National Environment and Planning Agency

Strengthening the operational and financial sustainability of the National Protected Area System (NPAS) Project

Marine Spatial Planning for the Pedro Bank, Jamaica

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Strengthening the Operational and Financial Sustainability of the National Protected Areas System (NPAS) Project

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Acronyms

AGRRA	Atlantic and Gulf Rapid Reef Assessment
CBD	Convention on Biological Diversity
C-CAM	Caribbean Coastal Area Management Foundation
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CLME	Caribbean Large Marine Ecosystem
CRFM	Caribbean Regional Fisheries Mechanism
DST	Decision Support Tools
EBM	Ecosystem Based Management
EBSA	Ecologically and Biologically Significant Area
EIA	Environmental Impact Assessment
FAC	Fisheries Advisory Committee
FAO	United Nations Food and Agriculture Organisation
FD	Fisheries Division
GIS	Geographical Information System
GoJ	Government of Jamaica
IBA	Important Bird and Biodiversity Area
IMO	International Maritime Organisation
IUU	Illegal Unreported and Unregulated
JET	Jamaica Environment Trust
JFSN	Jamaica Fish Sanctuaries Network
JNHT	Jamaica National Heritage Trust
MAJ	Maritime Authority of Jamaica
MSP	Marine Spatial Planning
NCOCZM	National Council on Ocean and Coastal Zone Management
NEPA	National Environment and Planning Agency
NGO	Non-Governmental Organisation
NPAS	National Protected Areas System
PBWG	Pedro Bank Working Group
PCJ	Petroleum Cooperation of Jamaica
PCMP	Pedro Cays Management Project
PGIS	Participatory Geographic Information System
PSC	Project Steering Committee
PSSA	Particularly Sensitive Sea Area
SEA	Social and Environmental Assessment
SFCA	Special Fisheries Conservation Area
SIDS	Small Island Developing States
SPAW	Specially Protected Areas and Wildlife
SST	Sea Surface Temperature
TBD	To Be Determined
TNC	The Nature Conservancy
UTM	Universal Transverse Mercator
UWI	University of the West Indies
VSD	Veterinary Services Division
WGS	World Geodetic System

Executive summary

In the Caribbean and around the world, human use of coastal and marine resources including transportation, fishing, tourism, recreation, oil exploration and other activities, is placing growing and often conflicting demands on natural resources. As place-based activities continue to increase, resources are being over-exploited and conflicts among users are escalating. Marine spatial planning (MSP) has emerged globally as a strategic approach to efficiently deliver ecosystem-based management to the coastal marine environment. To balance the need for development with the protection of the marine ecosystem and livelihoods, the Government of Jamaica together with The Nature Conservancy undertook a one year participatory MSP process to plan for the management of Pedro Bank's marine resources as part of United Nations Environment Programme/Global Environment Facility's: Strengthening the Operational and Financial Sustainability of the National Protected Areas System (NPAS) Project implemented by NEPA and TNC in collaboration with the Jamaica National Heritage Trust, Fisheries Division and the Forestry Department. The objective of this MSP process includes the drafting of a marine multi-use zoning design for the Pedro Bank to guide the sustainable use of marine resources for the benefit of future generations, but more specifically provide guidance regarding where on the Bank are the best places for protected areas to be declared.

In the Pedro Bank context, the process for MSP comprised a preliminary appraisal and stakeholder engagement; visioning and goal setting; data collection and compilation; creation of decision-support products; development of management measures and the drafting of a marine multi-use zoning design. Moreover a Participatory Geographical Information System (PGIS) approach applied to engage Jamaican partners ensured that the MSP included perspectives of a broad range of marine stakeholders. Stakeholders were engaged using a variety of communication mechanisms from the outset and include the use of workshops, periodic summary and validation meetings, the distribution of summary reports, hard-copy and electronic maps, project brochure, presentations at national committee meetings and via email using a dedicated internet Google e-group. The mechanisms were found useful to allow for transparent, inclusive and equitable cross-scale interactions and support a partnership approach in the development of the MSP. Over the course of the project the Pedro Bank Working Group (PBWG) collaboratively developed a MSP for the Pedro Bank based on a long-term 50 year vision with clear goals and objectives, recommended management measures and a marine multi-use zoning configuration that is thought to be fair for all sectors, minimises conflict and seeks to achieve goals in an optimal way. This included a prioritisation of resource use values together with the scientific data, local knowledge and associated socio-economic information collected over the years. The developed Geographical Information System (GIS) and decision-support tools were found useful to develop management measures that were seen to be appropriate, equitable and feasible by the PBWG members.

Continued effort and inputs beyond this planning exercise are required for the successful implementation of the Pedro Bank MSP. Thus the challenge for Jamaica will be to keep the MSP process moving forward and make this marine multi-use zoning design operational. Moving to a fully implemented marine multi-use zoning plan will take a concerted joint effort on the part of government, marine resource user groups, NGOs and the wider international community. A suite of longer-term activities to harness the political will to reform institutional and legislative frameworks, design a monitoring plan to evaluate the MSP and zoning plan efficacy as well as the develop long-term financing options for management operations are required to operationalise the Pedro Bank MSP and multi-use zoning design.

I. Introduction

Marine spatial planning

In the Caribbean and around the world, human use of coastal and marine resources including transportation, fishing, tourism, recreation, oil exploration and other activities, is placing growing and often conflicting demands on natural resources. Consequently important marine areas are under increasing pressure threatening the health of coral reefs, wetlands, mangroves and seagrass beds and the environmental services they provide, such as coastal protection from storms, food security and tourism-based economies. As place-based activities continue to increase, resources are being over-exploited and conflicts among users are escalating (Tallis et al. 2010). It is clear that there is an urgent need for a process to guide sustainable development of the marine environment, one that provides for a diversity of uses while protecting biodiversity and maintaining resilience and the services people depend upon. An ecosystem approach offers a constructive means to deal with the uncertainties associated with complex systems by focusing on the distinctive features of an individual place and tailoring management to the local circumstance through an adaptive learning cycle (Young et al. 2008).

Marine spatial planning (MSP) provides a means to improve decision-making as it relates to the use of marine resources and space. MSP has emerged globally as a strategic approach to efficiently deliver ecosystem-based management (EBM) to the coastal marine environment (Crowder and Norse 2008). Analogous to land-use planning in the terrestrial environment, MSP aims to systematically identify an equitable balance between social and economic demands for development, while protecting the health and resilience of ecosystems. MSP is therefore a comprehensive multi-disciplinary planning process which lays out a spatially-focused, multi-objective vision to be developed for an area in which ecological, economic and social objectives can be simultaneously accommodated within prevailing political and administrative regimes (Douvere and Ehler 2009). MSP addresses governance challenges by supporting EBM and establishing conditions to promote economies of scale thereby reducing institutional overlaps, space-use conflicts and the loss of ecosystem services.

A further tenet of MSP is that stakeholder engagement is central to the process. MSP provides a transparent framework that can accommodate a wide diversity of multi-disciplinary information including environmental and socio-economic considerations. It is important that the planning process is inclusive and objective, and that associated information is available in an accessible format that can serve to improve stakeholder understanding, involvement and acceptance of outcomes (Mackinson et al. 2011, Carocci et al. 2009, Pomeroy and Douvere 2008). Ultimately MSP is a collaborative planning approach in which stakeholders and institutions work together to develop a way forward or a 'blueprint' for future development. Ensuring the application of thorough participatory planning processes (including communication of the goals of the MSP, how it can improve the quality and efficiency of decision-making and in the collection of information) is essential for providing legitimacy for and the successful adoption of the MSP (Agardy et al. 2012).

A MSP process is a strategic, forward-planning approach that seeks to better address activities taking place in the ocean and integrate marine management strategies (Arkema et al. 2006). One outcome of the MSP process is typically a marine multi-use zoning design (Agardy 2010, Ehler and Douvere 2009), whereby the boundaries of the various uses are delineated in the marine space. Thereafter the marine multi-use zoning design is translated into a management plan, in which levels of use are defined and implemented through the development of regulations for each of the developed zones and/or management areas. Although the development of a marine multi-use zoning plan is often a central outcome of the MSP process, the two are not the same (Agostini et al. 2010). Marine spatial planning is a process that provides the framework that makes comprehensive multi-use zoning credible (Foley et al. 2010).

As MSP has a spatial component and requires the integration of information from a variety of sources at multiple scales, the application of geographical information systems (GIS) has gained wide acceptance (Carocci et al. 2009). Yet due to a diversity of factors including the financial, technical and human resources required for MSP, its application has been less prominent in small island developing states (SIDS) than in developed countries (Baldwin et al. 2013, Pomeroy et al. in 2014). In recent years the use of GIS as a tool coupled with participatory and collaborative approaches has emerged as a novel science known as Participatory GIS (PGIS) (McCall 2003). In light of an ecosystem approach, the participation of stakeholders in the creation of MSP information, including representation of spatial knowledge, can support the production of cost-effective holistic information and increase understanding of the linkages between marine resources and livelihoods (Baldwin and Mahon 2014). The employment of multi-sectoral collaborative PGIS approach can maximise resources and management efforts thus better guiding MSP and aiding equity and ownership in decision-making (Pomeroy and Douvere 2008).

The case of Pedro Bank, Jamaica

Located in oceanic waters approximately 80 kilometres southwest of Jamaica, the Pedro Bank is a submarine plateau more than three quarters the size of mainland Jamaica (Figure 1). The Pedro Bank comprises Jamaica's most significant reef ecosystem area and is of significant importance for marine biodiversity. The Pedro Bank represents one of the largest and most productive fishing grounds in the Caribbean (Kramer 2006) sustaining Jamaica's artisanal and industrial conch, lobster and finfish fisheries (Halcrow 1998). Accordingly the Pedro Cays and Portland Rock, the only terrestrial areas, are actively used as fishing bases. Furthermore the Pedro Cays provide critical habitat for nesting sea turtles and are home to some of the largest seabird breeding colonies (Hay 2006) and thereby are internationally recognised as an Important Bird and Biodiversity Area (IBA) by BirdLife International.

Due to the myriad of sixteenth to seventeenth century shipwrecks and artefacts scattered across the seafloor in 2004 the Pedro Bank was declared a National Underwater Cultural Heritage site by the Jamaica National Heritage Trust (JNHT). Correspondingly due to its biological, cultural and economic importance, the National Strategy and Action Plan for Biological Diversity in Jamaica (2003) recommend protected area status for the Pedro Cays and Bank, and was globally recognised by the United Nation's Convention of Biological Diversity as an Ecological or Biological Significant Marine Area (EBSA) in 2012. In the same year under the Fisheries Industry Act, a no-take Special Fishery Conservation Area (SFCA) was declared around South West Cay to conserve dwindling fisheries resources of the Pedro Bank. Despite these efforts, unplanned *ad-hoc* infrastructural development and human settlement have contributed to the degradation of the Pedro Cays (Espeut 2006, Appropriate Technologies 2007). Accordingly a management plan for the Pedro Cays including the South West Cay SFA (2015 – 2020) to effectively manage the cays and its' surrounding coastal marine ecosystem was undertaken (Otuokon 2015) and an assessment of marine governance arrangements for the Pedro Bank conducted by the Caribbean Large Marine Ecosystem (CLME) Project to determine the inter-sectoral and inter-issue integration required for effective EBM (Mahon 2013).

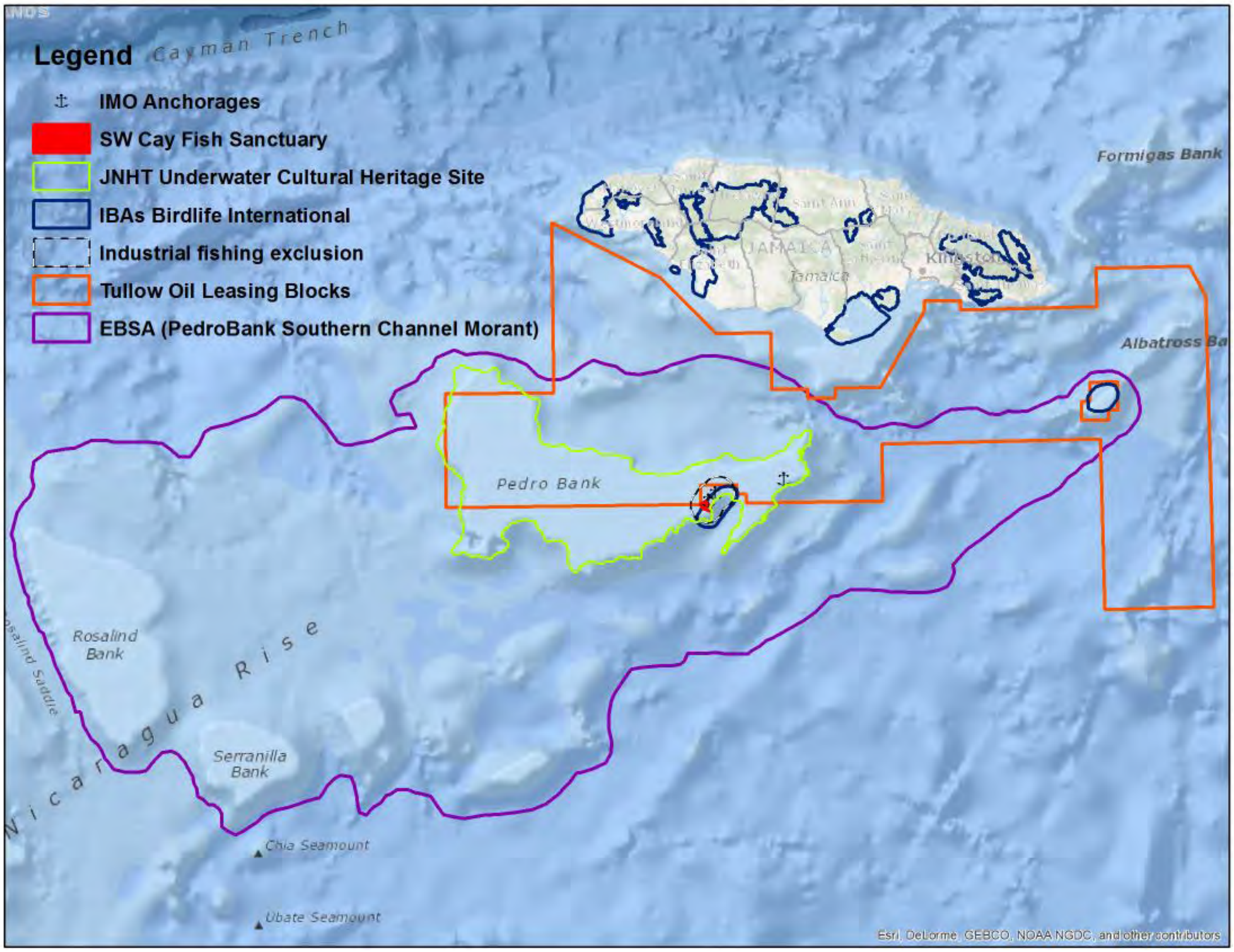

Figure 1. Geographic location of the Pedro Bank including the representation of existing spatially-based management measures for the area. (*Data sources provided in Table 2*)

Nevertheless development and demand for marine space in Jamaica is steadily increasing. More recently offshore oil exploration has been restarted in Jamaica and marine transportation is likely to increase as a result of the Panama Canal expansion and the potential future development of a large-scale commercial port on the south coast of Jamaica. Although a number of international, regional and national commitments, including Jamaica's National Development Plan: Vision 2030, recognise a need to address these diverse and dynamic systems in an adaptive manner using inter-sectoral cooperation and broad stakeholder participation based on the best available information, the development of practical tools needed to make EBM approach operational particularly in marine and SIDS contexts is just starting (Pomeroy et al. 2014, Tallis et al. 2010).

Establishing authority for MSP

To balance the need for development with the protection of the marine ecosystem and livelihoods, the Government of Jamaica (GoJ) together with The Nature Conservancy (TNC) undertook a one year participatory MSP process to plan for the management of Pedro Bank's marine resources. As part of the United Nations Environment Programme/Global Environment Facility's - Strengthening the Operational and Financial Sustainability of the National Protected Areas System (NPAS) Project implemented by the National Environment and Planning Agency (NEPA) in collaboration with the Jamaica National Heritage Trust, Fisheries Division and the Forestry Department, a MSP process including the drafting of a marine multi-use zoning design was conducted to guide the sustainable use of the Pedro Bank's resources for the benefit of future generations, but more specifically provide guidance regarding where on the Bank are the best places for protected areas to be declared. Thus this project serves to provide information and decision-making support for the NPAS Project Steering Committee (PSC)/GoJ authorities to sustainably plan for the conservation and use of the Pedro Bank marine resources.

The primary objectives of Pedro Bank MSP project are:

- To develop a draft multi-use zoning design for the Pedro Bank using new and existing information to increase Jamaica's capacity to protect, manage and sustainably use marine resources
- To collect, create, integrate and disseminate spatial information required for marine multi-use zoning and decision-making
- Develop and implement an awareness campaign targeting key Pedro Bank stakeholders (i.e. upper level decision-makers, Pedro Bank resources users, and marine related NGOs and government agencies) to support marine multi-use planning and integrated management of the Pedro Bank coastal and marine resources

The Pedro Bank MSP project deliverables include:

An objective-based comprehensive MSP and marine multi-use zoning design for the Pedro Bank

- Construction of a marine Geographic Information System (GIS) database of mapped habitats, resources and space-use features
- MSP decision-support products (i.e. GIS feature maps, spatial analyses, zoning scenarios)

Project summary reports (7) and final MSP report

- Methodologies applied including the level of success and constraints of the process
- Nature and quality of stakeholder participation
- Recommendations for MSP implementation and constraints anticipated
- Lessons learned

Outreach and communication products

- E-group announcements, emails, workshops, outreach meetings, press releases, one-on-one and group discussions and interviews
- Dropbox file sharing folder (to provide access to reports, maps and data)
- Project brochure and a MSP zoning design poster
- Presentations at various national committee meetings

Project approach

The employment of multi-sectoral collaboration including meaningful participation in the information gathering, research and evaluation processes can maximise resources and management efforts by better guiding the MSP process including equity and ownership in decision-making (Baldwin and Mahon 2014).

In recent years the use of GIS as a tool coupled with participatory and collaborative approaches has emerged as a novel science known as participatory GIS (PGIS) (Baldwin 2012). Promoting the participation of stakeholders in the development of a technical representation of spatial knowledge can allow for a comprehensive understanding of the social and economic characteristics of natural resource use patterns (Quan et al. 2001; St. Martin and Hall-Arber 2008; IFAD 2009). Participation not only demonstrates the relevance of information provided by stakeholders, but also supports an ecosystem-based approach through the utilisation of multi-discipline and multi-knowledge information for management (Christie and White 2007). Ultimately, stakeholder empowerment through the application of principles that reflect good governance (e.g., participation, transparency, inclusiveness, respect) underlies both the PGIS and MSP approaches (Baldwin et al. 2014). This includes not only the participatory process, but also the production of information in a format which is both understandable and accessible to all stakeholders; thereby facilitating equity, collaboration, capacity building and ownership (McCall 2003; Rambaldi et al. 2006). Moreover, by broadening the information base for management, a PGIS approach can be of particular relevance for MSP in data-poor, resource-limited situations, typical of marine environments in SIDS (Pomeroy et al. 2014).

II. Generating a marine spatial plan and multi-use zoning design for the Pedro Bank

Typically the steps of a MSP process involve establishing a planning area and vision, defining uses and setting management objectives, gathering data and information on present and future uses, evaluating trade-offs to identify potential management scenarios, drafting a multi-use zoning design and corresponding spatial management measures and then developing the required regulations and management plan required to implement the MSP (Beck et al. 2009). In the Pedro Bank context, the process for MSP comprised: a preliminary appraisal and stakeholder engagement; visioning and goal setting; data collection and compilation; creation of decision-support products; development of management measures and a marine multi-use zoning design. Each of these stages of the MSP and the associated participatory approaches applied are briefly described in the following sub-sections. Detailed review (i.e. methodologies applied and overall results) of each step are provided in six associated MSP project summary reports produced over the contract period (see Baldwin 2014 a; b; c; d; Baldwin 2015 a; b).

Instituting stakeholder participation

A wide collaborative approach was employed to identify stakeholders considered to be necessary for the development of a comprehensive marine resource and space-use information system and planning of the management of the Pedro Bank's marine resources. A multi-sectoral stakeholder group, the Pedro Bank Working Group (PBWG), was formed based in part on the pre-existing (2005) Pedro Bank Management Project (PBMP) members to guide the MSP process. The PBWG comprises 35 persons from 26 marine-related public sector agencies, NGOs, academics, artisanal and industrial fishing representatives, and various national marine committee members (Appendix I). The role of the PBWG was to guide stakeholder engagement, provide direction for the project and methods applied, review data and analyses, and work together to make final recommendations for the Pedro Bank.

Each element of the MSP process (from identifying stakeholders, collecting information, determining uses to plan for and recommending management measures) needs national and local champions to be effective (Pomerory et al. 2014, Agardy et al. 2012, Agostini et al 2010). During this project, a PGIS approach was applied to engage Jamaican partners and ensure that the MSP included the perspectives of relevant marine stakeholders. To allow for transparent, inclusive and equitable cross-scale interactions, stakeholders were engaged through a variety of communication mechanisms from the outset. These included: periodic summary and validation meetings; the distribution of summary reports; hard-copy and electronic maps; a project brochure and press release (produced by JET); presentations at national committee meetings, relevant working groups and agencies; and via email using a dedicated internet Google e-group: https://groups.google.com/forum/?fromgroups#!forum/pedro-bank-msp

Meetings were used to engage stakeholders. Table 1 lists the methods for each core stakeholder engagement activity, timeframe, main objectives, major outputs and key participants. Seven associated MSP project summary reports produced over the course of the project provide detailed review of methods applied, meeting results and other key data and information gathered during the project for use in .

Table 1. Table of stakeholder engagement methods, meetings and activities conducted during the MSP project.

Meeting / Activity	Timeframe	Main Objectives	Major Outputs	Key Participants
Data scoping and preliminary data collection meeting	27-30 May 2014	Share the project work plan, discuss the scope of the project area, source existing information and determine stakeholders	Identification of the PBWG; finalise project work plan; preliminary data collection; Summary Report 1	Birds Caribbean, CCAM, FD, JCFU, JET, TNC, UWI, VET Serivces
Planning Workshop 1: Visioning for the Pedro Bank MSP	26-27 June 2014	Define a shared vision, determine resource use values, develop clear goals and objectives for the MSP, determine the planning extent, review existing data and identify data gaps	Introduction of MSP and the project; development of a vision, goals and objectives for Pedro Bank; identification of stakeholders, resources and use values; Summary Report 2	Birds Caribbean, CaribSave, CCAM, FD, JCFU, JET, JDF-CG, JNHT, MAJ, NEPA, NSWMA, PCJ, TNC, UWI, VET Services, artisanal fishers
Data collection and field surveys	30 June-17 July 2014	Preliminary field assessment, outreach meetings targeting fishing stakeholders in Kingston, the Pedro Cays and the south coast to share and obtain feedback on the vision, goals and objectives of the MSP and key informant interviews	Feedback on the vision, goals, objectives and planning extent, six fisher outreach meetings, KI interviews, Summary Report 3	Artisanal fishers (Pedro Cays, Cross the Bank), CCAM, FD, JET, JDG-CG, MAJ, PAC, UWI
Field surveys, fishing space-use rapid assessment, outreach meetings	25 August-26 September 2014	Ground-truthing habitat maps, resource and space-use mapping exercises, fisher assessment and fisher update outreach meetings, presentations to NEPA, NPAS, NCOCZM, JDF-CG	Validation of habitat map, socio-demographic and space-use profiles for 78 artisanal fishers, production of GIS data, industrial fisher feedback on MSP, Summary Report 3	Artisanal fishers (Pedro Cays, Cross the Bank), industrial fishers, CCAM, FD, JET, NEPA, NPAS, JDF-CG, UWI
Planning Workshop 2: Refining and prioristing the MSP and identifying the applicability of DSTs for Pedro Bank	29-30 September 2014	Project update, revise the vision, goals and objectives, review collected data and information, identify data gaps, review DSTs and options for the Pedro Bank MSP, establish technical review sub-committee	Revised MSP vision, goals, objectives and planning extent; introduction to DSTs; prioritisation of resource use values; compatability matrix; identification of technical review sub-committee, Summary Report 4	Birds Caribbean, CaribSave, CCAM, FD, JCFU, JET, JDF-CG, JNHT, MAJ, NEPA, PCJ, TNC, UWI, VET Services, artisanal and industrial fishers
Technical review sub-committee meeting	11-13 November 2014	Project, data and GIS review, overview of DSTs and Marxan, feedback on input parameters and developed scenarios, identify proxys for data gaps, NCOCZM presentation	Marxan DST parameters refined; identificaiton of proxies for data gaps; deterimation of final Marxan scenarios; Summary Report 5	Birds Caribbean, CaribSave, CCAM, FD, JCFU, JET, JDF-CG, NEPA, PCJ, TNC, UWI, artisanal and industrial fishers, NCOCZM
Planning Workshop 3: Drafting potential management measures and zoning design	17-18 February 2015	Project update, review of biological and fishery objectives MSP deisgn principles, review MSP data and DSTs (GIS analysis and Marxan), draft potential management measures and marine multi-use zoning design, outline remaining information needs	Priority areas identified for conservation and fishing; potential management measures identified; list of remaining questions for fisher feedback; Summary Report 6	Birds Caribbean, CaribSave, CCAM, FD, JET, JDF-CG, JNHT, MAJ, NEPA, PCJ, TNC, UWI, VET Services, artisanal fishers
Fisher feedback: Outreach meetings and semi-structured interviews	15 March - 2 April 2015	Project update, feedback on management measures, fishing and conservation priority areas, space-use patterns, interest in comanagement, supporting implementation needs	6 artisanal fisher outreach meetings and 29 key informant interviews, 1 industrial outreach meeting, identification of fishing and conservation priority areas, management measures with fisher support, fisher prioritisation of implementation needs; Summary Report 7	Artisanal fishers (Pedro Cays, Cross the Bank), industrial fishers, FD, JDF-CG, JET, TNC
Final Planning Workshop: Finding consensus on the MSP and multi-use zoning design	11-12 May 2015	Project review, consider fisher feedback results, draft management measures and a marine zoning design, achieve consensus on MSP recommendations	Final recommendations for the Pedro Bank MSP: including associated management measures and a multi-use zoning design; identification of support needs for implementation; Summary Report 7	Birds Caribbean, CaribSave, CCAM, FD, JET, JDF-CG, JNHT, NSWMA, MAJ, NEPA, PCJ, TNC, UWI, VET Services, artisanal and industrial fishers

Establishing clear objectives and goals

A MSP generally is guided by strategic goals that define what needs to be done to achieve a vision for the planning area and therefore requires the definition of clear planning objectives (Ehler and Douvere 2007). Building these elements through a transparent participatory process creates a strong basis for successful implementation of the MSP and multi-use zoning plan (Agardy et al. 2012). Correspondingly the following vision, guiding principles, goals and objectives for the Pedro Bank MSP were defined by the PBWG during a workshop early in the project (Table 1; Baldwin 2014b). During this first planning workshop, the PBWG discussed their vision for the future of the Pedro Bank and collaboratively identified resource and use values for their seascape. This also included the establishment of guiding principles for the MSP process and development of strategic goals and objectives for the identified resource use values.

