water alternatives)	1
Activities (more nature/marine walks)	8
Activities (more)	9
Activities (more overnight stay options)	6
Activities (more picnic spots)	2
Activities (snorkelling)	1
Activities (marine citizen science)	1
Activities (heritage walks)	1

Activities (VR tours)	1
Activities (helicopter)	1
Activities (more at beach)	1
Transportation (more frequent)	8
Transportation	6
Transportation (more types)	4
Transportation (lower cost)	4
Transportation (buggies on island)	1
Transport (escoters on island)	1
Transportation (greener)	1
Infrastructure	16
Infrastructure (telcom)	8
Infrastructure (security post)	1
Environment (more protection)	7
Environment (outreach and education)	7
Environment (more reforestation)	5
Environment (more biodiversity)	1
Environment (coastal park)	1
Environment (nature parks and park activities)	1
Development (pristineness)	7
Development (moderated)	5
Development (moderated human traffic)	4
Development (coastal intact)	1
Development (moderated reclamation)	1

D Summary of specific recommendations (A-Z) and the key research areas, key industry sectors and potential key agency stakeholders identified.

Appendix Table D 1

Thrust	Specific recommendation		Key research areas	Key industry sectors	Agency stakeholders
Hub for Marine Science R&D	A	Coastal defence R&D	Marine climate change science & solutions; Sustainable design & eco-engineering	Marine technology & engineering industry; Environmental consultants & developers	PUB, BCA, NCCS
	B	Eco-innovation testbed	Marine climate change science & solutions; Sustainable design & eco-engineering	Marine technology & engineering industry; Environmental consultant & developers; Architects & designers	PUB, ESG, SDC, BCA, CLC
	C	Marine renewable energy	Marine climate change science & solutions; Sustainable design & eco-engineering; Energy research	Marine technology & engineering industry; Environmental consultant & developers; Architects & designers; Renewable energy companies	PUB, NCCS, ESG, EMA
	D	Marine Environment Sensing Network	Marine climate change science & solutions; Marine technology R&D; Food Security (mariculture); Marine ecology; Environmental impact assessment and monitoring	Marine technology & engineering industry; Environmental consultant & developers; Fisheries; Environment education	NEA, SFA, PUB, MPA, NParks
	E	Nature-based solutions & Blue Carbon	Marine climate change science & solutions; Marine technology R&D; Marine ecology; Environmental impact assessment and monitoring	Environmental consultant & developers; Marine technology & engineering industry; Environment education	NParks, BCA, PUB, SDC
	F	Eco-resilience	Marine climate change science & solutions; Marine ecology; Biodiversity; Environmental impact assessment and monitoring	Environmental consultant & developers; Biotechnology; Environment education; Tourism	NParks, SFA
	G	Marine science R&D, aquaculture innovation and partnerships	Marine climate change science & solutions; Marine technology R&D; Food Security (aquaculture innovation &	Marine technology & engineering industry; Environmental consultant & developers; Fisheries; Biotechnology;	NRF, SFA, MOE

			biotechnology); Marine ecology	Environment & STEM education	
Champion of Experiential and Environment Education	H	Outdoor education	Environment and STEM education	Environment education; Schools	MOE
	I	Environmental education	Environment and STEM education	Environment education; Tourism; Schools	MOE, NParks
	J	Regional capacity building	Marine climate change science & solutions; Environment & STEM education	Environment education; Tourism; Schools	NRF, MFA, MOE
	K	Experiential learning	Marine climate change science & solutions; Sustainable design & eco-engineering; Environment & STEM education	Environment education; Tourism; Schools; Environmental consultant & developers; Architects & designers; IT solutions	MOE, NRF (Virtual Singapore), MPA (Geospace), GovTech
	L	Skills and professional development	Marine climate change science & solutions; Marine technology R&D; Food Security; Marine ecology; Sustainable design & eco-engineering; Environment & STEM education	Education; Environmental consultant & developers	MOE, MOM
Beacon for Urban Coastal Solutions in a Multi-use Landscape	M	Eco-tourism and immersive experiences	Environment education; Socio-ecological resilience; History & heritage	Recreational; Tourism; Environment & STEM education	SDC, STB, NParks. SFA (Singapore Food Story)
	N	Closed-loop concepts	Marine climate change science & solutions; Marine technology R&D; Food Security (sustainable and innovative aquaculture); Marine ecology; Energy research	Marine technology & engineering industry; Environmental consultant & developers; Fisheries; Architects & designers; Tourism; Environment & STEM education; Tourism; Renewable energy companies	ESG, NRF, SDC, PUB, SFA, NParks, CLC
	O	Improved amenities	Sustainable design & eco-engineering; Energy research	Tourism; Environmental consultant & developers; Architects & designers; Tourism; Renewable energy companies	SLA, SDC
	P	Improved transport links	Sustainable design & eco-engineering; Energy research	Tourism; Environmental consultant & developers; Architects & designers; Tourism; Renewable energy companies	SLA, SDC
	Q	Sustainable aquaculture	Food Security; Marine ecology; Marine	Fisheries; Marine technology & engineering industry;	SFA

			climate change science & solutions	Environmental consultant & developers	
Bridge for Natural and Cultural Capitals	R	Forest restoration	Ecology; Marine climate change science & solutions; Conservation & restoration	Environmental consultant & developers; Landscaping	NParks, SLA
	S	Heritage & visitor centre	Environment education; History & heritage	Tourism	NHB, SDC, NParks, SLA
	T	Community hall	History & heritage; Environment education	Tourism	NHB, SDC, NParks
	U	Community activities	History & heritage; Environment education	Tourism	NHB, SDC, NParks
	V	Historical features	History & heritage; Environment education	Tourism	NHB, SDC, NParks, SLA
	W	Artificial reefs	Marine climate change science & solutions; Marine ecology; Conservation and restoration; Sustainable design and eco-engineering	Tourism; Environment education; Architects & designers	NParks, SDC, MPA
	X	Coral reef conservation (Kusu Island)	Marine climate change science & solutions; Marine ecology; Conservation and restoration	Tourism; Environment education	NParks
	Y	Coastal forest conservation (Lazarus Island)	Ecology; Conservation and restoration	Tourism; Environment education	NParks
	Z	Natural rocky shore conservation (Lazarus Island)	Ecology; Geology; Conservation and restoration	Tourism; Environment education	NParks

Acknowledgements

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