The vision for the Pedro Bank MSP was developed by the PBWG was slightly adapted based on the vision developed for the Pedro Cays Management Plan (Otuokon 2014).

Our Vision for the Pedro Bank

‘A future where effective and collaborative management of the Pedro Bank and Cays biodiversity and ecosystem health support sustainable livelihoods’

Guiding Principles for the Pedro Bank Marine Spatial Planning (MSP) Process

Healthy resources and human well-being

- Ensure pristine marine life and productive resources
- Promote sustainable livelihoods
- Provide resilience to climate change
- Support educated communities
- Encourage honesty and respect by all
- Develop an eco-community on the Pedro Cays

Access to comprehensive information

- Generate baseline of conditions and monitor changes
- Improve accountability of decision-making
- Increase education and awareness of the importance of Pedro Bank

Effective integrated management

- Establish an integrated governance structure for MSP implementation
- Regulate access and ensure sustainable use of resources
- Create efficient administration, monitoring and evaluation programmes
- Institute effective regulatory and enforcement mechanisms
- Facilitate responsive and adaptive management

Pedro Bank MSP Goals and Objectives

Conservation of biodiversity

- Ensure healthy, productive and resilient environment
- Safeguard ecological diversity and integrity of species and habitats
- Protect natural resources and cultural heritage
- Develop effective long-term monitoring of resources and ecosystem services

Abundant and healthy fisheries

- Enhance size and diversity of fish stocks
- Ensure safety for fishers and sustainable fishing practices
- Optimise sustainable yield (e.g. spend less time at sea to earn living)
- Improve fisheries management using a collaborative approach
- Generate incentives for compliance, value-added markets & livelihood diversification
- Create effective regulations supported by severe penalties & functional enforcement
- Strengthen monitoring, control and surveillance using technology

Safe transportation

- Prevent marine pollution and improve maritime safety and management through international, regional and local frameworks
- Establish transportation corridors, install navigational makers and moorings
- Enhance education of navigation and safety at sea for fishers
- Facilitate safer vessels and equipment to reduce accidents
- Institute vessel monitoring and safety systems for all vessels

Sustainable future development

- Establish rigorous permitting and environmental auditing procedures to monitor new development
- Adopt best practices (innovative clean technologies) for oil and natural gas development
- Assure compensation for potential impacts to marine resources and livelihoods
- Encourage potential for renewable energy production (i.e. wind, tides) opportunities

Research for awareness

- Generate a baseline of conditions using a collaborative monitoring and evaluation framework
- Strengthen scientific research capacity and ensure access to information
- Increase knowledge and awareness of the importance of Pedro Bank
- Educate communities to achieve behavioural change (voluntary compliance)
- Facilitate an interpretative experience (representative ecosystem components) and promote potential for alternative livelihood (research tourism)

Preliminary assessment

A preliminary assessment (based on Baldwin 2012, Berkes *et al.* 2001) was conducted at the outset to share the objectives, identify existing information, better understand the levels and types of stakeholders and institutions, and build working relationships necessary for a collaborative (partnership) approach across the scale of the Pedro Bank (Table 2). The preliminary appraisal began with an extensive literature and data search of secondary information on the distribution, uses and management of coastal and marine resources of the Pedro Bank (e.g. environmental and marine-related legislation, policies, management plans, GIS datasets, imagery and maps, and other collateral information). Next, meetings were held with the pre-existing PCMP members whom included marine-related government agencies, NGOs and fisher stakeholders to explain research principles, augment objectives, share information, ascertain gaps and foster transparent collaboration. The preliminary assessment also included visits to the Pedro Cays and key fishing villages along the south coast of Jamaica (i.e. Whitehouse, Treasure Beach, Rocky Point, Old Harbour Bay) known to utilise the Pedro Bank. Meetings were held to share and explain MSP objectives and principles, identify the types of fishing stakeholders and determine their capacity for participation. A rapid baseline study of the demographics of each fishing community, the locations of coastal activities, key marine resources and their current uses was also collected through participant observation, key informant and informal interviews with fishers (Baldwin 2014c). Furthermore preliminary mapping exercises were conducted with fishers to assess their understanding of map features (e.g. useful map elements, units of measurement commonly used) and determine toponymy (locally-used place names) of the Pedro Bank fishing grounds for use in subsequent data collection exercises.

Pedro Bank stakeholders

- Artisanal fishers (by landing site)
  - Pedro Cays (Middle Cay, North Cay, Portland Rock)
  - South Coast 'Cross the Bank' (Old Harbour Bay, Rocky Point, St. Elizabeth / Treasure Beach, Whitehouse)
- BirdsCaribbean
- Caribbean Coastal Area Management (C-CAM) Foundation
- CaribSave Partnership
- Jamaica Defence Force Coast Guard (JDF-CG)
- Fisheries Division (FD)
- Industrial fishing companies
- Inter-ministerial Committee for the Pedro Cays
- Jamaica Defence Force - Marine Police (JDF-MP)
- Jamaica Environmental Trust (JET)
- Jamaica Fish Sanctuary Network (JFSN)
- Jamaica Fishermen's Cooperative Union (JFCU)
- Jamaica National Heritage Trust (JNHT)
- Jamaica Yachting Association
- Kingston and St. Andrew Corporation
- Maritime Authority of Jamaica (MAJ)
- Ministry of Foreign Affairs and Foreign Trade
- Mines and Geology Division

- Ministry of Water, Land, Environment and Climate Change (MWLECC)
- National Council Oceans & Coastal Zone Management (NCOCZM) - and the Cays Committee
- National Environment & Planning Agency (NEPA)
- National Solid Waste Management Authority (NSWMA)
- Petroleum Cooperation of Jamaica (PCJ)
- Protected Areas Committee (PAC)
- Shipping Association of Jamaica
- The Nature Conservancy (TNC)
- University of the West Indies (UWI)
- Urban Development Corporation (UDC)
- Veterinary Services Division - Ministry of Agriculture and Fisheries (MOAF)

Resources of the Pedro Bank

- Conch
- Lobster
- Finfish (reef and pelagic)
- Seabirds (nesting sites, foraging grounds)
- Sea turtles (nesting sites, foraging grounds)
- Sea cucumbers
- Sea urchins
- Sharks and rays
- Cetaceans (whales and dolphins)
- Nursery grounds
- Spawning aggregation sites
- Upwelling / current patterns of Pedro Bank (productivity, SST, Chl. a)
- Cultural / historical sites (shipwrecks, cannons, ruins, lighthouse)
- Coastal marine habitats (reef, seagrass, macroalgae, mangrove, salt pond, sand)

Space-uses of the Pedro Bank

- Fishing grounds (artisanal small-scale, industrial)
- Activities on cays (wildlife, living infrastructure, fish cleaning areas, solid waste)
- Oil exploration (bathymetric surveys) and potential for drilling
- Marine transportation and infrastructure (shipping routes, anchorages, landing sites, underwater cables, navigational markers, lighthouse)
- Military operations / restricted areas (Middle Cay Coast Guard Base)
- Scientific research areas (research station, AGGRA, FD conch survey sites, VET Services zones)
- Recreation (diving, wildlife watching, sport-fishing)
- Areas of threat (land and marine-based pollution, IUU fishing)
- Potential future uses (research tourism, offshore oil/gas, tidal/wind energy, mariculture)

Defining existing and future conditions

Existing spatial data were collected and evaluated for use. Much of the collected GIS data required additional processing and preparation into thematic layers. To start, the ArcToolbox 'Environment Settings' were used to allow for a standard coordinate system (WGS 84 UTM Zone 17N) and spatial extent (scope of Pedro Bank Planning Area) to be applied to all geoprocessed data. Then, existing GIS data determined to be of use were imported, clipped to extent of the Pedro Bank planning area and re-projected if necessary to a common coordinate system. Imagery, nautical charts and maps were scanned and georeferenced using GIS.

Typical in most SIDS, spatial data for the terrestrial realm in Jamaica was much more prevalent than data for the marine realm, particularly for the Pedro Bank. Consequently filling marine data gaps represented a major effort and contribution of this project. One clear gap was the lack of data on marine uses for waters surrounding Pedro Bank. We applied three main approaches to fill data gaps: (a) marine habitat mapping; (b) marine resource and space use mapping (using experts/fisher surveys); and lastly data proxy based on recommendations given by PBWG members.

Mapping marine habitats

A marine habitat map of the Pedro Bank was created in two parts. In 2012 the Living Oceans Foundation (LOF) conducted a number of marine surveys on the Pedro Bank (i.e. AGGRA surveys, benthic habitat videos and side-scan sonar measurements). In 2014 Landsat 8 and WorldView-2 satellite imagery were acquired and the LOF data (Bruckner 2012) were classified using digital image processing techniques to develop two benthic habitat mapping products. A broad scale map of the entire Pedro Bank (Figure 2) out to the 30 metre bathymetry contour (comprising of 6 classes) was developed by S. Schill of TNC based on Landsat 8 imagery (30m resolution). A second, more detailed (comprising of 8-10 classes) fine scale (2m resolution) benthic habitat map of the Pedro Cays and surrounding near-shore area (Figure 3) and associated bathymetry products were developed by S. Purkis of NOVA based on WorldView-2 imagery (see Appendix II for detailed review of this sub-project). Validation exercises with fishers, marine spot-check field and cross-validation with the location of fishing activities surveys were undertaken to preliminarily assess the accuracy of the derived habitat maps.

Mapping marine resources and space-uses

Participatory research methods (e.g. socio-economic surveys, questionnaires and mapping exercises, marine field surveys) were employed to solicit and incorporate spatially-based local knowledge within the geodatabase and fill information gaps on human use. To start, a number of semi-structured interviews were held with PBWG experts to collect identified resource and space-use information (i.e. Dr. Ann Sutton regarding sea birds and turtles, Dr. Karl Aiken regarding previous fisheries research, Commanding Chief of the Jamaica Defence Force - Coast Guard regarding Illegal Unreported & Unregulated (IUU) fishing). A part of the questionnaire comprised a mapping exercise component, in which a pictorial legend of features was used to guide the mapping of space use patterns (e.g. anchorages, shipping lanes, recreation) and the distribution of key resources (e.g. seabird and sea turtle nesting sites, cultural/ historical sites).

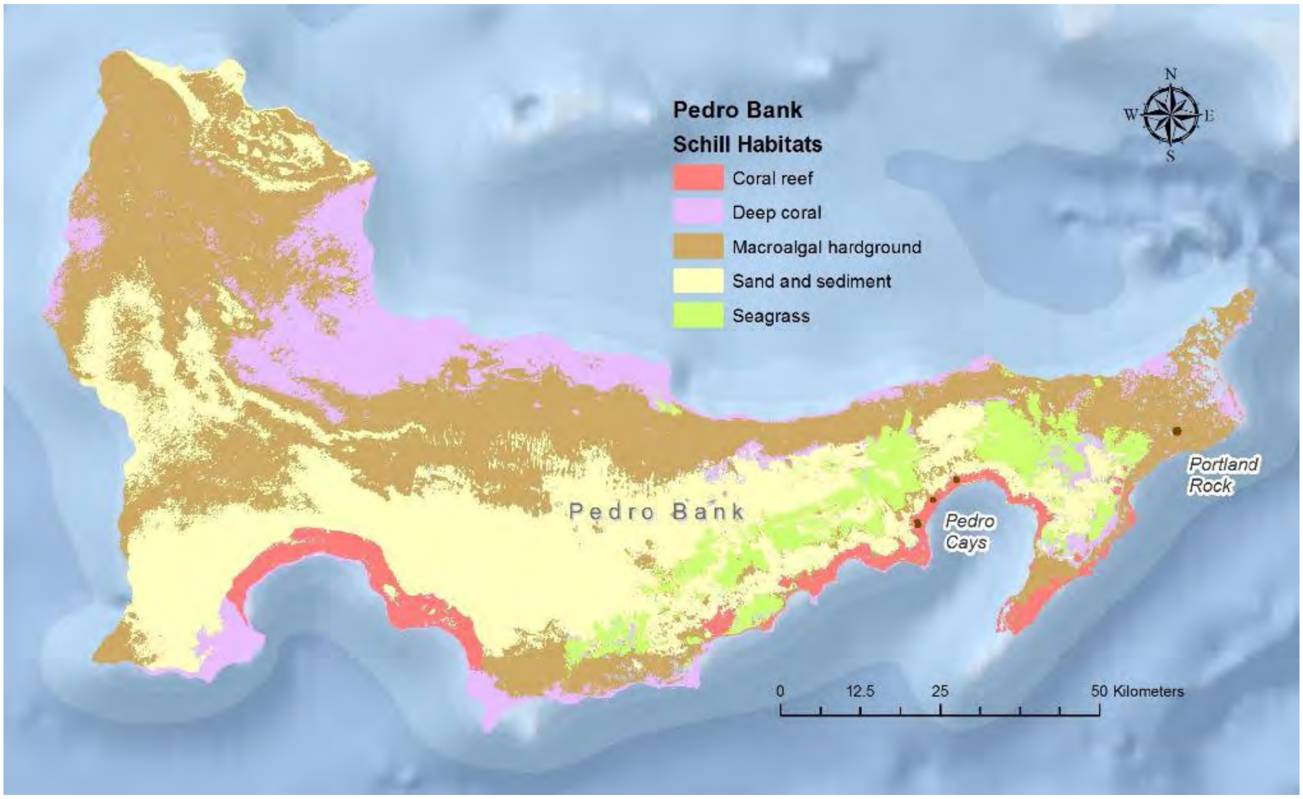

Figure 2. Broad scale map of the Pedro Bank (out to the 30 metre bathymetry contour) comprising of 5 habitat classes developed by S. Schill of TNC based on Landsat 8 imagery (30m resolution).

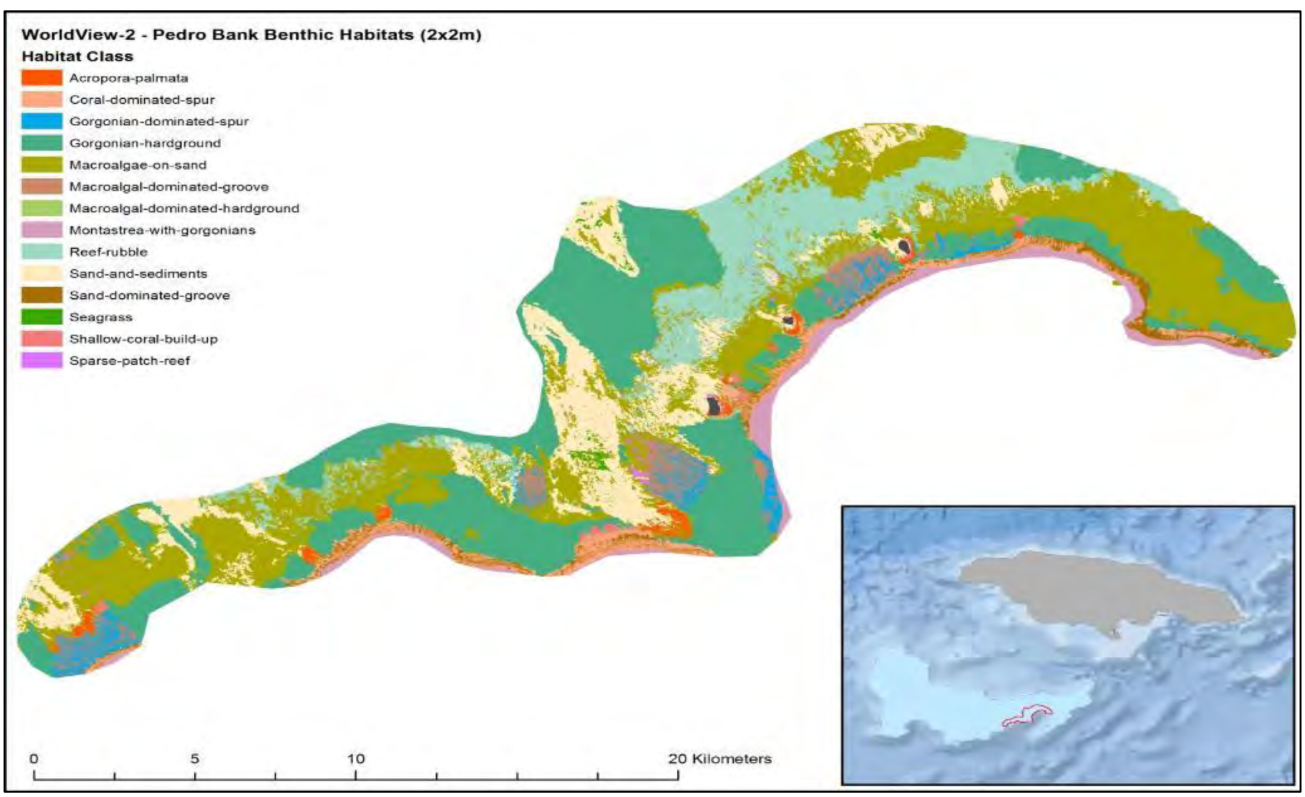

Figure 3. Fine scale habitat map of the Pedro Cays and near-shore areas comprised of 14 habitat classes developed by S. Purkis of NOVA based on WorldView-2 imagery (2m resolution).

Next a rapid fishing resource use assessment (drawing upon Baldwin 2012, Bunce and Pomeroy 2003) was conducted with fishers using semi-structured interviews to better understand the abundance and space-use profiles of Pedro Bank. Based on data collected from Fisheries Division and the preliminary assessment, we aimed to sample approximately 15% of fishers stratified by fishing base (i.e. Pedro Cays, 'Cross the Bank') and fishing gear (i.e. line, net, trap, free diving, compressor diving). An effort was also made to speak with industrial fishing companies and carrier 'packer' boat owners. Questionnaires sought information on fishing demographics, livelihood strategies, resources and use patterns. As part of the questionnaire, a mapping exercise component was included to map both the maximum extent of fishing grounds and identify priority fishing areas (drawing upon Scholz et al. 2010). Lastly several open-ended questions were included to obtain information on areas of conflict, IUU fishing and perceptions about conservation areas. Recommendations on potential locations for new conservation areas and types of fishing zones to be applied on the Pedro Bank were also collected. More than 90 key informant semi-structured interviews of which 78 were Pedro Bank fishers (i.e. 40 Pedro Cays, 31 'Cross the Bank', 6 industrial fishing companies) were conducted. Spatial information derived from mapping exercises was scanned, imported into GIS and features of interest were digitised. Corresponding attributes collected as part of socio-economic assessment (Baldwin 2014c) were first entered into Excel as tables and subsequently connected (using a table join) to associated mapping spatial data.

Building a multi-objective database

The basic requirements for MSP include an inventory of important ecological areas, current human activity and the identification of conflict or threat among and between uses and the environment (Douvere and Ehler 2009). Thus the geodatabase design was driven by the need to understand the Pedro Bank environment and influence of present and future human activities to support MSP. The geodatabase was created using ArcInfo version 10.1 software. All data were imported and standardised using ArcMap, ArcCatalog and ArcToolbox along with the Spatial Analyst extension. All data collected and created were organised and grouped into feature datasets or similar 'themes' of the resource use values, each of which contain a number of corresponding feature classes or 'layers' categorised by name, methods, source, geoprocessing performed and identified priority goals (Table 2). Additionally metadata was produced for each feature class describing the data source, methods and timeliness.

Collecting data, defining the database structure and populating the geodatabase was an iterative process that continued throughout the life of the project. A total of four satellite imagery datasets, three nautical charts, 57 technical reports (many containing maps or atlases), and more than 40 GIS files were collected and reviewed for use. The Pedro Bank geodatabase consists of nine feature datasets, comprising 42 feature classes (Table 2) of which 40% is derived in part based on the use of local knowledge sources. A detailed report of the methods for data creation and compilation is given in Baldwin (2014c) and Baldwin et al. (2014d).

Providing decision-support products

One of the most important aspects of a successful marine spatial planning process is having access to comprehensive information that can facilitate informed decision-making. The application of GIS to integrate, display, query and analyse information is widely recognised as valuable for ecosystem-based decision-support and MSP (Ehler and Douvere 2009; FAO 2013). GIS allows users and decisions makers to view and overlay different layers of information and is invaluable in a decision-making process when a variety of scenarios and trade-offs must be considered. Given the wide range of technical knowledge that a diverse set of stakeholders and decisions makers are likely to have, it is important that decision-support products accommodate a range of technical skills and are stored in a manner that it is understandable and easily accessible. Thus a major aim of this project was to integrate a range of multi-sector information to generate a suite of products that will help the people of Jamaica to make decisions, finalise and implement a marine multi-use zoning design. A benefit of GIS is that it provides users with the ability to easily create maps to provide a better understanding of the interactions occurring within a particular environment. Therefore individual feature layer maps and a number of composite maps (e.g. benthic habitats, conservation features, fishing space-use) were created and organised into corresponding resource value or zone folders (Table 2; Appendix 2). Furthermore to support the effective use of the MSP data, this project used two main modes for delivering spatial data: a spatial database provided in both ArcGIS and Google Earth formats; and access to web-based feature maps via Dropbox.

https://www.dropbox.com/sh/30ea7xzxwf0klu9/AAB1vLfMSu6PheYGC9CEWPQ6a?dl=0).

Table 2. Table of the Pedro Bank MSP geodatabase: feature layers are listed by zone, feature dataset, layer name, DST priority (percentage), methods and data source.

Pedro Bank MSP Feature Layers (17 Feb 2015)

Zone	Feature dataset	Layer name	Priority (%)	Methods	Source(s)
CONSERVATION	Habitat	Shallow Coral Reef	30	Remote sensing & field measurement	The Nature Conservancy, S. Purkins
		Deep Coral Reef	30		
		Sand and Sediments	30		
		Seagrass	50		
		Macroalgal Hard Bottom	30		
		Deep Ocean	N/A		
		Wetlands (Mangroves/Salt Pond)	N/A	Digitised from imagery, reports	WV2 imagery (2014), Pedro Cays Management Plan
	Resources	Seabird nesting areas	75	Buffer 1km from Cays	Seabird Management Plan
		Seabird foraging areas	30	Tracking point data	P. Jodice
		Sea turtle nesting beaches	75	Buffer 1km from Cays	Pedro Cays Management Plan
		Nursery areas	30	Mapping exercises	Fishers
		Spawning grounds (potential)	30	Modelled surface	Potential SPAGs (Krammer & Heyman)
		Biophsical parameters (Upwelling, SST, Chl)	N/A	Modelled surfaces	NOAA global datasets
		Cultural/Heritage Sites (shipwrecks)	N/A	Digistise features	Nautical charts, JNHT
	Management	Marine protected areas (Proposed)	N/A	Mapping exercises	Fishers
		Fish sanctuaries (Designated)	Locked in	GPS coordinates	The Nature Conservancy
		EBSA boundary	N/A	Downloaded	Conventional of Biological Diversity (2012)
		IBA boundary	N/A	Downloaded	Birdlife International (2012)
		Scientific research areas / data collection	N/A	Digistise features	Conch survey sites (2011), AGGRA sites
FISHING	Fishing grounds	Conch industrial fishing grounds	N/A	Vessel tracking	CRFM 2010 & 2012 (no data for lobster)
		Fish - Pelagics (Quality)	50	Gear Proxy	Maximum extent of Line fishers
		Fish - Reef (Trash)	50	Gear Proxy	Net, free dive & compressor fishing extent
		Lobster	50	Habitat Proxy	Deep reef & macroalgal hardground
		Conch	50	Density surface model	Conch assessment survery (2012)
		Baitfish	75	Mapping exercises	Fishers
	Fishing gear	Traps	N/A	Mapping exercises	Artisinal fishing extent (frequency maps) by gear (Schill) & by fishing base
		Compressor	N/A		
		Free Lung	N/A		
		Line	N/A		
		Nets	N/A		
	Fishing pressure	Fishing priority (artisinal)	N/A	Mapping exercises; Weighted overlay analysis	Fishers, Modelled surface applied to weight fishing grounds for Marxan (Schill)
		Fisher (socio-deomgraphic) profile	N/A	Excel table	Fisher surveys, Fisheries Division
TRANSPORTATION		Shipping routes	N/A	Downloaded	NOAAs SEAS BBXX dataset
		PSSA	N/A	Pedro planning area	Scope of planning area (600 m)
		Anchorages	N/A	Mapping exercise	Nautical charts, fishers, Fisheries Division
		Fish landing sites	N/A		
		Military areas	N/A	Mapping exercise	Coast Guard
FUTURE USES		Potential oil extraction	N/A	Digistise features	Petroleum Corporation of Jamaica
		Eco-tourism (wildlife viewing, diving, research)	N/A	Mapping exercises	Yardie Environmental Conservation
THREATS		Invasives (cats / rats / crabs)	N/A	Digitise features	Pedro Cays Management Plan, experts
		Sources of Pollution (land-based & marine)	N/A	Mapping exercises	Pedro Cays Management Plan, fishers
		Illegeal (IUU) fishing	N/A	Mapping exercises	Fishers, Coast Guard

Identifying priority conservation areas

Understanding the amount and distribution of ecosystems, structurally and functionally, is essential for MSP initiatives (Ehler and Douvere 2009). GIS can be used as a tool to monitor a country's progress towards achieving marine conservation targets. To demonstrate, the GIS interface was applied to quantify the existing amount of the various coastal and marine habitats currently existing on the Pedro Bank and in the South West Cay Special Fishery Conservation Area (SCFA) (Table 3). At present less than 0.5% of the Pedro Bank is protected comprising less than 0.04% (5 m^2) of seagrass habitat.

Table 3. Table of key marine habitats of the Pedro Bank (found in less than 30 m depth); summarised as total area (in km^2) and percent (%) total of the Pedro Bank and broken down by total area (in m^2) of each habitat type contained within the South West Cay Fish Sanctuary.

	Pedro Bank		South West Cay SFCA	
Habitat type	Area (km^2)	% total	Area (m^2)	% total
Coral reef	1,388	18	4,781	37
Macroalgae	3,139	41	2,568	20
Sand	2,590	34	5,624	43
Seagrass	474	6	5	0.04
	7,591		12,978	

Although basic GIS functions such as summarising and visualising information are valuable, the development of a marine space-use plan typically includes advanced spatial queries (Agardy 2010; Agostini et al. 2010; Maelfait and Belpaeme 2010). Spatial queries based on the proximity of features can be valuable for marine conservation prioritisation (FAO 2013). For example, a well-connected reef ecosystem is known to include adjacent areas of mangrove, seagrass and reef habitat. The identification of areas where these habitats occur in such a way as to represent a reef ecosystem can be an important step in identifying critical areas for conservation (Gombos et al. 2013). To demonstrate, a spatial query was applied to detect the existence of seagrass habitat within a distance of 100m of coral reef habitat. Furthermore all conservation resource features (i.e. identified nursery grounds, sea bird nesting and foraging grounds, spawning sites) identified as important for reef and fisheries resilience were also mapped (Figure 4). This information was useful to evaluate conservation efforts and identify additional areas for management protection.

Visualising fishing patterns

An important aspect of ecosystem-based management is to understand not only the location of resources but the influence that humans are having on them. GIS was used to explore the interactions among variables, evaluate trade-offs and prioritise management objectives. For instance visual examination of the location of preferred artisanal fishing grounds by landing site revealed spatial patterns (i.e. TURFs) that are not obvious from summary statistics. Additionally overlaying the location of priority fishing grounds (Figure 5) with the location of conservation features (Figure 4) provided insight on human-environment interactions and patterns of space-use on the Pedro Bank. Based on an examination of the fishing intensity map, it is apparent that artisanal fishers prefer to fish on the eastern half of the Pedro Bank in shallower water. This pattern is probably due to several factors: high diversity and density of conservation features (reefs, seagrass, spawning sites, seabird foraging), economic (cost of fuel and time of travel), physical (limitation of depth and current relating to the deployment of gear and diving), and perhaps safety. This finding has several important implications for MSP as it indicates a spatial preference by fishers. As a result there may be a certain degree of 'natural or environmental' protection of habitats and resources located on the western half of the bank taking place by virtue of the limitations of fishing methods and vessels that are currently in use.

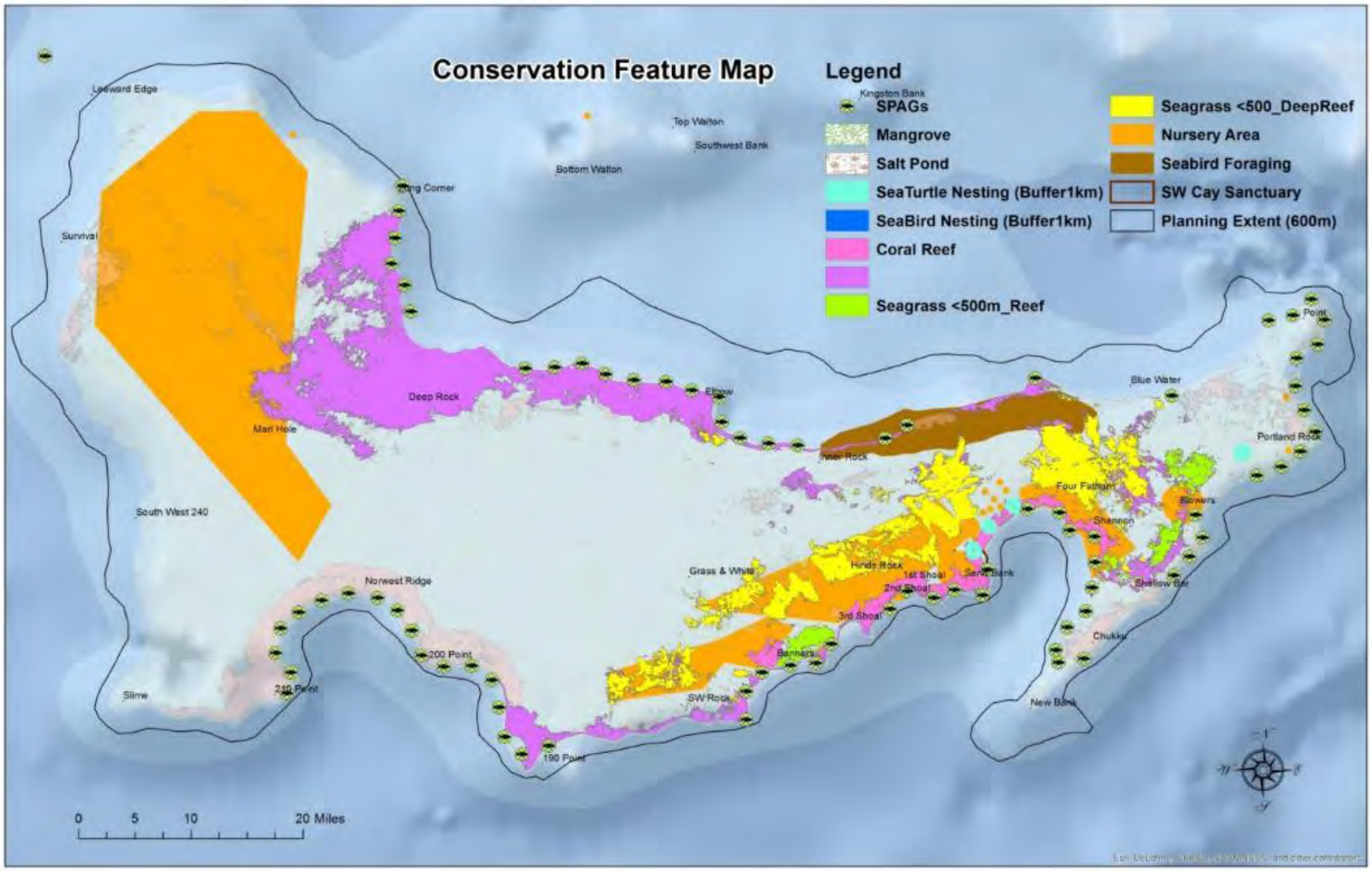

Figure 4. Composite conservation feature map created based on existing information for the Pedro Bank.

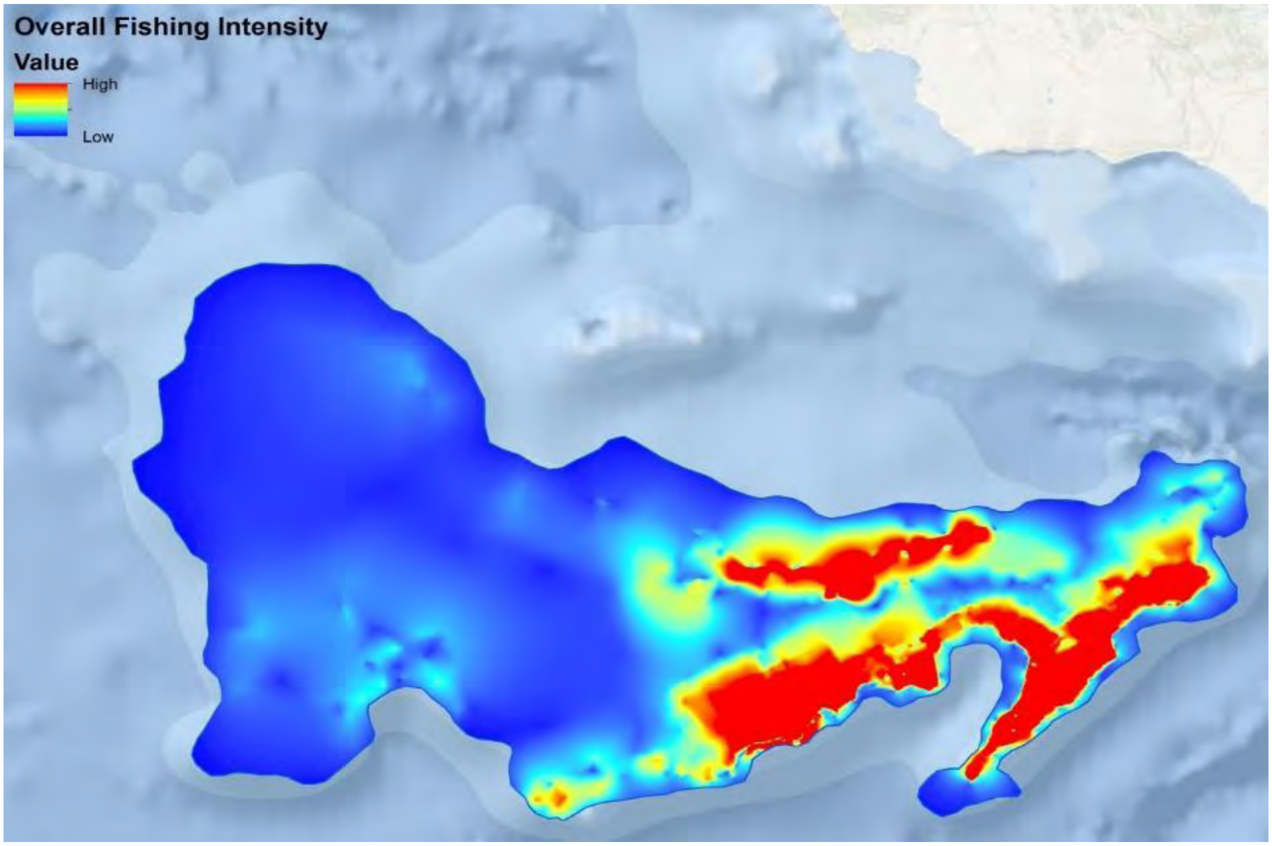

Figure 5. Map of overall fishing intensity modelled based on artisanal fishing priority areas (Baldwin 2014c).

Multi-objective DST analyses

Interactive decision-support tools (DSTs) are useful for MSP in that they can capture, share, and compare many people's ideas about planning options and help to understand the real-world implications of different management regimes and environmental conditions (Beck et al. 2009). 'Marxan' and 'Marxan with Zones' are one of the most popular conservation planning DSTs developed by the University of Queensland (www.uq.edu.au/marxan). This free software application allows users to incorporate multiple social and ecological objectives or priorities when designing a portfolio of management areas. The following section provides a brief explanation of the Marxan software input parameters we applied. Please see Baldwin (2014c; 2014e; 2015a) for a detailed review of the application of DSTs and Marxan over the course of the MSP project.

The Marxan version 2.43 software was run several times to develop a number of possible zoning scenarios for the Pedro Bank over a four month period. Due to limited data availability for all identified resource use values, only the Marxan software was applied (and not Marxan with Zones) to develop two DST scenarios for conservation and fishing values. Detailed descriptions of the Marxan input parameters and analysis results are presented in Baldwin 2014c; e and Baldwin 2015a.

Marxan requires that each resource and activity (i.e. spatial feature) in the project area be summarised into planning units. Planning units are a pre-defined grid, typically hexagons, used to consistently summarize each spatial feature, which is determined based on the scale and complexity of the input data. This allows the program to run comparison and selection spatial analyses between features and candidate zoning areas. Based on the scale of data collected in this project, one km^2 planning unit hexagons (i.e.

10,985 planning units) were chosen and integrated using two strata (east and west) out to a boundary extending to the 600 m depth contour in order to provide replication in the zoning solution across the Pedro Bank using the developed scenarios (Figure 6).

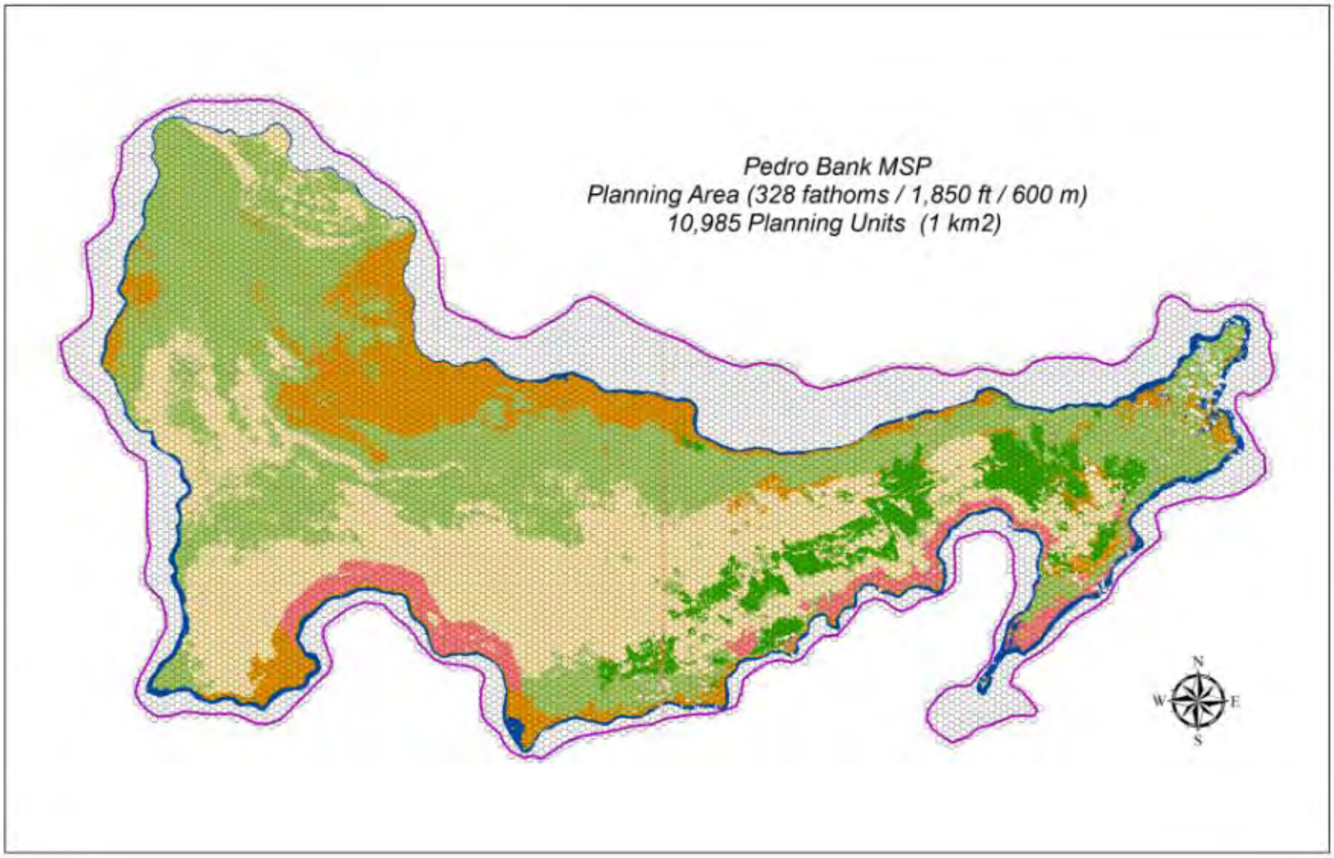

Figure 6. Map of the planning units, two (east and west) strata, and the 600 m depth contour that comprised the Marxan analysis boundary applied for the Pedro Bank MSP.

Different activities occurring in the marine environment may have an effect on another, in addition to the coastal and marine ecosystem. Marxan aims to model these interactions using an input variable called a 'cost matrix'. In other words, Marxan identifies and allocates an optimal selection of planning units to each zone, while trying to achieve each zone's goals at a minimum 'cost'. Thus the 'cost' values used ultimately influence where (planning unit) goals can most reasonably be achieved. The statically optimal solution is referred to as the 'most efficient' solution. To model compatibility of uses (cost) for Pedro Bank, fishing intensity was used as a cost surface for the conservation scenarios (Figure 7), whereas the conservation Sum Solution (SSOL) output (Figure 8) was used as a cost surface for the fishing scenarios.

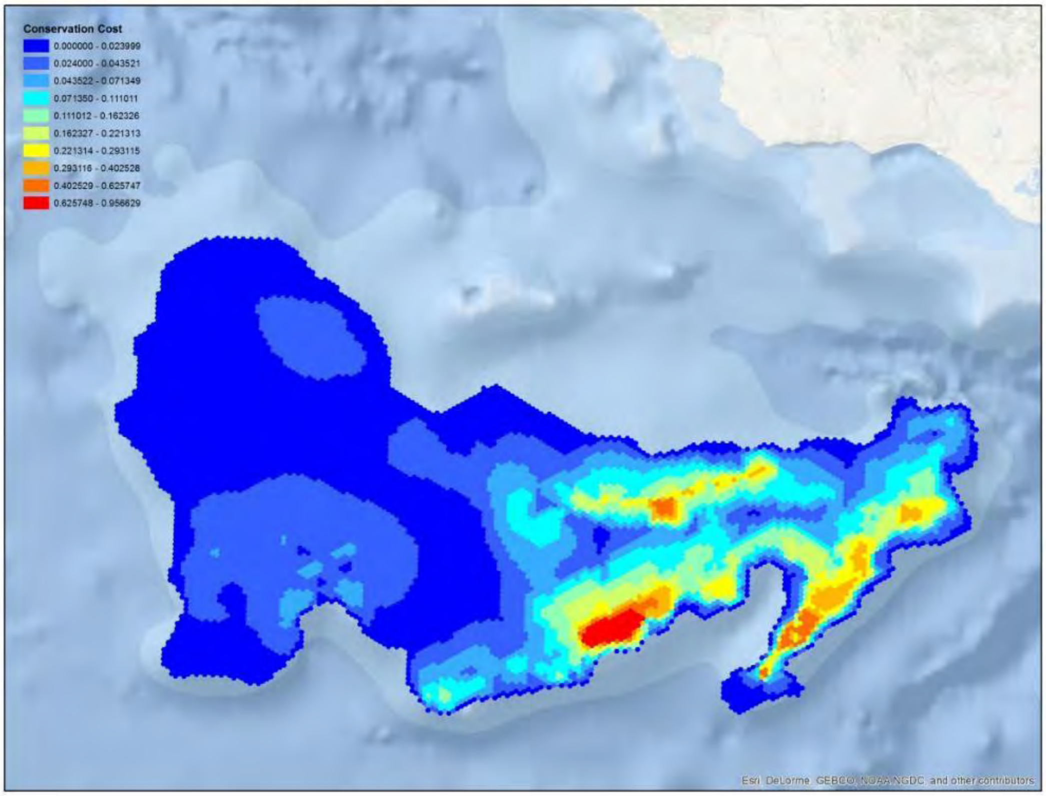

Figure 7. Conservation cost surface model (i.e. fishing intensity model) created for use in the development of Marxan scenarios.

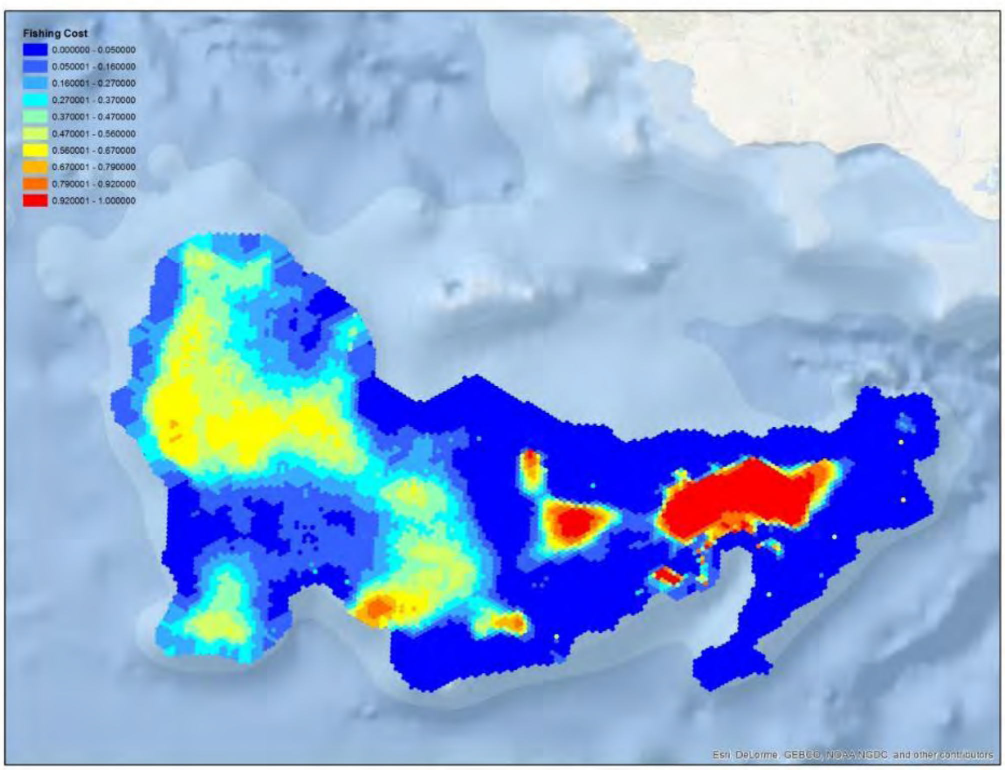

Figure 8. Fishing cost surface model (i.e. Conservation SSOL) created for use in the development of Marxan scenarios.

How fragmented a specific zone is has an impact on management feasibility and effectiveness (i.e. how costly implementing a zone will be). Exploring the impact of varying levels of fragmentation is achieved in Marxan with a parameter representing compactness (i.e. boundary length modifier). Optimal parameters for spatial compactness and buffering of zones were derived through a standard calibration process (Watts et al. 2010). Therefore a Boundary Length Modifier (BLM) of 0.1 was applied to Marxan analysis for the Pedro Bank.

Two DST scenarios were developed for conservation and fishing resource values. For each scenario, Marxan was run using 100 repetitions, with each repetition having 1 million iterations. The first Marxan scenario (Figure 9) was based on the variable goals (listed in Table 2) that were identified by the PBWG (with no pre-selected areas 'locked in' to the solution). The second scenario (Figure 10) utilised the variable feature goals with designated (e.g. South West Cay SFCA) and proposed SFCAs (i.e. those areas recommended by fishers) 'locked in' to this Marxan solution.

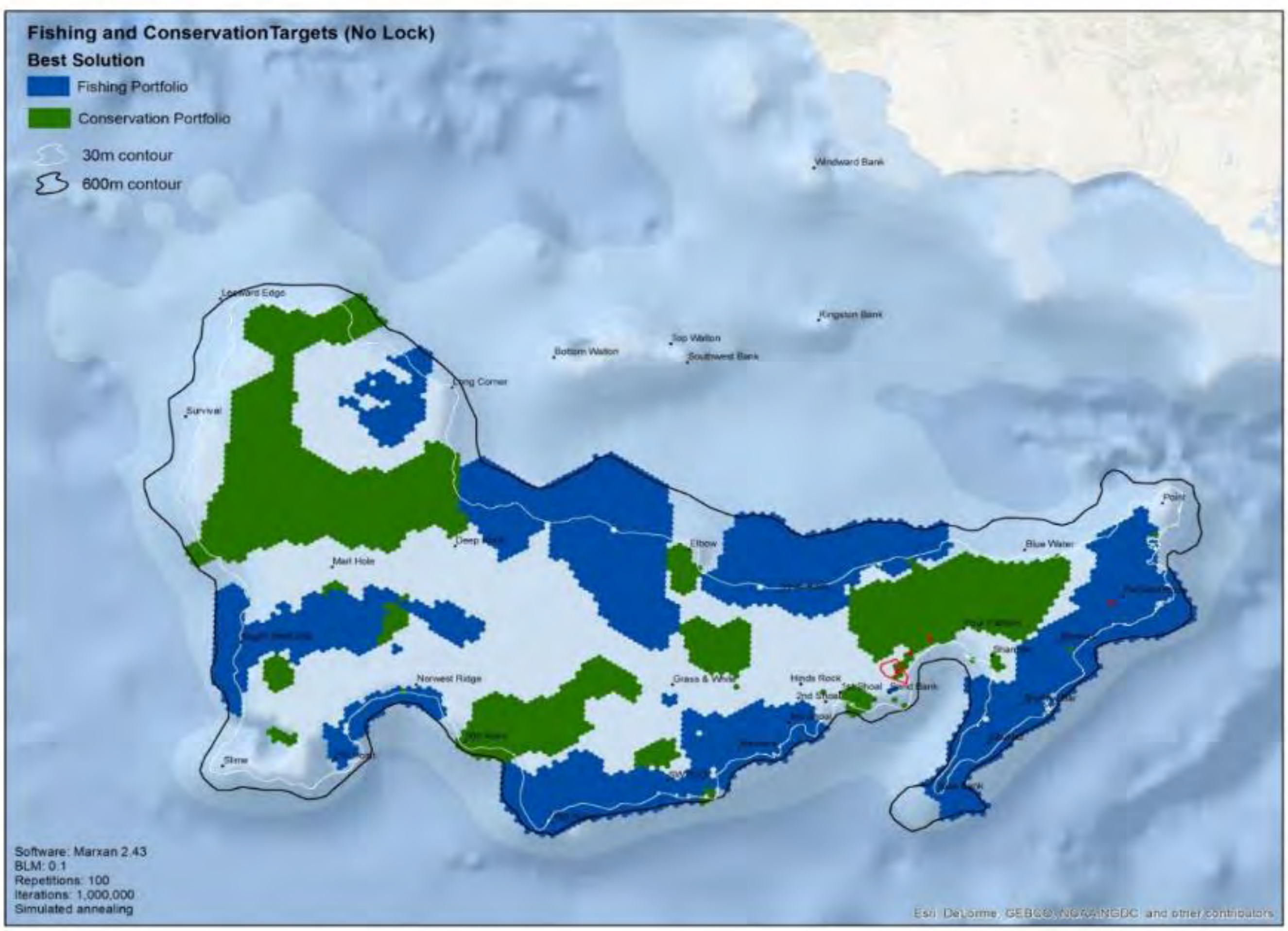

Figure 9. Marxan Scenario 1: Fishing and conservation targets based on variable goals

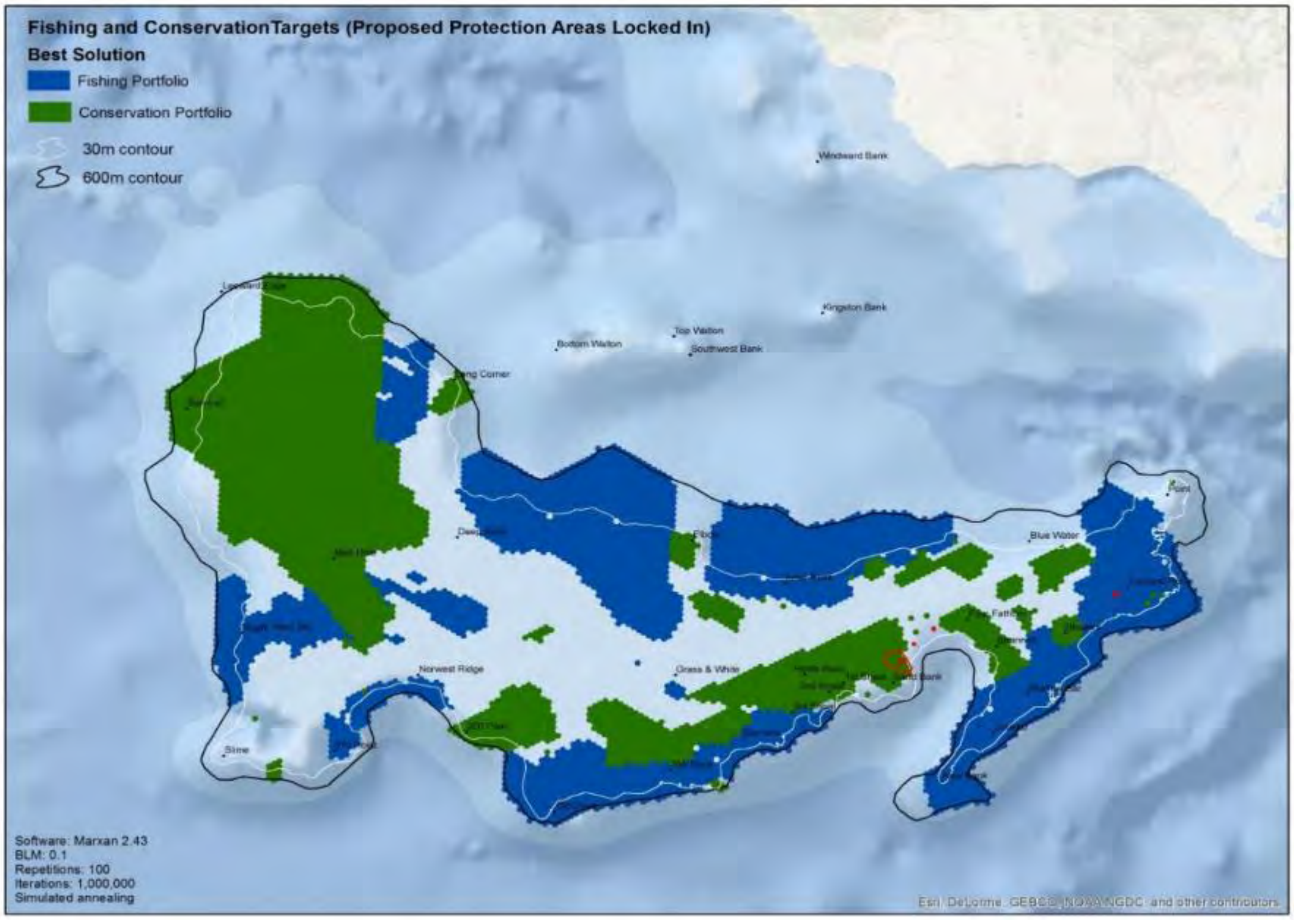

Figure 10. Marxan Scenario 2: Conservation and fishing targets based on variable goals with designated and proposed protected areas locked-in to the solution

At the third planning workshop, the PBWG broke into two groups to discuss the DST spatial analysis results, evaluate appropriateness and assess trade-offs afforded by each of the developed zoning scenarios. The PBWG collectively identified several areas of importance for conservation, including the western part of the bank near Marl Hole, 200 Point to Grass and White, an area near Banners Reef, South West Cay to San Bank, Top Cay to Four Fathom / Shannon, and Blowers. Identified fishing priority areas extended from Point to New Bank, 190 Point to Banners, and Inner Rock along the northern (or inner) edge of the Pedro Bank (Baldwin 2015a). These maps were imported into ArcGIS, total areas (in km^2) were calculated for each identified area, and identified priority fishing and conservation areas were merged with areas of overlap between the two groups highlighted (Figure 11). At this workshop the PBWG also identified potential management measures that could be applied to the Pedro Bank MSP and nationally in Jamaica. The PBWG concluded that additional feedback was needed from all fishing stakeholders to appropriately evaluate the representativeness, feasibility and fairness of identified conservation and fishing priority areas and to ascertain management measures with the largest fisher support before making a final recommendation to the NPAS project on the Pedro Bank MSP.

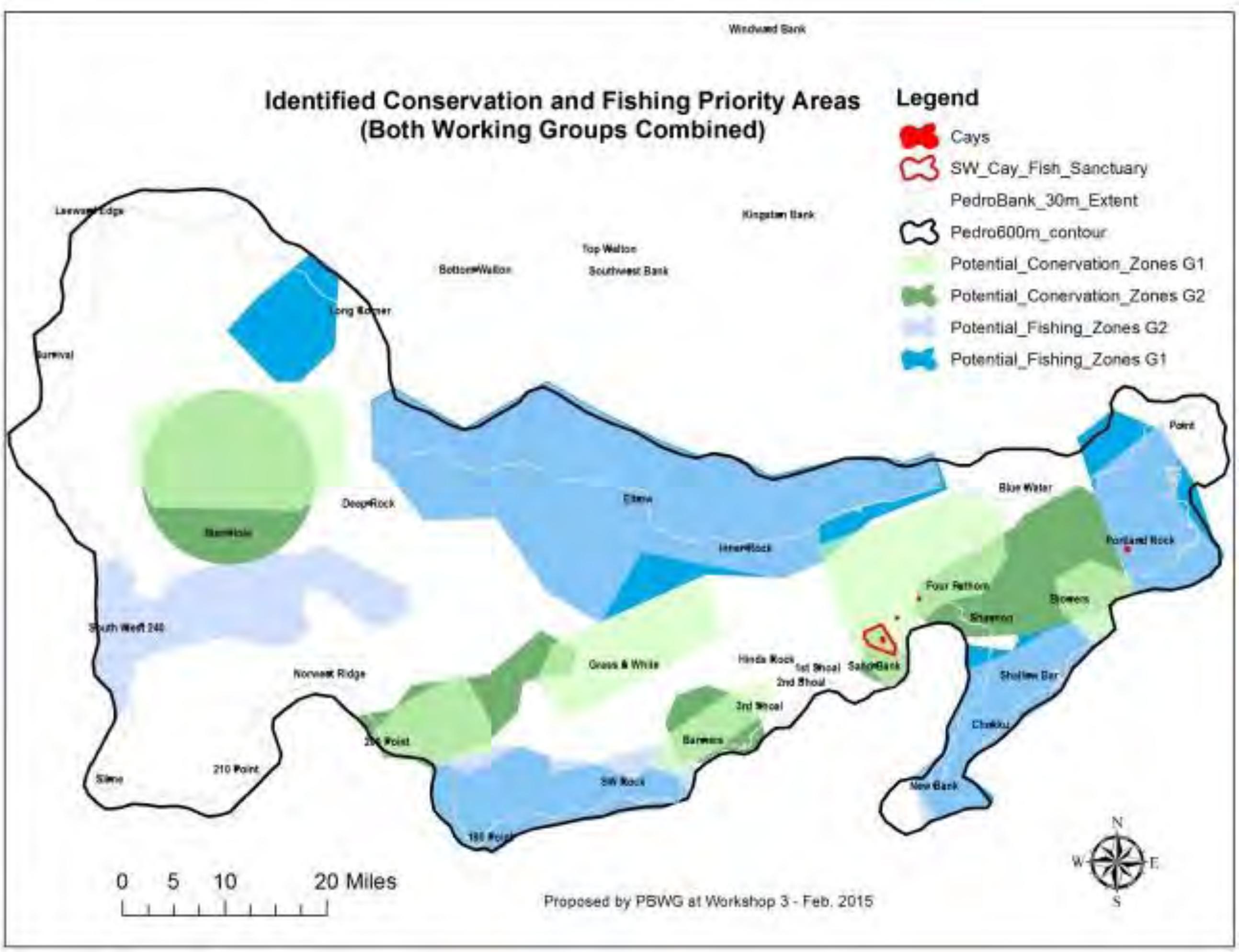

Figure 11. Merged map showing overlaps of priority fishing and conservation areas identified by each of the two PBWGs at Workshop 3. *(N.B. All areas are not intended to be allocated; figure to highlight overlaps).*

Allocating marine resource and space-use management

Previous marine spatial planning efforts have found that MSP must carefully accommodate stakeholders' needs and are most effective when generated by those who will be involved in the management and enforcement of a plan (Agardy et al. 2012, Gilliland and Laffoley 2008). Particularly in SIDS making scientifically-sound information available to both managers and stakeholders so that they are better able to make informed decisions has been found to be effective for MSP (Pomeroy et al. 2014). Likewise the use of the e-group and DropBox sharing folder together with numerous formal and informal meetings to update stakeholders (Table 1) was fundamental to ensure access to all produced information including reports, data and maps.

Recommending area-specific marine management measures

At each of the various MSP planning workshops (Table 1) time was taken to review and re-adapt the vision, goals and objectives based on any new information collected and the suite of multi-objective decision-support tool analysis outputs presented to the PBWG over the course of the project. This step was a culmination of the aforementioned activities, which served as the basis for generating an acceptable marine zoning design based on sound scientific knowledge and appropriate management recommendations. It should be recognised that in a MSP there are four general types of management measures (i.e. input, process, output, spatial/temporal) applied for MSP (Ehler and Douvere 2009). As a 'zoning design' typically only comprises spatially based measures, a MSP typically recommends various management measures required to achieve the vision for the area. The following the management measures grouped by resource use value are recommended by the PBWG were reached via group consensus. *Measures in italics* are prioritised to be achieved in the longer-term. It is anticipated that these recommendations will be ultimately be used in the development of a management plan for the Pedro Bank MSP.

Transportation Zone (15,792 km^2)

- Designated to protect the marine resources of the Pedro Bank against marine-based pollution and damage from transportation activities
- Comprises the entire Pedro MSP area plus a 5 mile buffer around the extent of the Pedro Bank
- Permit shall be required for all vessels to enter or use the Pedro Bank
- No anchoring or discharging bilge or ballast on Bank
  - Mooring buoys to be installed to replace designated anchorages
- VMS implemented for all licensed fishing vessels to allow for zone boundary notification, monitoring, enforcement and safety at sea
- *Support the designation of the Pedro Bank as an IMO Particularly Sensitive Sea Area (PSSA) by the MAJ*
- *Two-stroke outboard engines phased out in to reduce marine pollution in Jamaican waters*

Future Development Zone (10,497 km^2)

- Designated to ensure that new development for the Pedro Bank is compatible with existing designations and uses as well as to provide for sustainable use of the Pedro Bank resources
- Comprises the entire Pedro MSP area
- Permit shall be required for all new (extractive & non-extractive) activities, including prospecting
- As a specially protected area EIA, SEA, risk analysis, compatibility assessments will be required for all new (extractive & non-extractive) activities (with varying levels based on proposed activity)
- 'Best environmental practice' standards will be applied for all new developments and become specific conditions for permits

Conservation Zones (622 km^2)

- *No entry zone*
  - No-entry zones tend to be small and are often used to protect areas of high sensitivity
  - *No areas presently identified; TBD in future if needed*
- Limited-entry (research only) zone (58 km^2)
  - Restricted access area that is used for research and is off limits to the public
  - Permit required for entry and research activities
  - Area identified: extend South West Cay SFCA to Sand Bank
- No extraction (no-take): SFCAs (564 km^2)
  - Four areas identified and listed in order of priority. (*N.B. Exact boundaries TBD)*
    1. Top Cay to Four Fathom and Shannon (94 km^2)
    2. Blowers Reef (87 km^2)
    3. *200 point (edge of Northwest Ridge)* (154 km^2)
    4. *Long Corner to Deep Rock* (174 km^2)

- *Emergency transit channels to be demarcated for each protected area if deemed necessary*

Research Zone (10,497 km^2)

- Designated to monitor changes and evaluate the MSP management effectiveness
- Comprises the entire Pedro MSP area and to occur in all designated zones
- Permit required for all research and conditional based on provision of data/information collected
- Area specific restrictions TBD by type of zone (e.g. conservation vs. development)

Fishing Zones (4,775 km^2)

- Can be designated anywhere in the Pedro MSP area to protect and conserve fishing resources

<u>Fishing and Biodiversity Priority Zone</u> (3,866 km^2)

- Designated to protect marine biodiversity and resources of the Pedro Bank
- Comprises the eastern half of Pedro Bank extending from South West Rock to the eastern extent of the bank (approximately 35% of Pedro Bank)
  - Oil exploration and extraction is prohibited
  - All potential future development will be carefully examined and assessed for compatibility

<u>Limit Entry Zones (Artisanal and Industrial Fishing)</u> (10,497 km^2)

- Limit and reduce number of licenses for fishing the Pedro Bank based on both fisheries specificity (i.e. conch, lobster, fish) and gear specificity (i.e. compressor, trap, net, line)
- Revocation of license / restrict entry for violators (using a graduated scale)
  - Detention (fine), suspension (restrict access), expulsion (ban)
  - Fine both the boat owner and all crew aboard vessel to aid accountability

<u>Lobster Sanctuary Zone</u> (909 km^2)

- Designated to allow for the protection of juvenile lobsters
- Gear restriction (no traps, spearguns, nets, or lines): primarily no-fishing zone
- Seasonal closure: only can be used to harvest conch by hand during the annual open season
- Two potential areas identified:
  - Grass and White: Designate approximately 25% or one of the three identified areas (exact location in the Grass and White TBD)
  - *Marlhole (exact location TBD in the future)*

<u>Fish Refuge Zone</u>

- Rotating fish sanctuary: temporary no-take zone (2-5 yr. closure) designated to repopulate intensely overfished marine areas
- One or more areas can be designated anywhere on the Pedro Bank (exact locations TBD)
- *Complete closure of entire Pedro Bank for a period of time if needed for disaster or misuse*
- *Moratorium on certain species for determined period allowing for replenishment (parrotfish)*

Other recommended fisheries-related non-spatial management measures include:

<u>Limited entry (Industrial fishing)</u>

- Reduce number of industrial fishing licenses for lobster
- Increase transparency of condition and granting of license (i.e. Board)
- Limit number of traps per industrial license
- *Limit number of licenses for all industrial fisheries (including sea cucumbers)*

<u>Fishing effort measures</u>

- Limit number of licenses for Pedro Bank based on BOTH fisheries specificity (conch, lobster, fish) and gear specificity (compressor, trap, net, line)
- Extend closed season for lobster one additional month
  - *Gradual increase by one more month (if needed)*

<u>Gear restrictions</u>

- Prohibit dredging and trawling, dynamite, electrocution, vacuum, etc.
- Prohibit night dive fishing
- Increase net mesh size used on Pedro Bank (recommend 2.75 inch)
  - *Gradual increase (TBD)*
- *Prohibit use of compressor for fish and lobster fisheries (no use outside conch season)*
- *Use of compressor phased out completely*

<u>Catch measures</u>

- Quota/TAC system for the lobster export fishery
- Quota/TAC system for the sea cucumber export fishery
- *Taxation for all export fisheries*

<u>Size limits</u>

- Prohibit landing of undersized and berried lobsters
- Change minimum size for lobster to a tail length measurement (recommend 5 in tail length)
- *Implement a maximum size for lobster (slot limit)*
- *Minimum size for all fish species (by species)*

Generating a marine multi-use zoning design

The identified management measures and marine multi-use zoning design are based on the Pedro Bank MSP's vision, and the goals and objectives for each resource use value (Planning Workshop 1). This included a prioritisation of resource use values (Planning Workshop 2) based on scientific data and associated socio-economic information collected over the course of the project. The developed GIS and DSTs products (Planning Workshop 3) were useful in the development of management measures that were seen to be appropriate, equitable and feasible as seen by the PBWG members (Final Planning Workshop). Figure 12 is a map of the spatially-explicit management measures developed as part of the Pedro Bank marine multi-use zoning design. The zoning design was reached by group consensus among the PBWG at the final MSP planning workshop (Baldwin 2015b). It is noteworthy that the boundaries of the conservation and fisheries zones represented in the multi-use zoning design in many cases are 'fuzzy' and are merely used to draw reference to the type or manner of spatially-explicit management measure to be applied. Therefore the depicted zoning boundaries are not to be viewed as 'final' as further work with key stakeholders must be undertaken to identify the most feasible arrangements for the Pedro Bank.

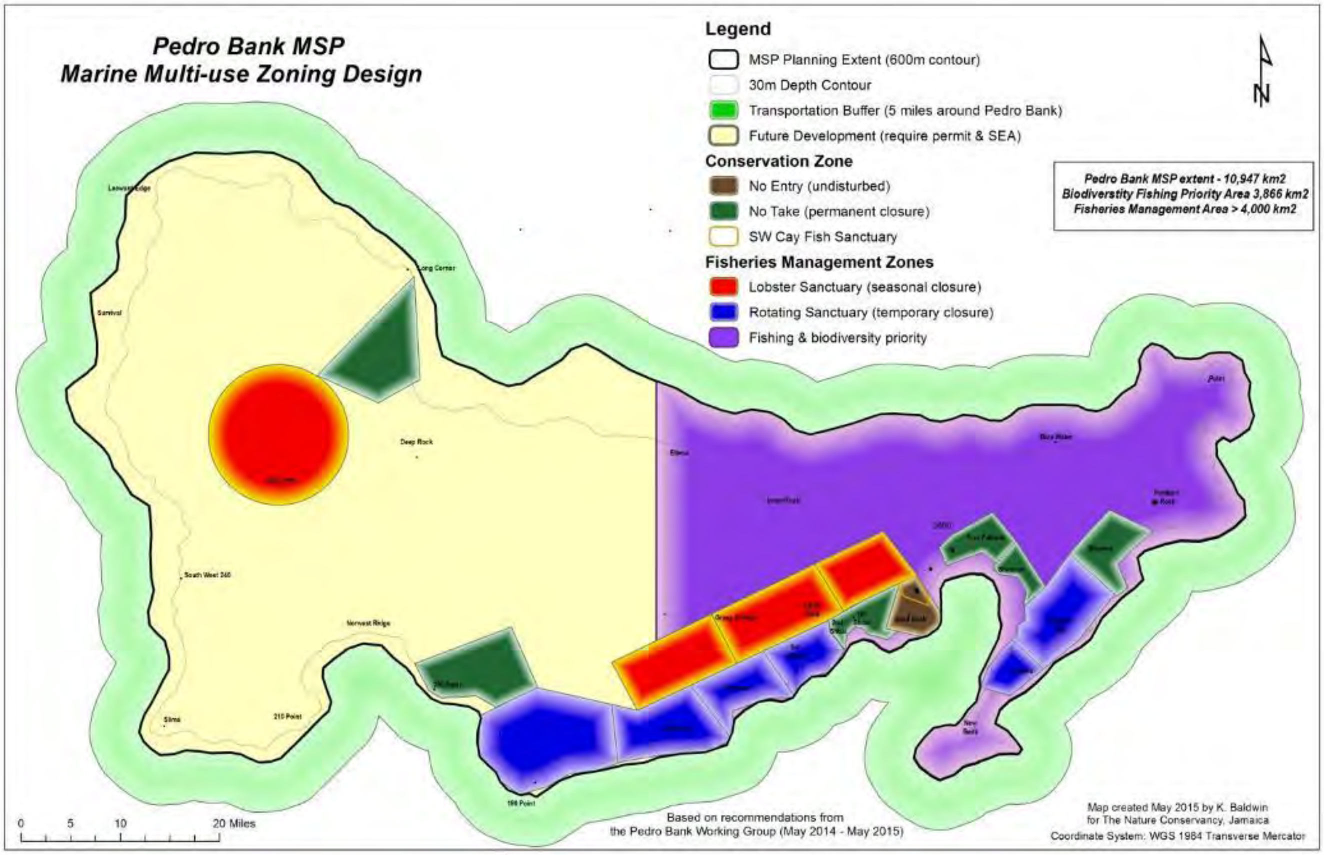

Figure 12. The marine multi-use zoning design developed for the Pedro Bank MSP extent.

Over the course of the project the PBWG collaboratively developed a MSP for the Pedro Bank based on a long-term 50 year vision with clear guiding principles, goals and objectives. The recommended management measures and marine multi-use zoning configuration was reached by consensus amongst the PBWG members and is thought to be fair for all sectors, minimise conflict and seeks to achieve the MSP goals in an optimal way. Likewise several series of stakeholder consultations were held over the course of the project with key marine and fishing interests regarding the purpose and objectives of the MSP, potential management measures, and the subsequent multi-use zoning design (Table 1). Overall stakeholders recognise an increasing demand for marine space and as a result are already experiencing a number of space-use conflicts, and in principle support the implementation of the marine zoning design to achieve a healthy and productive marine environment that can sustain their livelihood for years to come. Despite this recognition, it must be underscored that stakeholders call for the implementation of effective management and MCS measures for wide-spread acceptance and support of the developed MSP.

Implications of marine spatial planning for Pedro Bank

The goal of a MSP framework is to deliver an ecosystem-approach to managing human activities in the marine environment, yet to do this requires the successful implementation of the multi-use zoning design and associated multi-sectoral management measures. This therefore requires that all relevant sectoral agencies and stakeholders work together to comply with the management measures identified by the MSP and the zoning design.

Moving from design to implementation

Unfortunately the application of MSP is still novel; many efforts cease after the planning stage without reaching implementation (Agostini et al. 2010). Continued effort and inputs beyond this planning exercise are required for the successful implementation of the Pedro Bank MSP. Thus the challenge for Jamaica will be to keep the MSP process moving forward and make this marine multi-use zoning design operational. Moving to a fully implemented MSP will take a concerted joint effort on the part of government, marine resource user groups, NGOs and the wider international community. Globally and particularly for SIDS, co-management arrangements are a possible mechanism that are shown to support the effective implementation of MSP initiatives (Christie and White 2010). The PGIS approach fostered cooperation among the PBWG and associated marine stakeholders was seen as central to achieving the MSP and multi-use zoning design. A similar collaborative approach should be applied to continue to support an interactive marine governance framework in Jamaica.

Over the past 10 years a strong foundation of information has been built in regards to the large amount of research conducted on the Pedro Cays and the Pedro Bank. Studies ranging from: a number of ecological, social, and governance assessments; to the development of a management plan for Pedro Cays; and now a marine resource and space-use GIS; and the development of a comprehensive MSP including a marine multi-use zoning design for the wider Pedro Bank should be leveraged to keep the MSP process moving forward in Jamaica. As a result of this ancillary work, the MSP has made much progress to incorporate conservation goals with multiple resource use management with the opportunity for sustainable future development of the Pedro Bank. Despite this groundwork, a suite of longer-term activities are required to operationalise the Pedro Bank MSP. Namely the clear identification of the relevant actors and roles for each that are required for both the various marine policy and management frameworks, the drafting of regulations and corresponding legislative reforms to support the MSP recommendations, the design and implementation of a monitoring plan to evaluate the MSP and zoning plan efficacy and the development of long-term financing options for management. Although this document only provides a brief review, a full discussion can be found in a range of publications that synthesise and document other MSP and zoning efforts worldwide (e.g., Day et al. 2007, Day 2008, Douvere 2008, Douvere et al. 2007, Gilliland et al. 2008, Ehler 2015).

Next steps recommended to implement the Pedro Bank MSP include harnessing the required political will and upper-level commitment to implement the marine multi-use zoning design. To start several presentations with the relevant national marine policy and management committees (including the NCOCZM) should be made to explain the role of MSP and the project, how MSP can assist the country in the achievement of international commitments (i.e. CBD's EBSA, FAO's Code of Conduct), regional commitments (i.e. Caribbean Challenge Initiative, CRFM) and streamline the attainment of national sustainable development goals in Jamaica. Mahon 2013 provides an assessment and recommendations on marine governance needs required for implementing marine resource management on the Pedro Bank. In tandem, investment in a strong coordinated public outreach and education programmes to highlight the importance and role of MSP should be undertaken in Jamaica.

Once policy-level commitment to employ the MSP is attained, additional funding will need to be secured to successfully implement the drafted management measures prescribed in the multi-use zoning design. Specifically, the development of management plans for the conservation zones and fishing management zones will be needed to regulate human activities in each of these sub-zones. Although general objectives and management measures for each zone have been developed further work will need to be undertaken to clearly define spatial boundaries and specific regulations within the law for each of the various identified zones. Considering the diversity of the Pedro Bank fishing communities, it is recommended that these management plans are closely developed alongside fishers to appropriately determine feasibility and obtain community-level understanding and acceptance as has been done with the draft Pedro Cays and Surrounding Waters Management Plan.

Effective management of the Pedro Bank marine resources is increasingly complex. This may be due in part to its' remote location to the mainland of Jamaica which has resulted in limited infrastructure and constrained enforcement capacity to combat the large amount of IUU fishing occurring. Improving capacity for compliance, monitoring and enforcement on all levels (i.e. SFCA wardens, Fisheries Division, Coast Guard, Marine Police and the fishing communities) using a co-management approach will be of utmost importance. Additionally enacting the draft Fisheries Act (2015) and Fisheries Policy including increasing fines and penalties for violators as well as aiding accountability using novel collaborative approaches are required. Systematic monitoring of the health of resources, including financing mechanisms to ensure continuity, are essential to determine the effectiveness of the MSP and management measures. Likewise an investment in education and training are recommended to increase compliance, the potential for co-management and to diversify alternative livelihood options.

In summary the following are recommended in the short-term to keep the MSP process moving forward:

- Work with NCOCZM to affirm high-level government mandate for the Pedro Bank MSP
- Obtain official adoption of the MSP and the marine multi-use zoning design
- Identify the framework for national marine governance policy and identify clear roles for cooperation
- Draft legislation and regulations to support MSP and marine zoning (e.g. Fisheries Act)
- Integrate the outputs of this project into other sectors of government (i.e. coastal zone management, fisheries management, protected areas planning, maritime administration)
- Continue public, private sector and government engagement for co-management

Challenges and lessons learned

A number of lessons were learned that may be of interest to other MSP practitioners. Stakeholder engagement comprised a significant amount of time and effort. The four larger PBWG planning workshops are where essential elements of the MSP were defined. Although great care was taken to deploy effective approaches to engage a range of stakeholders, facilitate discussion and record their opinions and needs, bringing together such diverse interests and facilitating discussion among stakeholders was not a simple task. Future efforts should consider investing additional resources (including hiring a professional facilitator) to assist with planning mechanisms for engagement and the use of facilitation tools. Furthermore while our data collection and mapping efforts at landing sites was instrumental in building understanding and working relationships with the Pedro Bank fishers, the remote location of the Pedro Bank made the participation of Pedro Cay fishers at the PBWG workshops challenging. Additional thought on how best to engage these critical stakeholders should be apriority for future initiatives and may be best done on the Cays. In addition, clearly establishing the manner of implementation of the MSP (i.e. lead agency, legislation, etc.) should be clarified when possible from the outset. For example, in the Pedro Bank case the multi-stakeholder PBWG's role was advisory and the lead agency (NEPA) ultimately does not see themselves as the agency with responsibility to implement such a broad multi-disciplinary scope of work. Additional resources will be required to share this resulting MSP and its' benefits to upper level decision-makers and obtain buy-in and support. Notwithstanding this, over the course of this project numerous presentations were made at national marine committee meetings to share and obtain feedback on the MSP from relevant decision-makers. Despite this it is recommended that other MSP initiatives allocate adequate resources for these types of activities which are essential for implementation. Lastly access to essential data and information (i.e. location of industrial fishing effort, oil priority areas) were not granted to the MSP project despite extensive effort and the use of official channels for acquiring information (i.e. letters of request from CEO of NEPA, the Chief Fisheries Officer and an ATI request). As a result the MSP project and decision-making had to proceed without crucial existing information and may be seen as a short-coming of the resulting MSP.

Future of MSP for Pedro Bank and Jamaica

The goal of a MSP framework is to deliver an ecosystem-approach to managing human activities occurring in the marine environment. This may also improve decision-making as the MSP process has the potential to support an integrated multi-level management approach that ranges from the local fishing communities, the Pedro Bank and to the nation of Jamaica. The goals of the Pedro Bank MSP and the marine multi-use zoning design are consistent with global, regional and national policies of Jamaica. By allocating space-use for the various sectors including conservation, in an equitable and harmonised manner, MSP can reduce the potential for conflicts. Successful MSP can promote the conservation and sustainable use of biological diversity, the viability of marine-based livelihoods, the mitigation of the adverse effects of climate change and the maintenance of ecosystem goods and services on which Jamaica relies.

The development of a MSP framework can help to clarify the roles and responsibilities of regional and national marine agencies and thereby maximise efficiency and accountability of transboundary marine resource management. An institutional and management framework for marine resources is needed to allow for the effective implementation of the Pedro Bank MSP. The MSP's principle output, a marine multi-use zoning design prescribes a number of zones ranging from no-take conservation areas to multi-use areas providing for a range of artisanal, industrial, development and other marine activities to occur in unison. While existing laws may permit the government to regulate some of the coastal and marine activities that presently occur, it typically is insufficient to implement a comprehensive coordinated framework for ecosystem-based MSP. Thus close examination of legal and governance (i.e. institutional) arrangements to support MSP must be a priority. The development of such a framework will also rationalise and clarify the roles and responsibilities of the involved regional and national marine and environmental agencies thereby maximising efficiency and accountability of national and transboundary management of marine resources (Mahon 2013).

Good governance including stakeholder engagement underlies effective MSP (Baldwin et al. 2014, De Freitas and Tagliani 2009). Likewise a collaborative PGIS approach was found useful for collecting, integrating and understanding multi-knowledge interdisciplinary information and planning for the future of marine resource management of the Pedro Bank. The PGIS approach, including the collaborative development of the Pedro Bank GIS database, engaged a wide range of stakeholders in the development of the MSP from the outset. Information exchange and access mechanisms provided strengthened capacity for broad participation in governance and informed decision-making. The continued participation of the PBWG, including maintaining communication and access to information across such a wide-range of marine stakeholders, should be ensured and will be required for the successful implementation of MSP and the multi-use zoning design, particularly in a complex SIDS coastal and marine environment such as the Pedro Bank.

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Appendices

Appendix I. Membership of the PBWG listed by entity and participant's name.

Entity	Name
CaribSave	Simon Lee
C-CAM	Ingrid Parchment
C-CAM, Birds Caribbean	Ann Sutton
Jamaica Environment Trust	Jaedon Lawe
	Llewelyn Meggs
	Diana McCaulay
The Nature Conservancy	Donna Blake
	Steve Schill
	Nathalie Zenny
Protected Areas Committee, CITES	Elaine Fisher
University of the West Indies	Mona Webber
University of the West Indies, FAC, JFSN	Karl Aiken
University of the West Indies, NCOCZM	Dale Webber
Jamaica Fishermen's Coop Union	Haveland Honeygan
Gillings Gully Fisherman Coop	Neville Mitchell
Half Moon Bay Fisherman Coop	Glaston White
Old Harbour Bay Coop	Errol Cameron
Pedro Cays Fishers	Deon Simms
	Delroy Nembhard
B & D Trawling	Sean Francis
Rainforest Seafoods	Max Jardim
Fisheries Division	Andre Kong
	Junior Squire
	Angientte Murray
Jamaica Defence Force Coast Guard	Commander Judy-Ann Neil
Jamaica Defence Force Marine Police	Carl Ferguson
Jamaica National Heritage Trust	Dorrick Grey
Maritime Authority of Jamaica	Kenrie Valentine
	Austin Lobban
National Environment and Planning Agency	Andrea Donaldson
	Sean Green
Petroleum Corporation of Jamaica	Che Stewart
	Brian Richardson
Urban Development Corporation	Sean Townsend
Veterinary Services Division	Azra Blythe-Mollett
	Wintorph Marsden

Appendix II. Summary Report of WorldView-2 Satellite Mapping of Benthic Habitats & Bathymetry for Pedro Bank, Jamaica by S. Purkis.

Summary Report

of

WorldView-2 Satellite Mapping of Benthic Habitats and Bathymetry for Pedro Bank, Jamaica

The Nature Conservancy

Contract Number: FY15-C-CB-UNDP-SAMPURKIS

Client: The Nature Conservancy

Caribbean Science Program

255 Alhambra Circle, Suite 640

Coral Gables, FL 33134

Report Date: September 15th, 2014

Contract Manager: Steve Schill (sschill@tnc.org)

Prepared By: Sam Purkis (purkis@nova.edu)

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Executive Summary

Pedro Bank is a large bank of sand and coral, partially covered with seagrass, about 80 km south and southwest of Jamaica, rising steeply from a seabed of 800 metres depth. It slopes gently from Pedro Cays to the west and north with depths from 13 to 30 metres

The bank is the main harvesting ground for Queen Conch in the Caribbean and is highly valued by Jamaica's fishing community who have been operating on the Bank and using its small Cays as a base since the 1920s

Despite being the bank being declared an underwater cultural heritage site by the Jamaica National Heritage Trust in July 2004, fisheries assessments suggest that the bank is under considerable pressure from fishermen and a fisheries reserve has been proposed

During fieldwork conducted in collaboration with Living Oceans Foundation in March 2012, a total of 15 sq. km of backscatter data and 96 drop camera videos were acquired. In addition, 10 ichthyoplankton surveys were completed within the proposed boundaries of the fishery reserve

A benthic habitat map was developed using the 14 classes for the region of study which covers an area of 300 sq. km

Bathymetry was also extracted using a spectral derivation strategy which capitalizes on the differential attenuation of light by seawater. The extraction of a digital elevation model was guided by depth soundings acquired by TNC in the area of study

All geospatial data were assembled into a GIS

It is envisaged that these maps will help in the designation of the Pedro Bank fisheries reserve

Motivation

The Nature Conservancy (TNC) requested the development of satellite-derived maps for both biological cover and bathymetry for Pedro Bank. The purpose of the mapping endeavour is the creation a GIS product that will be used to support and implement the proposed fisheries reserve.

Description of the Pedro Bank Study Area

The Pedro Bank is located approximately 80 km south-southwest of the island of Jamaica, and is one of the biggest offshore banks in the Caribbean Basin. The bank is composed of a variety of marine habitats such as sand, coral reefs, deep reefs, seagrass beds, and three coral cays known as the Pedro Cays. Because of its size and distance from mainland Jamaica and its relatively intact biological systems, it is one of the country's last remaining healthy marine ecosystems.

Both regionally and nationally the Pedro Bank is an important commercial, biological and historical area. It represents Jamaica's main commercial and artisanal fishing grounds and serves as the primary harvesting area for the largest export of Queen Conch from the Caribbean region.

The Pedro Cays are regionally important seabird nesting and roosting areas (masked boobies, roseate terns and others) and also provide several endangered turtle species such as hawksbills and loggerheads with nesting grounds. The bank may also be a potential refuge and source of larvae for several regionally-threatened *Acropora* coral species. With an estimated 99% of mainland Jamaica's reefs in danger, the coral reefs on Pedro Bank are vital to long-term reef conservation in the country. In July 2004 the bank was declared an underwater cultural heritage site by the Jamaica National Heritage Trust as it is a veritable treasure trove of sixteenth to sixteenth century shipwrecks and artefacts.

TNC's Pedro Bank Management Project aims to reduce coral reef degradation by providing solutions to two main threats not currently addressed on the bank which are direct over-fishing of resources and degradation of coral reefs and coral cays due to unsustainable development. The conservancy's aim is to work closely together with multiple stakeholders such as fishermen and fish vendors and those agencies responsible for regulating and protecting reef resources (Fisheries Division and the National Environmental and Planning Agency (NEPA), to control and minimize these threats.

Figure 1 |True-colour (red, green, blue) WorldView-2 mosaic of Pedro Bank. The area encompasses approximately 300 sq. km. Water depths across the platform-top are in the range of 10-15 m and for this reason, the imagery appears blue in colour with only faint spectral differences representing changes in benthic character. Specialised spectral processing of the imagery was required to extract the seabed map. White areas in the imagery represent either clouds (north east of the mosaic) or a series of exposed sand cays that line the southern margin of Pedro Bank. Lacking a reef rim, the platform is subjected to open marine conditions and therefore represents an exposed hydrodynamic setting. North is top.

In collaboration with the Living Oceans Foundation and the National Coral Reef Institute, a team from TNC visited the study area March 10th-20th, 2012 to collect ground data to support the mapping effort. Figure 2 shows the position of the 96 GPS-referenced drop-camera videos acquired and associated AGRRA dive sites.

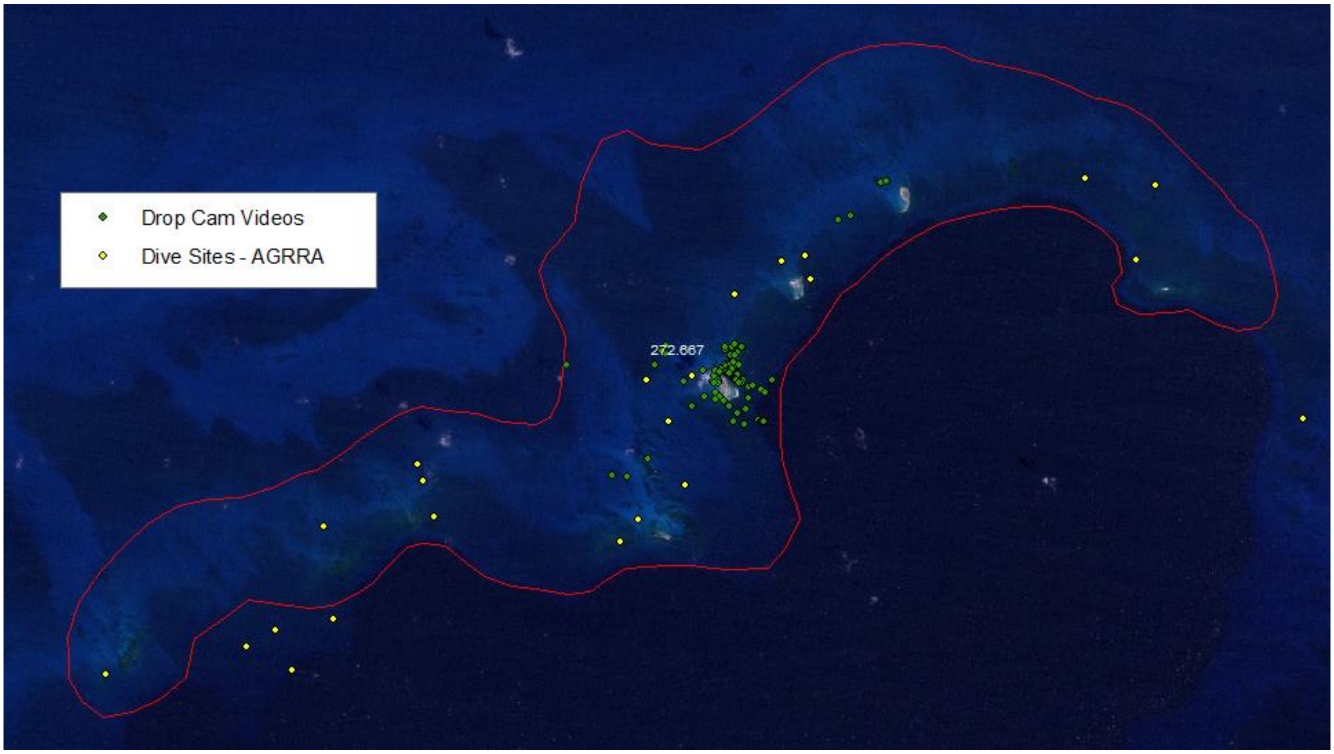


Figure 2 | The field team collected 96 GPS-referenced field points using a dropcam video and 27 km tracks of depth soundings. These video samples were analysed and interpreted, serving as training sites to classify WorldView-2 satellite images that were collected on April 17th, 2014. North is top.

Satellite Imagery Employed in the Study

WorldView-2, launched October 2009 and operated by DigitalGlobe Inc., is the first high-resolution 8-band multispectral commercial satellite. Operating at an altitude of 770 km, WorldView-2 provides 0.48 cm panchromatic resolution and 1.85 meter multispectral resolution. The mosaic used in this study was acquired on April 17th, 2014. The imagery was compromised by high-altitude cloud along the north-eastern limb of the bank but these areas could be mapped through cross-comparison with Landsat imagery and the Google Earth database. For cost savings, the WorldView-2 images used in this study lacked the panchromatic channel and contained only the blue, green, red and infrared spectral bands. The dataset was thus commensurate with WorldView's predecessor, QuickBird. The satellite's blue, green and red bands are useful for benthic habitat mapping and the fourth infrared band was used to identify emergent areas.

Image Preparation

All the images used in the project were radiometrically corrected and then atmospherically corrected to yield units of reflectance at the water surface. These routines were conducted using ENVI software (RSI Inc., v. 4.8). Since ancillary bathymetry data were collected by the field team, it was possible to apply a water column correction to the shallow water areas that were not confounded by excessive sun glint.

Object-based Mapping of Benthic Habitat

An object-oriented approach was adopted for delineating benthic habitat in the WorldView-2 imagery. This approach contrasts the more commonly employed "pixel-based" unsupervised classifiers that have traditionally been used for coral reef mapping. The principal disadvantage of the unsupervised classification approach in a submerged setting, such as Pedro Bank, is that, since light in the visible spectrum is so rapidly attenuated by water, bathymetric variations account for the majority of spectral variation within the remote sensing imagery, rendering the seabed habitat differences challenging to separate.

In contrast to pixel-based classification methods, object-oriented image analysis, the strategy used to produce the maps in this study, segments satellite data into landscape objects that have ecologically-meaningful shapes, and classifies the objects across spatial, spectral, and textural scales. In the context of this study, we employ object-oriented classification to delineate habitat "bodies", interpreted to be distinct patches of uniform benthic habitat. Because of the flexibility afforded by including non-spectral attributes of the imagery (e.g., texture, spatial, and contextual information) into the classification workflow, object-oriented methods have been shown to yield significant accuracy improvements over traditional pixel-based image analysis techniques (Kelly and Tuxen, 2009; Purkis and Klemas, 2011; Purkis et al., 2014a,b).

The software used for mapping in this study, eCognition (v. 8.9, Trimble Inc.), tenders a suite of object-oriented image analysis algorithms having particular utility for creating thematic maps from remote sensing data, including coral reefs.

A total of 96 ground-control points were provided to guide the object-based mapping of benthic habitat. These field observations straddle all of the benthic habitats found atop Pedro Bank.

Statistics pertaining to the spectral and textural properties of the satellite imagery corresponding to the habitat types were extracted at points where the 96 samples provide an unequivocal determination of benthic character. These statistics were used to drive a preliminary segmentation of the imagery into landscape objects using eCognition. Using expert experience, all landscape objects were subsequently assigned to a habitat category on the basis of their spectral and textural signatures. Next, a filter was applied to remove redundant divisions between objects – i.e. those divisions separating two objects of the same habitat category. This step was accomplished within eCognition using the "merge region" algorithm. In this way, the habitat map honours all of the ground-truth data to the extent of the 96 samples available, it is therefore 100% accurate. An alternative strategy would have been to set aside a proportion of the ground-control points for the purpose of conducting an independent accuracy assessment of the habitat map. With so few control points available, though, it was decided that all the survey data should be used to guide the mapping.

An example of the object-based mapping procedure is developed in Figure 3. This method was carried out on each of the available WorldView-2 image scenes. Once classified, the classes were exported into Global Mapper (Blue Marble Geo in., v. 15.1), where the habitat map was subjected to a round of QA/QC and changes manually implemented.

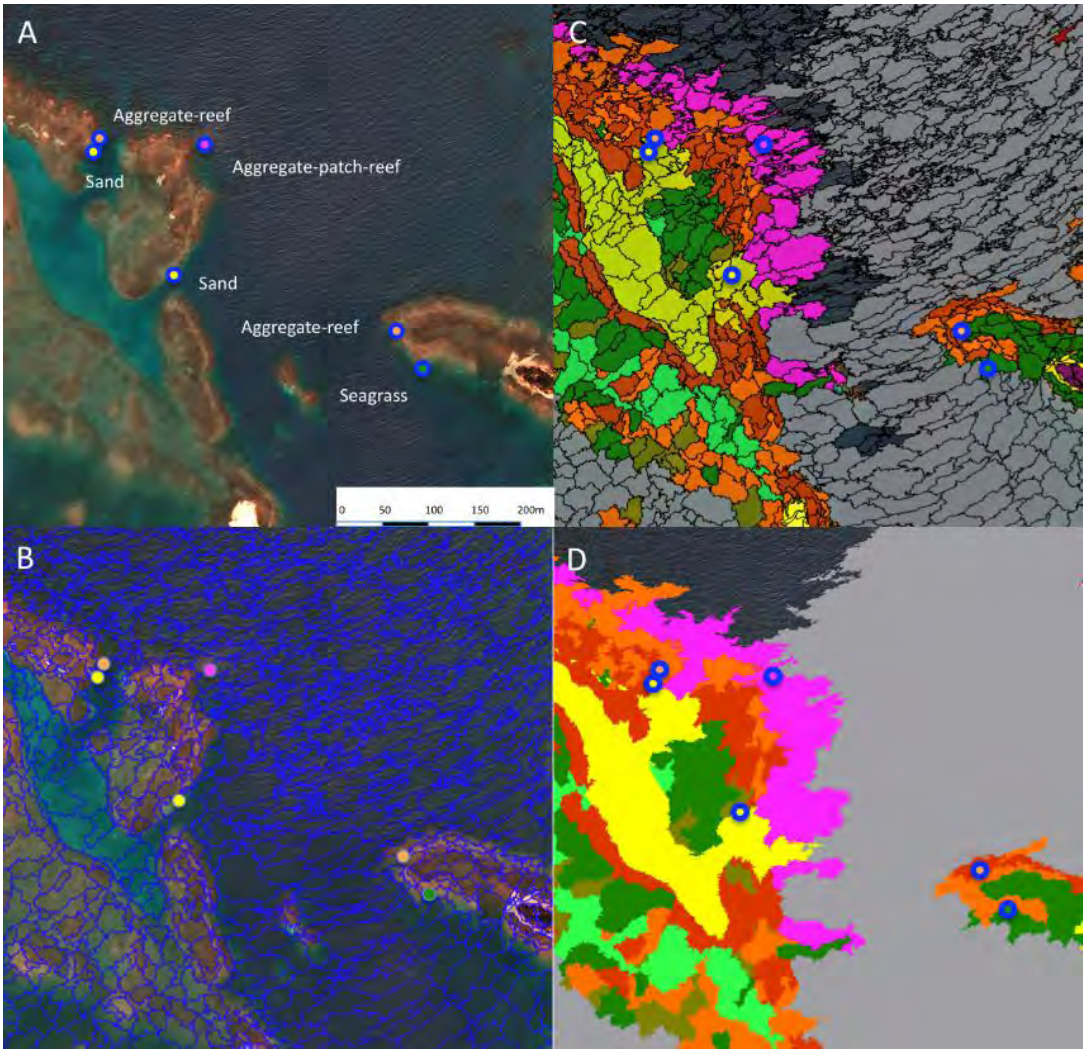


Figure 3 | Workflow for the creation of the habitat map: A) GPS-located seabed samples are assembled within a GIS atop the satellite imagery B) Statistics pertaining to the spectral and textural properties of the WorldView-2 imagery corresponding to the habitat types are extracted at points where the samples provide an unequivocal determination of benthic character, and are used to drive a preliminary segmentation of the imagery into landscape objects using eCognition; C) With reference to the seabed data, all landscape objects are assigned to a habitat category on the basis of their spectral and textural signatures; D) A filter is applied to remove redundant divisions between objects to produce the final habitat map composed of polygons.

Habitat Classification Scheme

Inspection of the 96 drop-camera and WorldView-2 imagery suggested that 14 habitat classes could be used to capture the benthic diversity of the study area. The following section and accompanying figures provides a description of each category and two representative screen-grabs for each, extracted from the drop-camera videos. The ID code for each grab is quoted.

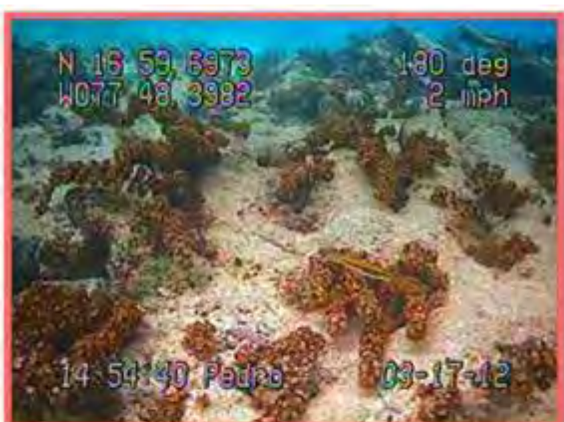
1. Acropora palmata

b17.mpg

c4.mpg

Reef formed by skeletons of *Acropora palmata, millepora,* massive and encrusting coral species. This class is typically found close to exposed reefs and sit above ~5 m water depth.

2. Shallow coral build-up

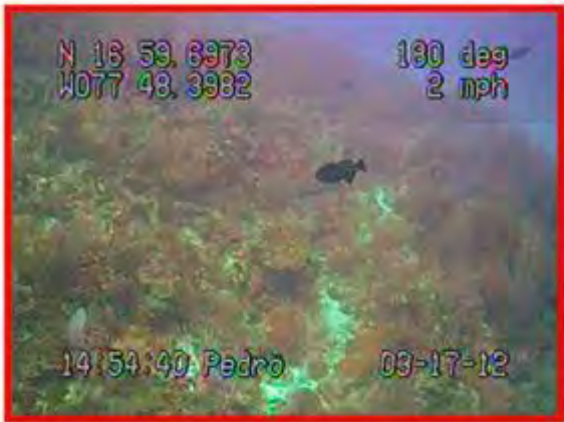


b14.mpg

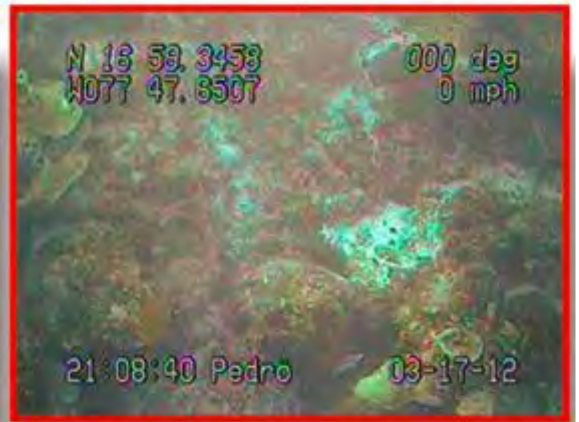
c7.mpg

Areas of coral framework located shallower than ~10 m and in close proximity to exposed reefs. Live coral cover (*Acropora palmata*, *Montastria*, *Agaricia tenifolia*, *Millepora*) is less than 15%. Macroalgae dominates the substrate.

3. Montastrea reef with gorgonians



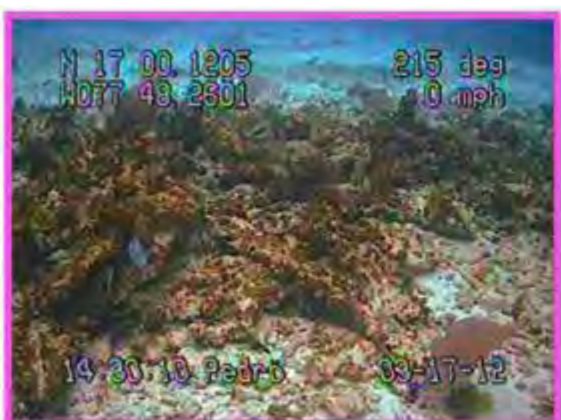
b27.mpg



c11.mpg

Areas of framework formed of coral species such as *Montastria* or *Dendrogyra*. Coral structure may or may not have a living coral veneer. The reef maintains the coral form. Live coral cover is patchy (<15 % overall). Gorgonians dominate the substrate between corals.

4. Sparse patch reef

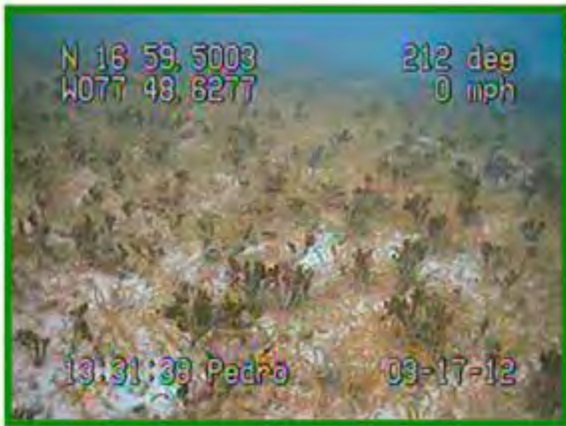


b8.mpg

c2.mpg

Sparse patch reefs found atop the platform. Corals occur as isolated colonies, or meter scale patches of framework. These patches are typically located on topographic highs and are separated by sand or seagrass. The assemblage consists of scleractinians, hydrocorals, gorgonians, and sponges. Patch reefs typically occur in depths shallower than ~10 m, and rise to a depth of ~1 m. Live coral cover is less than 10%.

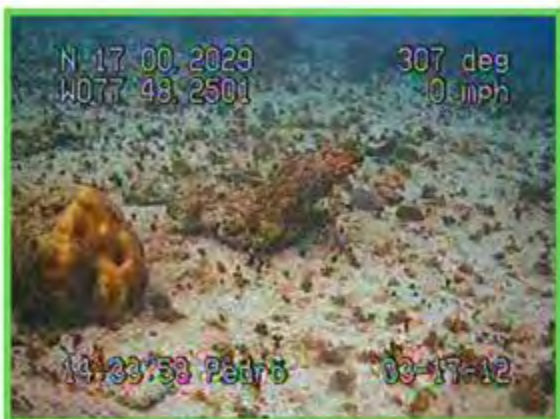
5. Seagrass



e3.mpg

Sand with seagrass/*Halimeda* cover. Community is dominated by *Thallassia testudinum* but other seagrasses (principally *Syrongodium filiforme*) and macroalgae (*Halimeda* sp.) contribute significantly to cover. Moderate – sparse seagrass is typically found atop the platform at depths shallower than ~15 m.

6. Macroalgae on sand

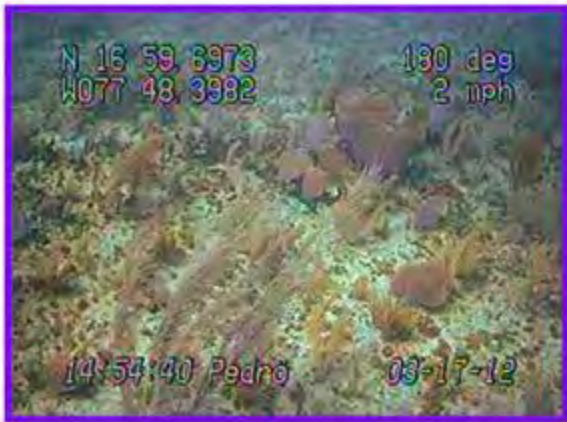


b9.mpg

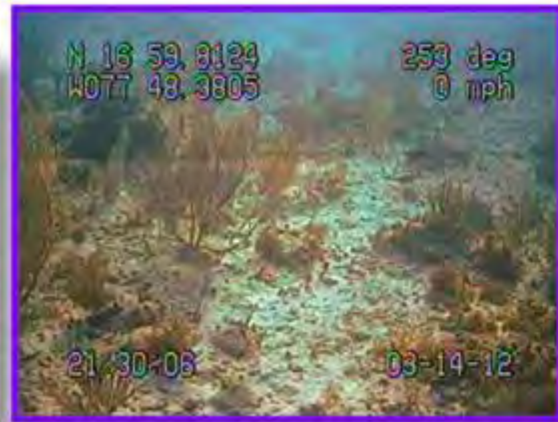
d15.mpg

Unconsolidated sand overlying relict reef and hardground with <5 % seagrass, but relatively high macroalgae cover (>60 %). Typically this class is located leeward of spur and groove reefs in depths greater than 5 m. Macroalgae include calcareous algae such as *Halimeda* as well as fleshy macroalgae such as *Padina*. Cyanobacteria often form dense mats between macroalgal stalks covering underlying substrate.

7. Gorgonian hardground



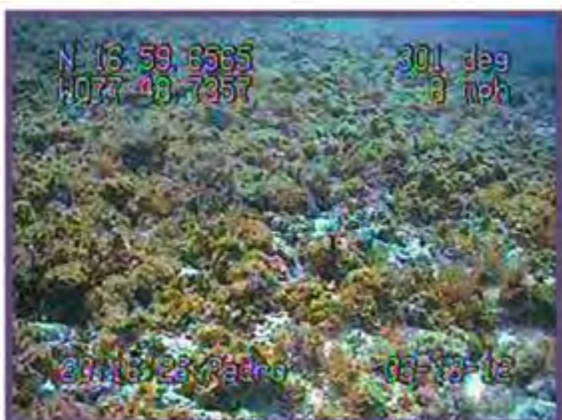
b23.mpg



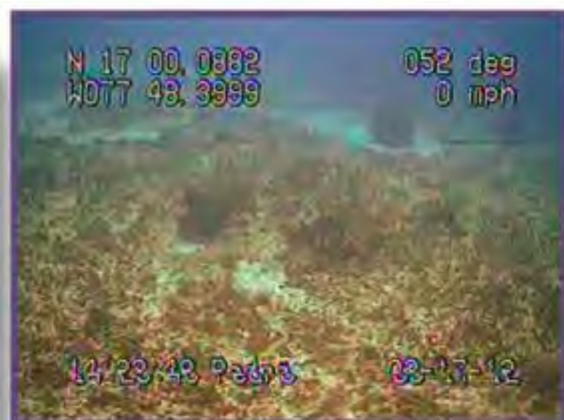
d1.mpg

Abrasion surface with a dominant cover of gorgonians (>60 %). Scleractinian coral cover is typically low (<5 %). Sponges and macroalgae occupy most of the remaining substrate.

8. Macroalgal dominated hardground



Algal-reef-flat.mpg



b5.mpg

Abrasion surface with a dominant cover (>60 %) of macroalgae, principally *sargassum* sp., or turf algae. Scleractinian coral cover is typically low (<5 %). Sponges, gorgonians and macroalgae occupy most of the remaining substrate.

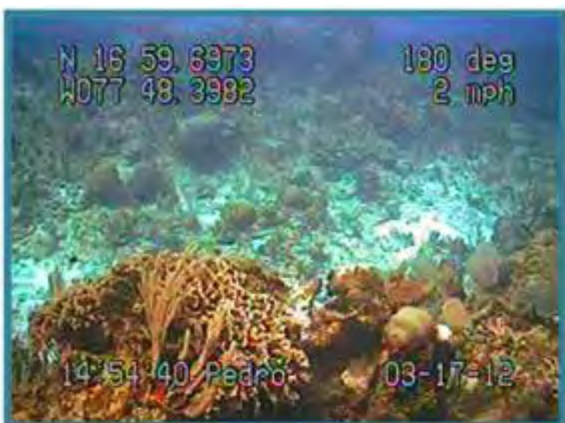
9. Sand and sediment

e1.mpg

d13.mpg

Unconsolidated clean carbonate sediment sheets with little-to-no invertebrate activity and <20% seagrass or macroalgal cover. This class occurs at all depths and in all geomorphological zones. Towards the windward margin of the bank, sediments become more skeletal. Coral clasts and rubble accumulate in proximity to patch reefs.

10. Coral-dominated spur

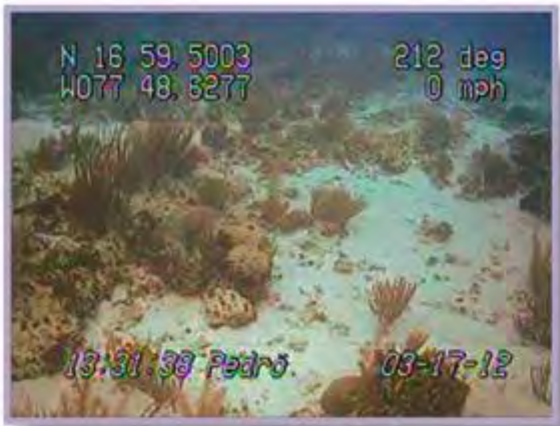


b19.mpg

b25.mpg

This coral assemblage occurs along the windward reef margin and adopts shore-normal striations. Dense interlocking framework of a variety of corals including, but not limited to: *Acropora*, *Montastria, Dendrogyra, Porites and Colpophyllia.* Live coral cover is generally >30 %, with gorgonians dominating substrate between corals. Typically lying at depths <10 m. The spurs sit atop topographic highs, separated by topographic lows with habitat class 'Sand-dominated-grooves'.

11. Sand-dominated groove

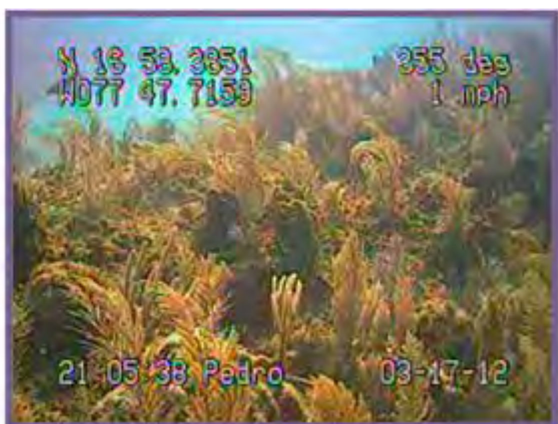


b1.mpg

c8.mpg

Unconsolidated sand sheets veneering hardground abrasion surfaces with bedforms visible in the videos. Sand-dominated-grooves lie parallel to coral-dominated spurs and adopt shore-normal striations. There is little to no seagrass, macroalgal or turf covering the sand.

12. Gorgonian-dominated spur



c10.mpg

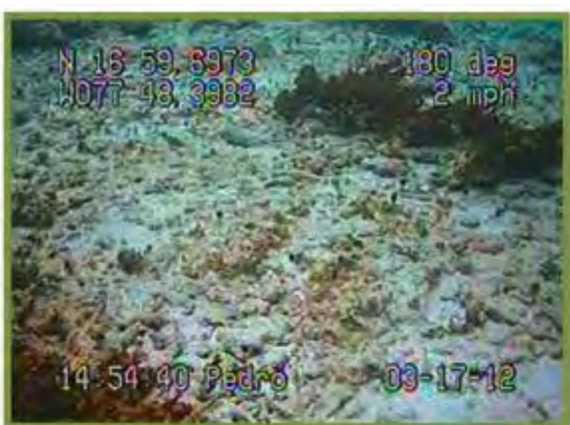
Reef framework on topographic highs host a dominant cover of gorgonians with <30 % live coral colonies. These gorgonian spurs lie windward and at greater depths than the coral-dominated-spurs. These spurs are separated by the class Macroalgal-dominated-grooves.

13. Macroalgal-dominated groove

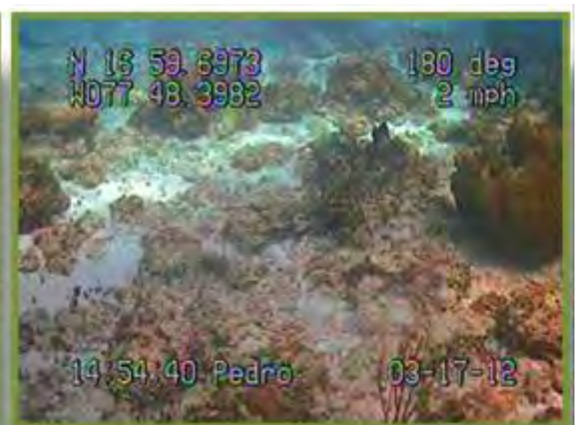
b24.mpg

Macroalgal-dominated grooves lie parallel to Gorgonian-dominated spurs and adopt shore-normal striations. They comprise unconsolidated sediment and coral rubble covered by a veneer of macroalgae (>60 %).

14. Reef Rubble



b15.mpg



b32.mpg

Unconsolidated sand with abundant but patchy coral rubble, often colonized by fleshy macroalgae.

Habitat Map

The benthic habitat map for Pedro Bank is shown in Figure 4. The southerly (windward) margin of the platform can be seen to support the most vigorous coral growth which follows the typical Atlantic pattern of zonation of a *Montastrea* dominated fore-reef which grades platformward into spur-and-groove morphology that in turn transitions into a platform-top dominated by unconsolidated sands and seagrass and macroalgal meadows. The map emphasizes how up to 50% of the Pedro Bank is characterised by Gorgonian hardgrounds (purple) which likely are Pleistocene-aged abrasion surfaces now scoured clean of most topography and sediment. While in times of a more healthy Caribbean coral reef system these hardgrounds might be expected to represent good settlement substrate for corals, they now languish in deep water and are predominantly colonized by gorgonians.

In the submitted GIS, all habitats are structured in a single shape file. Attribute "HABITAT" contains the habitat ID. Also submitted in the GIS bundle, is a shapefile containing the ground-truth stations with an interpretation into the 14-class mapping scheme based on visual inspection of each video. Attribute "Habitat" holds that class ID.

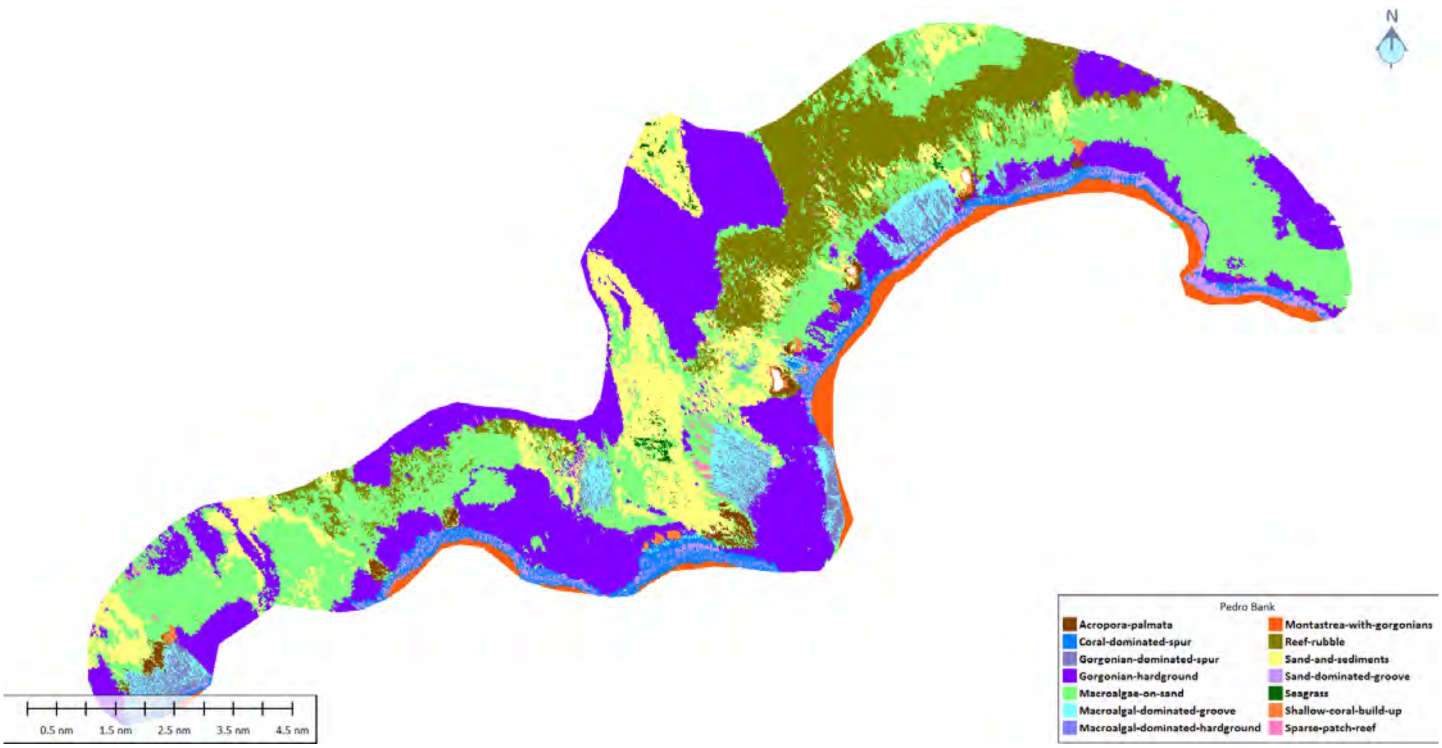


Figure 4 | Benthic habitat map for Pedro Bank.

Spectral Mapping of Bathymetry

Following the ratio-algorithm method of Stumpf et al., (2003), all of the single-beam depth soundings collected in the field were used as training data to tune the algorithm's coefficients and spectral bathymetry was extracted from the WorldView-2 mosaic. A digital elevation model (DEM) was constructed for study area. This DEM captures seabed topography from the low-water mark to 25 m water depth and has a spatial resolution of 2 m × 2 m, that of the WV2 imagery from which it was derived. Vertical resolution of the DEM is approximately 0.01 m.

Units in the DEM are meters with float (16-bit) precision. Values are positive such that “5.55” represents 5.55 m below sea level. Masked areas of the bathy surface are flagged with value = 0. Because of the high water clarity, the spectral derivation appears robust but is confounded in some areas by cloud cover. To yield the most complete bathymetry surface a kriging algorithm was used to fill the holes caused by sun glint, clouds and their shadows. The interpolation only becomes apparent when the surface is stretched to highlight the deeper values, at which point the different texture between the spectrally-extracted and kriged values can be seen.

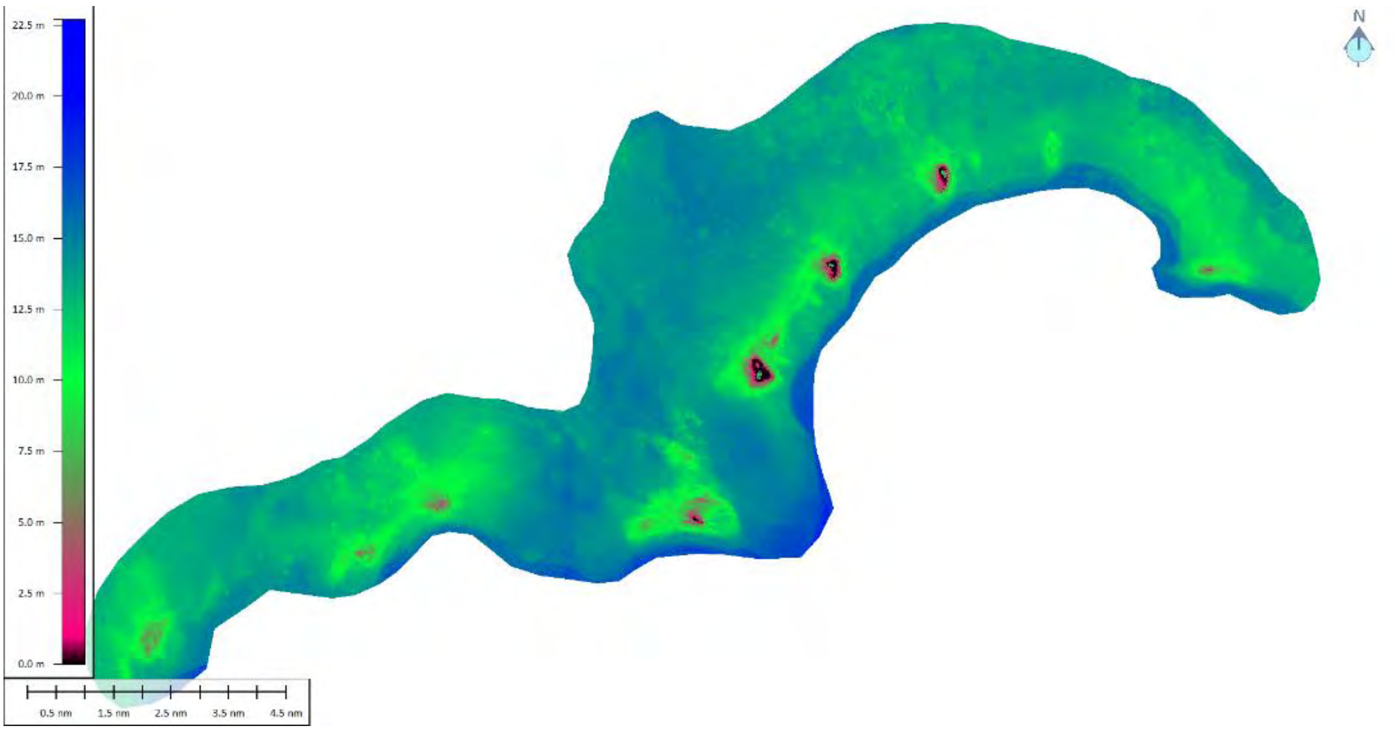


Figure 5| Spectrally-derived digital elevation model for the study area.

References

Kelly M, Tuxen M (2009) Remote sensing support for tidal vegetation research and management. In: Remote sensing and geospatial technologies for coastal ecosystem assessment and management (Ed X. Yang), p. 341-362, Springer Verlag, Berlin.

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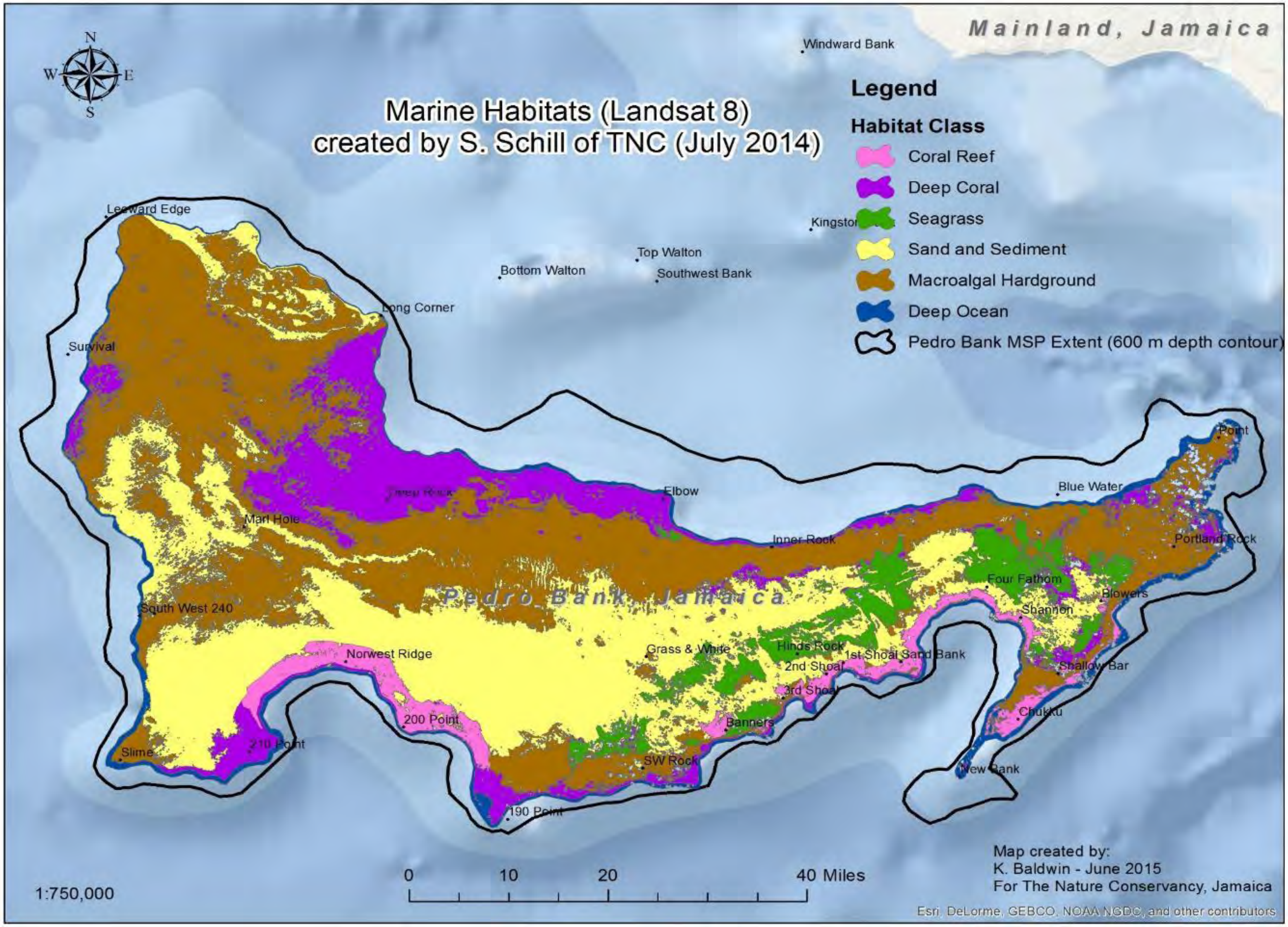
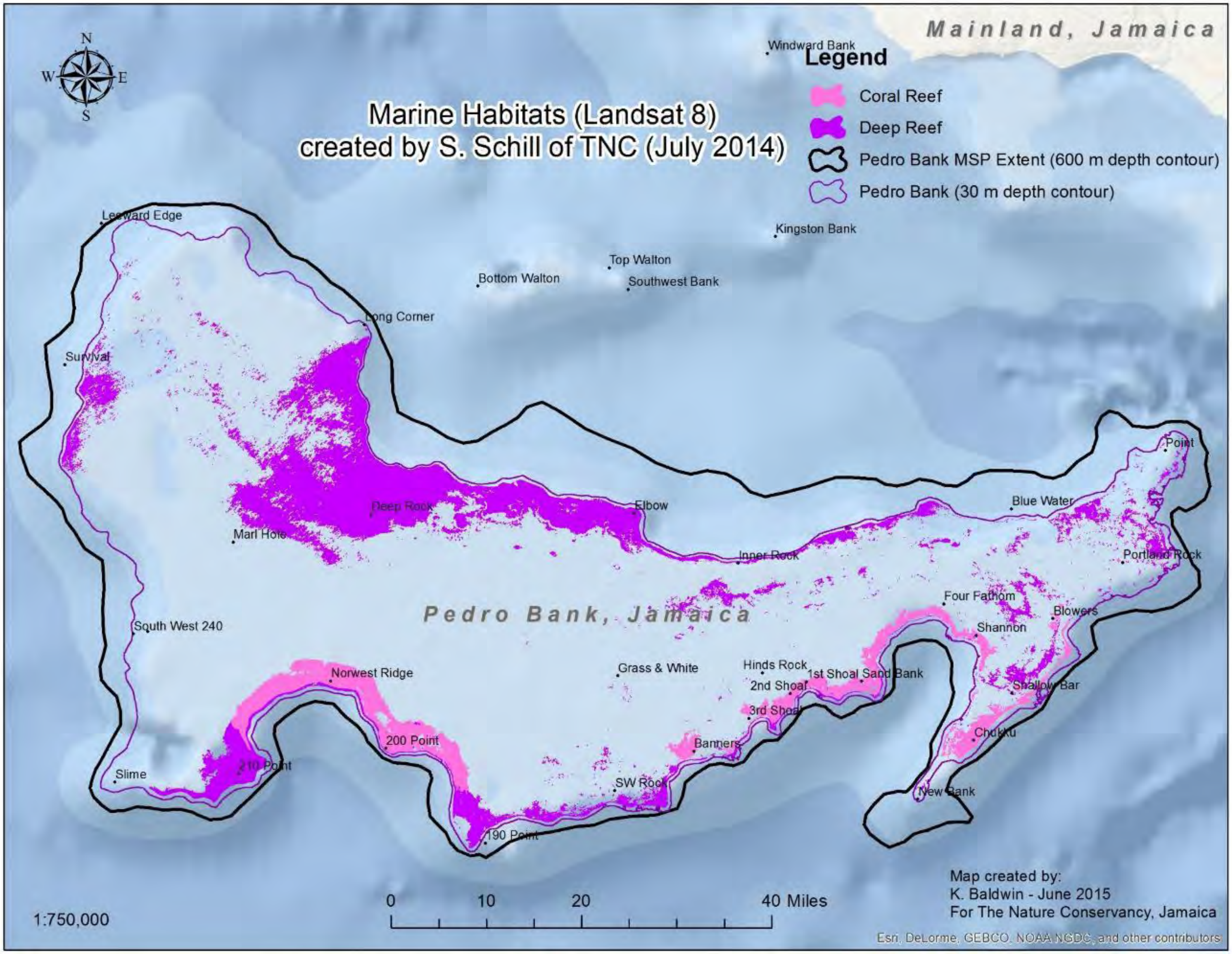
Purkis SJ, Klemas V (2011) Remote Sensing and Global Environmental Change. Wiley-Blackwell, Oxford, 368 pp.

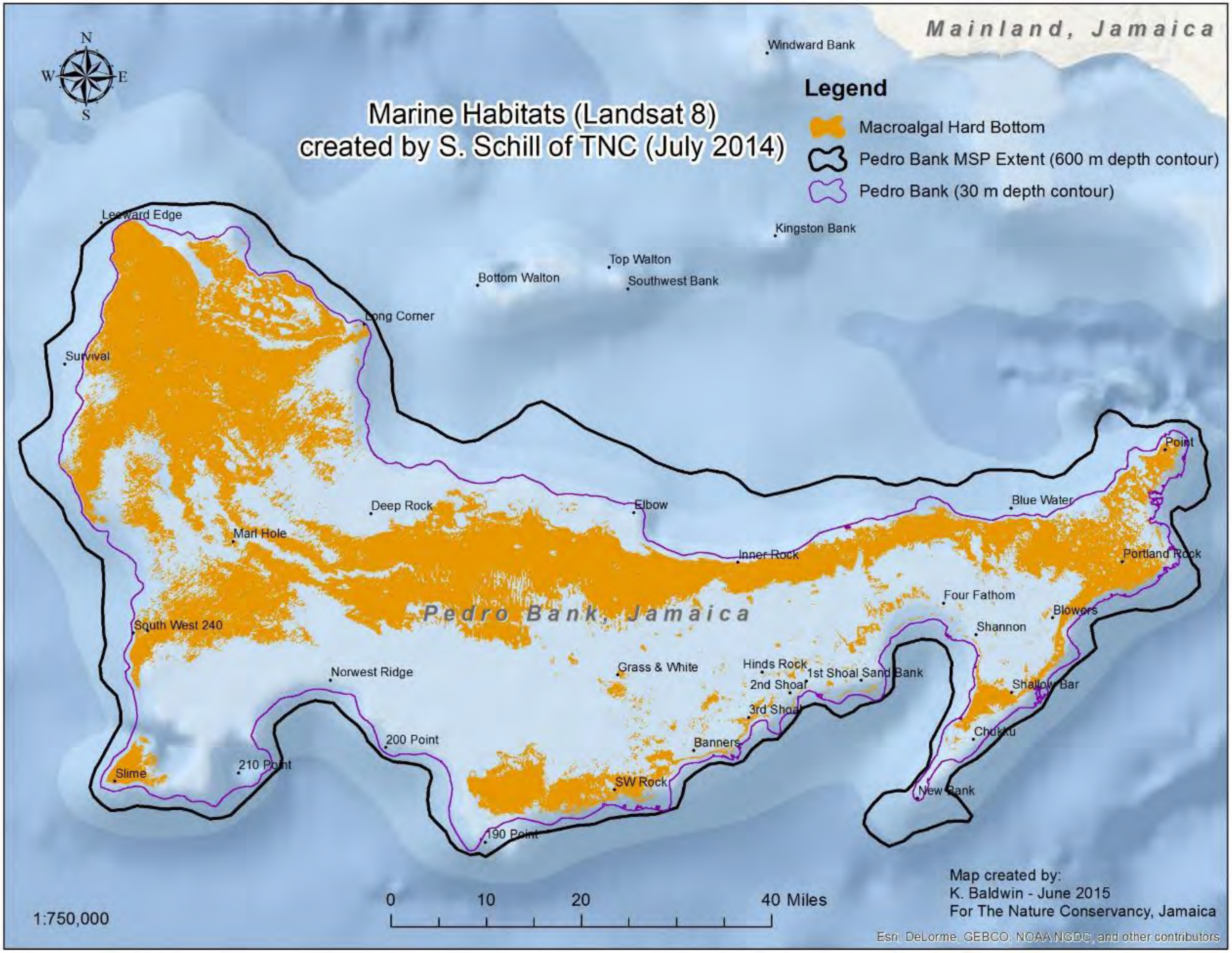
Purkis SJ, Rowlands G, Kerr JM (2014a) Unravelling the influence of water depth and wave energy on the facies diversity of shelf carbonates. Sedimentology, DOI: 10.1111/sed.12110.

Stumpf RP, Holderied K, Sinclair M (2003). Determination of water depth with high-resolution satellite imagery over variable bottom types. Limnology and Oceanography 48:547-55

Appendix III. Maps of conservation features produced for use in the Pedro Bank Marine Spatial Planning project.




Mainland, Jamaica
Windward Bank
Legend
Coral Reef
Deep Reef
Pedro Bank MSP Extent (600 m depth contour)
Pedro Bank (30 m depth contour)
Marine Habitats (Landsat 8)
created by S. Schill of TNC (July 2014)
N
S
E
W
Leeward Edge
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Long Corner
Survival
Point
Blue Water
Deep Rock
Elbow
Marl Hole
Inner Rock
Portland Rock
Four Fathom
Blowers
Pedro Bank, Jamaica
South West 240
Shannon
Grass & White
Hinds Rock
1st Shoal Sand Bank
Norwest Ridge
2nd Shoal
Shallow Bar
3rd Shoal
200 Point
Chukku
Banners
210 Point
Slime
SW Rock
New Bank
190 Point
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
0
10
20
40 Miles
1:750,000
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Mainland, Jamaica
Marine Habitats (Landsat 8)
created by S. Schill of TNC (July 2014)
Legend
Macroalgal Hard Bottom
Pedro Bank MSP Extent (600 m depth contour)
Pedro Bank (30 m depth contour)
Windward Bank
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Leeward Edge
Long Corner
Survival
Deep Rock
Elbow
Marl Hole
Inner Rock
Blue Water
Point
Portland Rock
Four Fathom
Blowers
Shannon
Pedro Bank, Jamaica
South West 240
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal
Sand Bank
2nd Shoal
3rd Shoal
Shallow Bar
Chukku
200 Point
Banners
210 Point
Slime
SW Rock
New Bank
190 Point
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40 Miles
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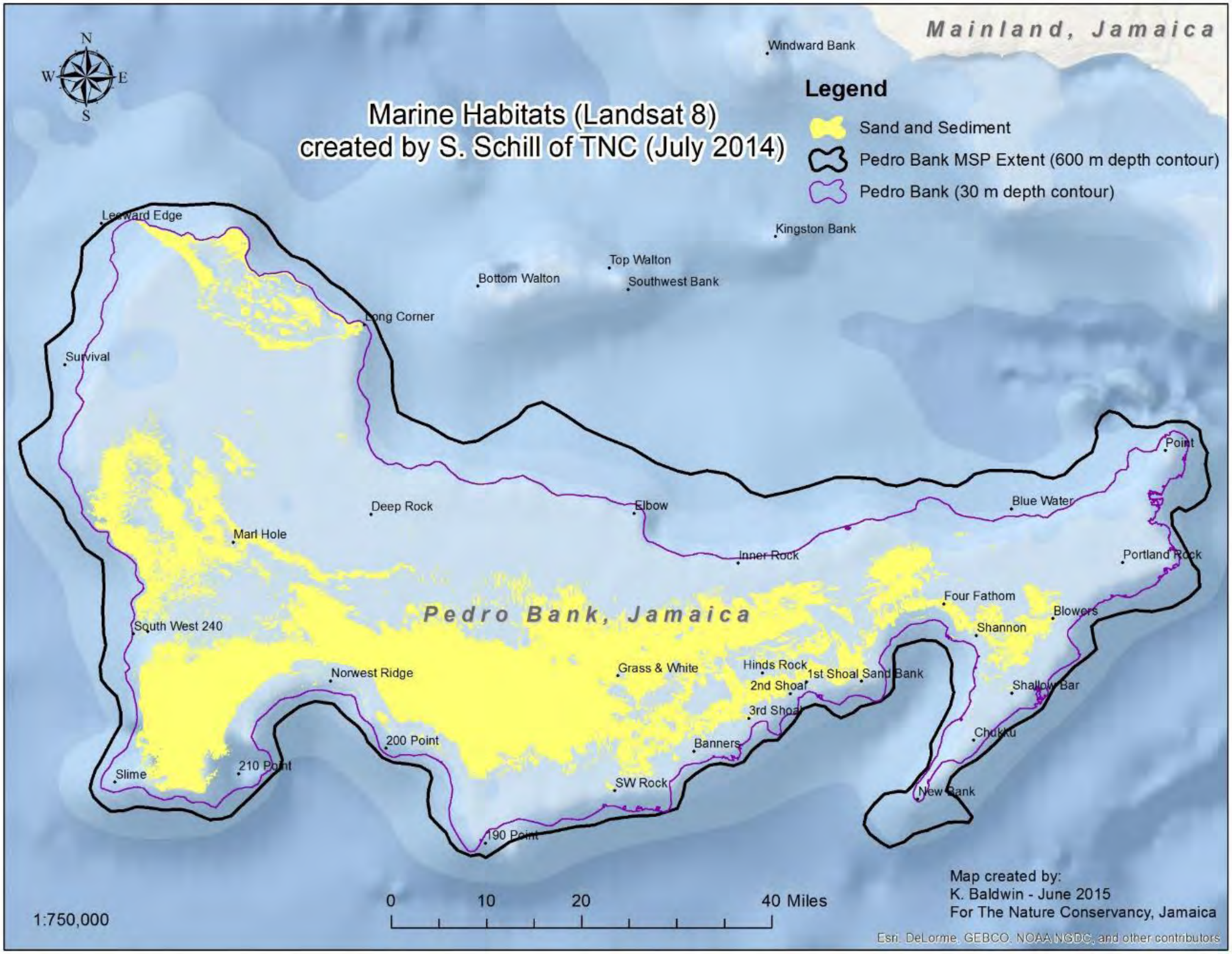
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Mainland, Jamaica
Marine Habitats (Landsat 8)
created by S. Schill of TNC (July 2014)
Legend
Sand and Sediment
Pedro Bank MSP Extent (600 m depth contour)
Pedro Bank (30 m depth contour)
N
S
E
W
Windward Bank
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Leeward Edge
Long Corner
Survival
Deep Rock
Elbow
Marl Hole
Inner Rock
Point
Blue Water
Portland Rock
Four Fathom
Blowers
Shannon
Pedro Bank, Jamaica
South West 240
Norwest Ridge
Grass & White
Hinds Rock
2nd Shoal
1st Shoal
Sand Bank
3rd Shoal
Shallow Bar
Chukku
200 Point
Banners
Slime
210 Point
SW Rock
New Bank
190 Point
0
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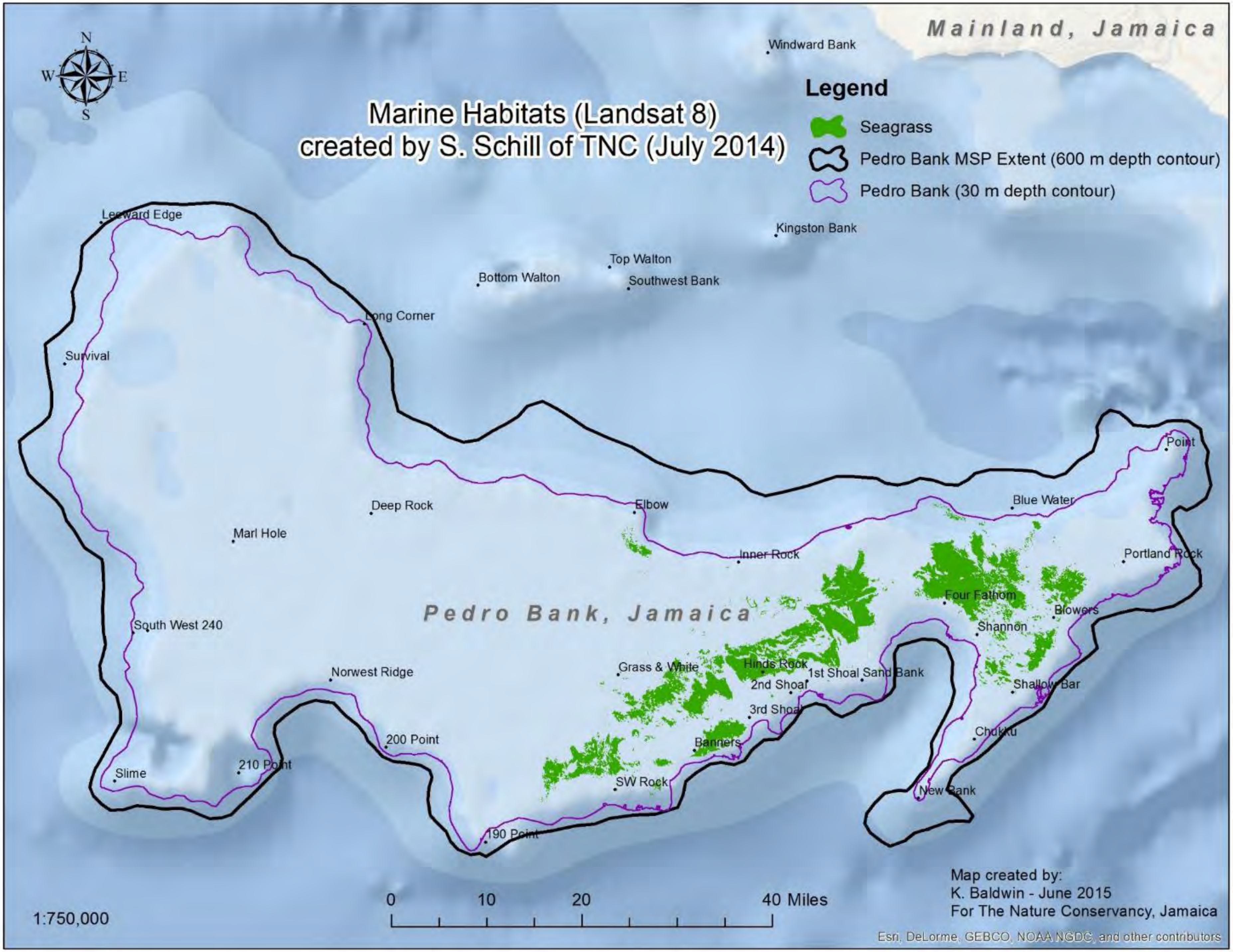
40 Miles
1:750,000
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Marine Habitats (Landsat 8)
created by S. Schill of TNC (July 2014)
Mainland, Jamaica
Legend
Seagrass
Pedro Bank MSP Extent (600 m depth contour)
Pedro Bank (30 m depth contour)
N
S
E
W
Windward Bank
Kingston Bank
Top Walton
Southwest Bank
Bottom Walton
Leeward Edge
Long Corner
Survival
Deep Rock
Marl Hole
Elbow
Blue Water
Point
Inner Rock
Portland Rock
Four Fathom
Blowers
Shannon
Pedro Bank, Jamaica
South West 240
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal
Sand Bank
2nd Shoal
Shallow Bar
3rd Shoal
Chukku
Banners
200 Point
210 Point
Slime
SW Rock
New Bank
190 Point
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40 Miles
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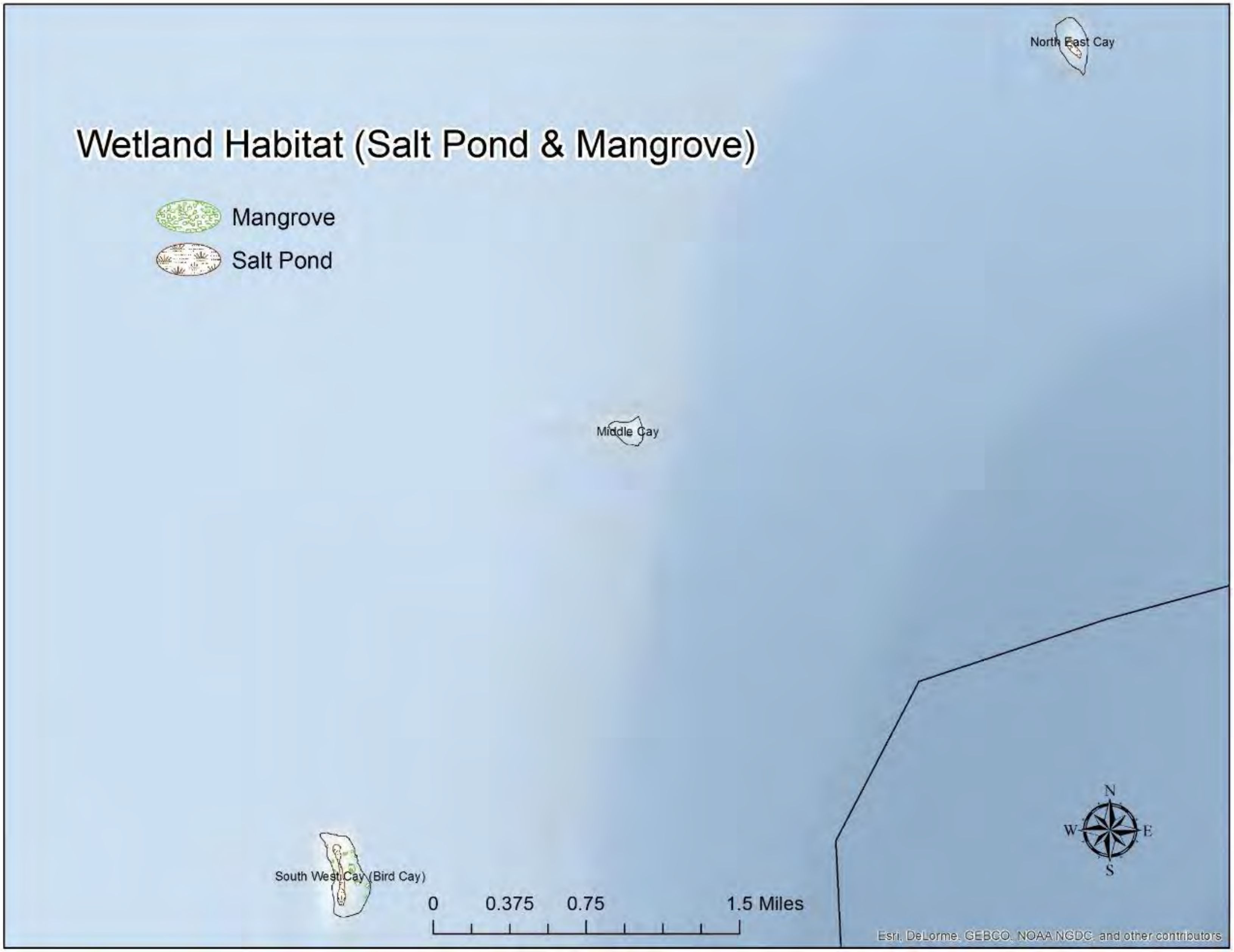
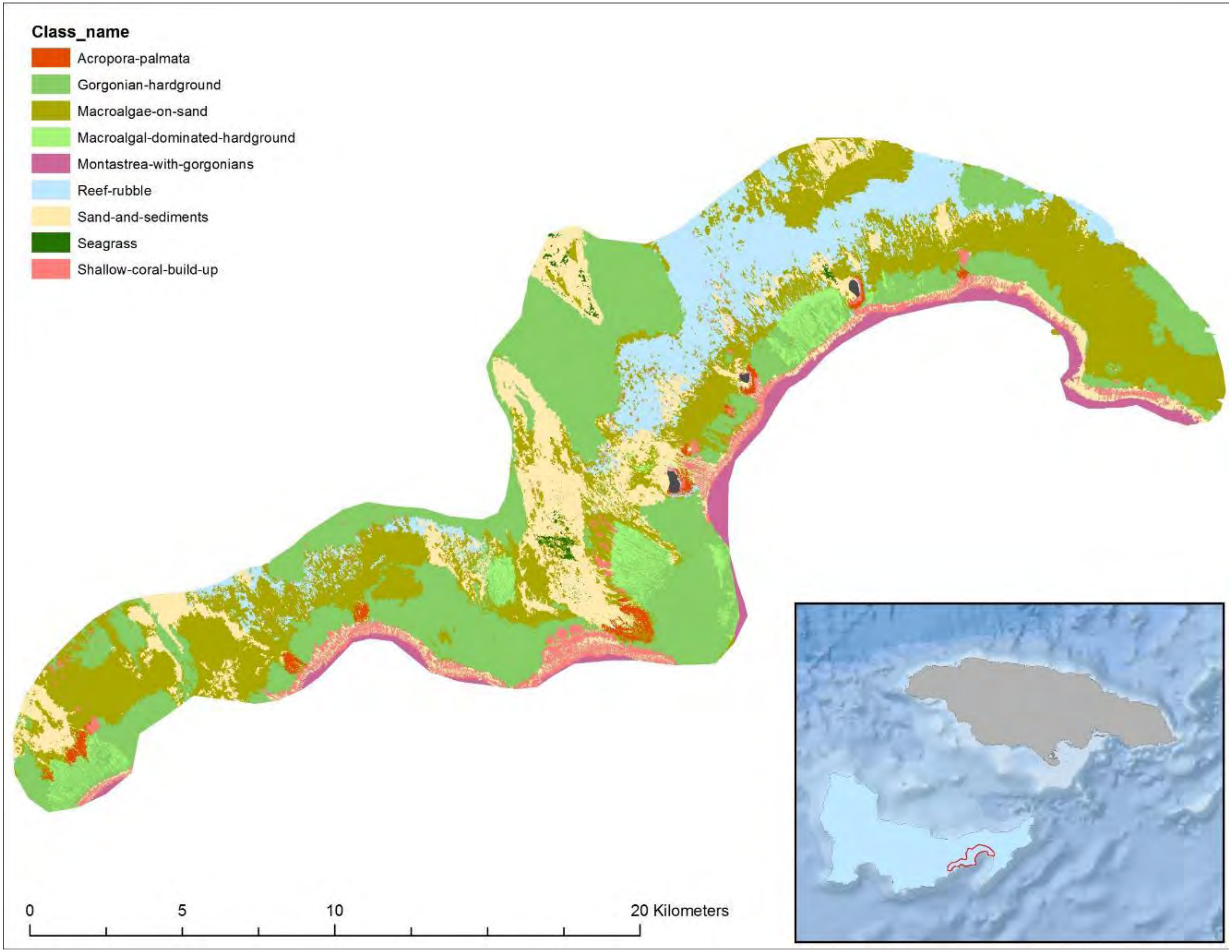
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Wetland Habitat (Salt Pond & Mangrove)
Mangrove
Salt Pond
North East Cay
Middle Cay
South West Cay (Bird Cay)
0 0.375 0.75 1.5 Miles
N
W
E
S
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors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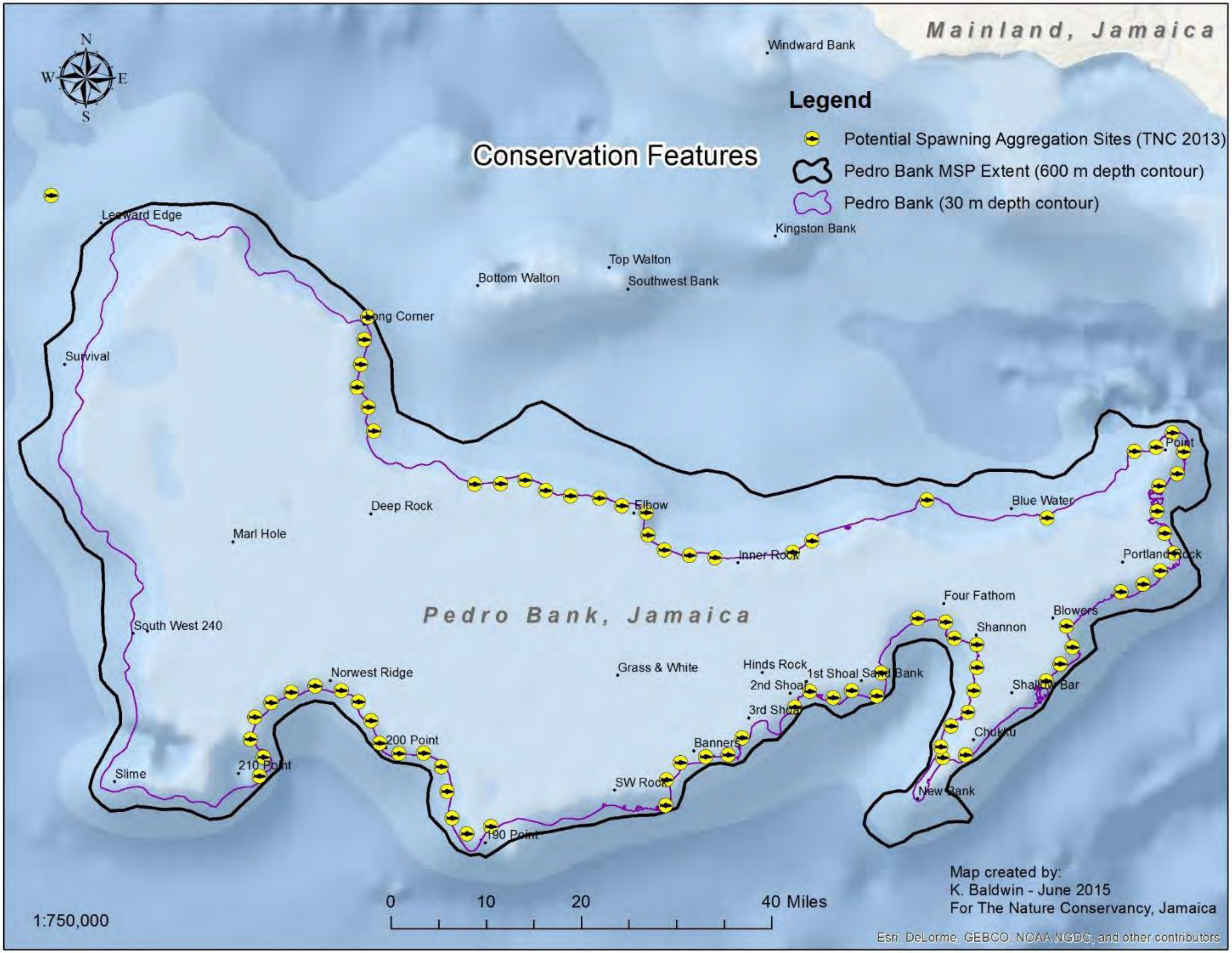
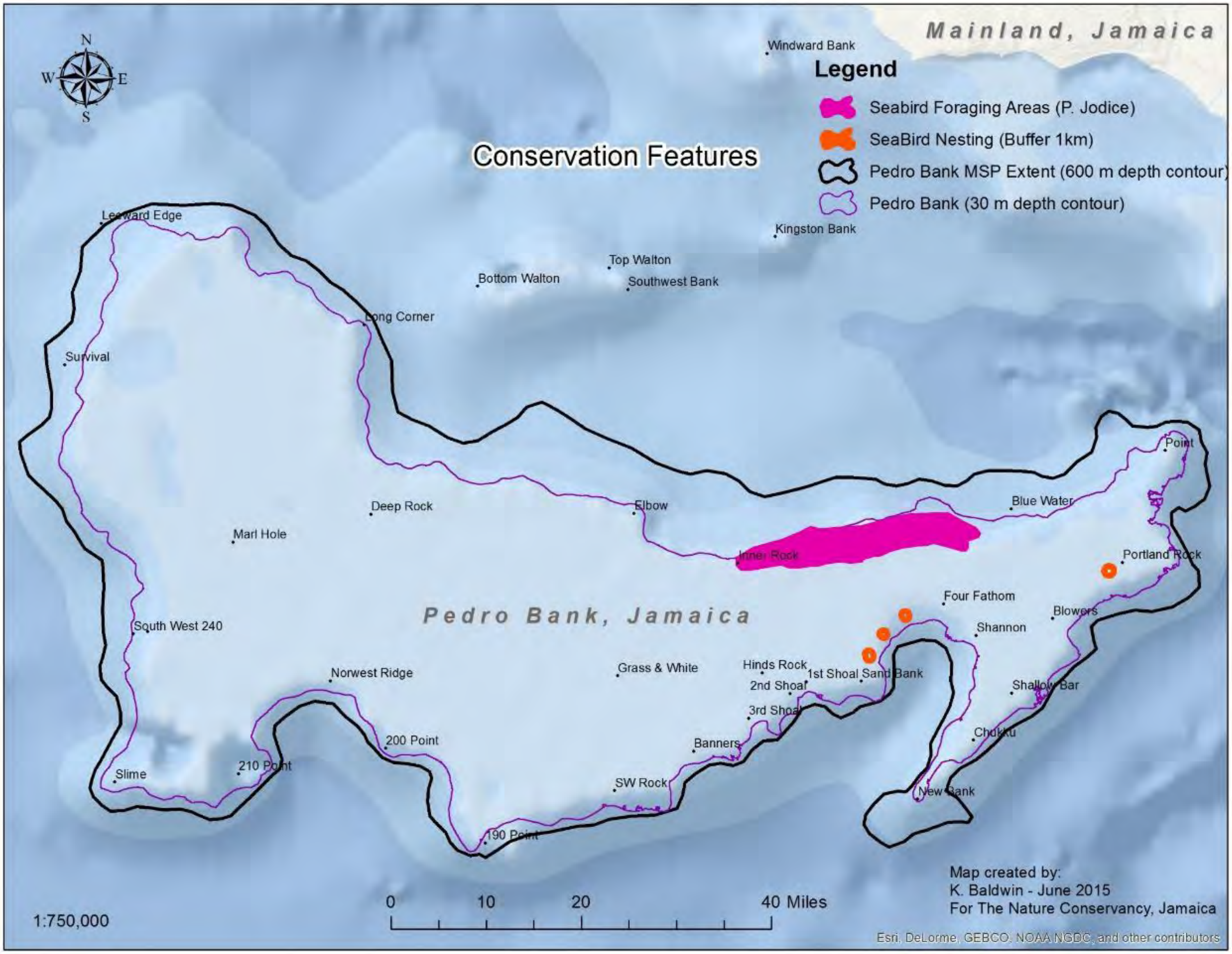
Gorgonian-hardground
Macroalgae-on-sand
Macroalgal-dominated-hardground
Montastrea-with-gorgonians
Reef-rubble
Sand-and-sediments
Seagrass
Shallow-coral-build-up
0
5
10
20 Kilometers


Mainland, Jamaica
Conservation Features
Legend
Potential Spawning Aggregation Sites (TNC 2013)
Pedro Bank MSP Extent (600 m depth contour)
Pedro Bank (30 m depth contour)
N
S
E
W
Windward Bank
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Survival
Deep Rock
Marl Hole
Blue Water
Four Fathom
Shannon
Blowers
Pedro Bank, Jamaica
South West 240
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal
200 Point
Banners
SW Rock
Slime
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
0
10
20
40 Miles
1:750,000
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Mainland, Jamaica
Legend
Conservation Features
Pedro Bank, Jamaica


Conservation Features
Legend
Seabird Foraging Areas (P. Jodice)
SeaBird Nesting (Buffer 1km)
Pedro Bank MSP Extent (600 m depth contour)
Pedro Bank (30 m depth contour)
Mainland, Jamaica
Pedro Bank, Jamaica
N
S
E
W
Windward Bank
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Leeward Edge
Long Corner
Survival
Deep Rock
Marl Hole
Elbow
Inner Rock
Blue Water
Point
Portland Rock
Four Fathom
Blowers
Shannon
South West 240
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal
Sand Bank
2nd Shoal
3rd Shoal
Shallow Bar
Chukku
Banners
200 Point
210 Point
Slime
SW Rock
New Bank
190 Point
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10
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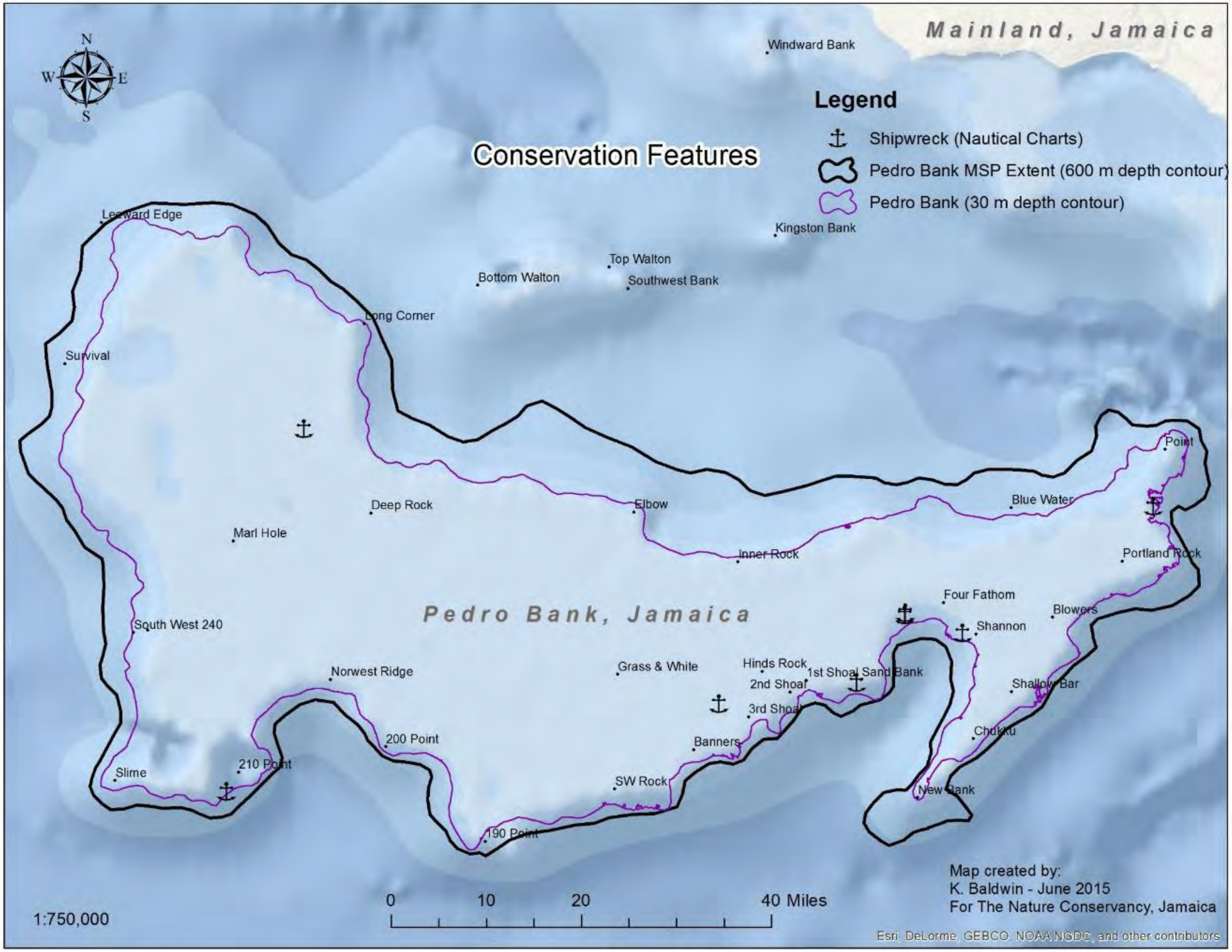
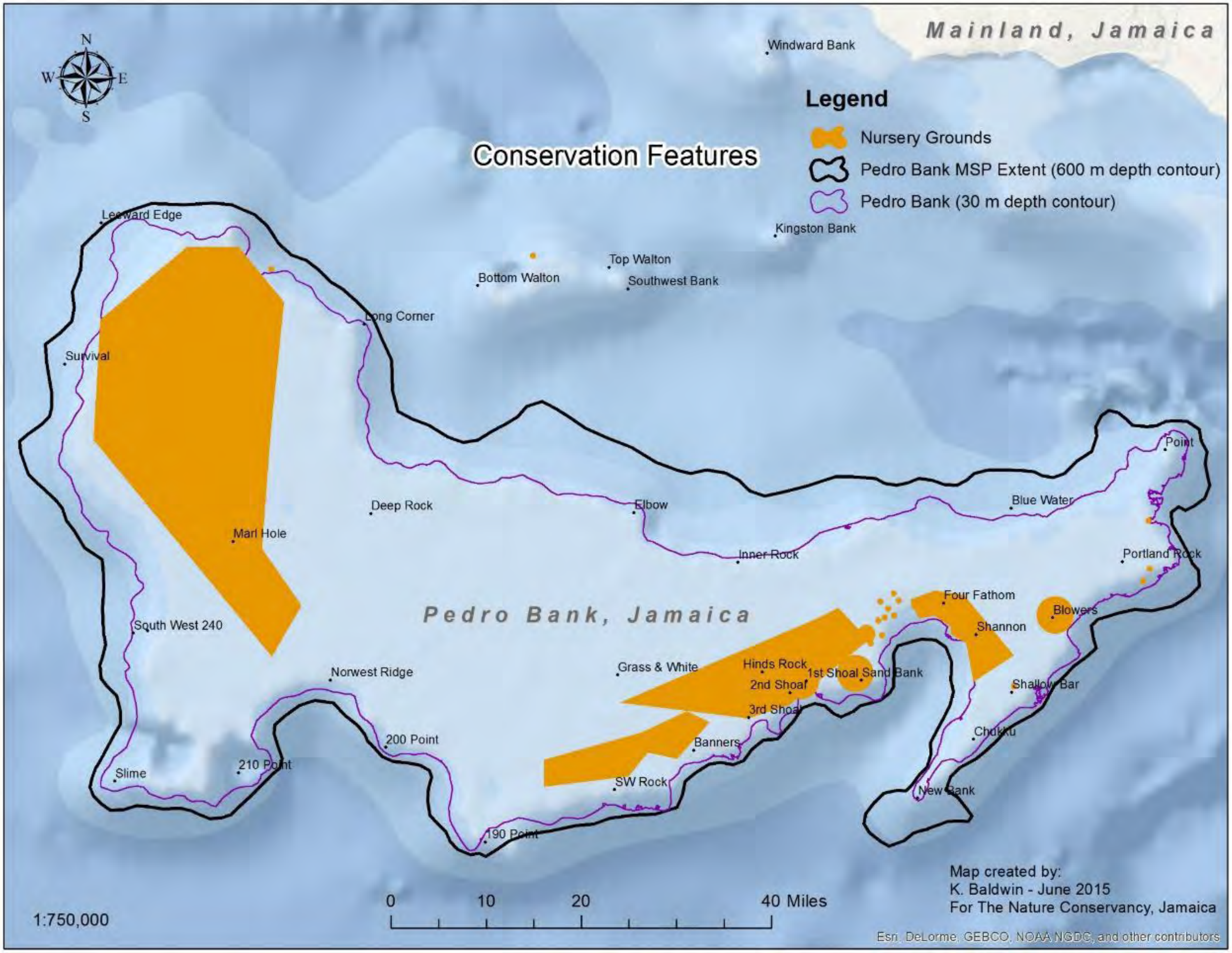
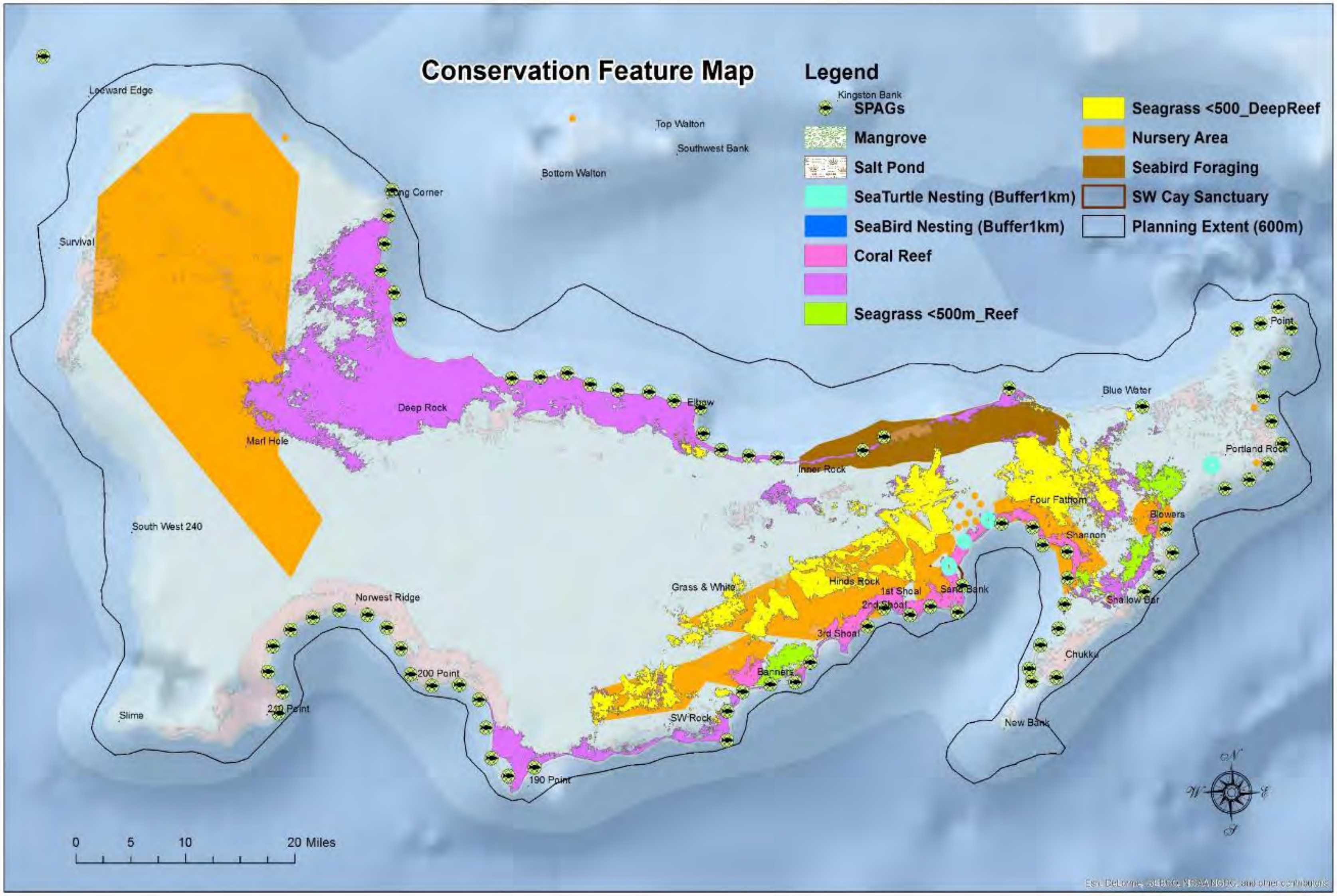
40 Miles
1:750,000
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

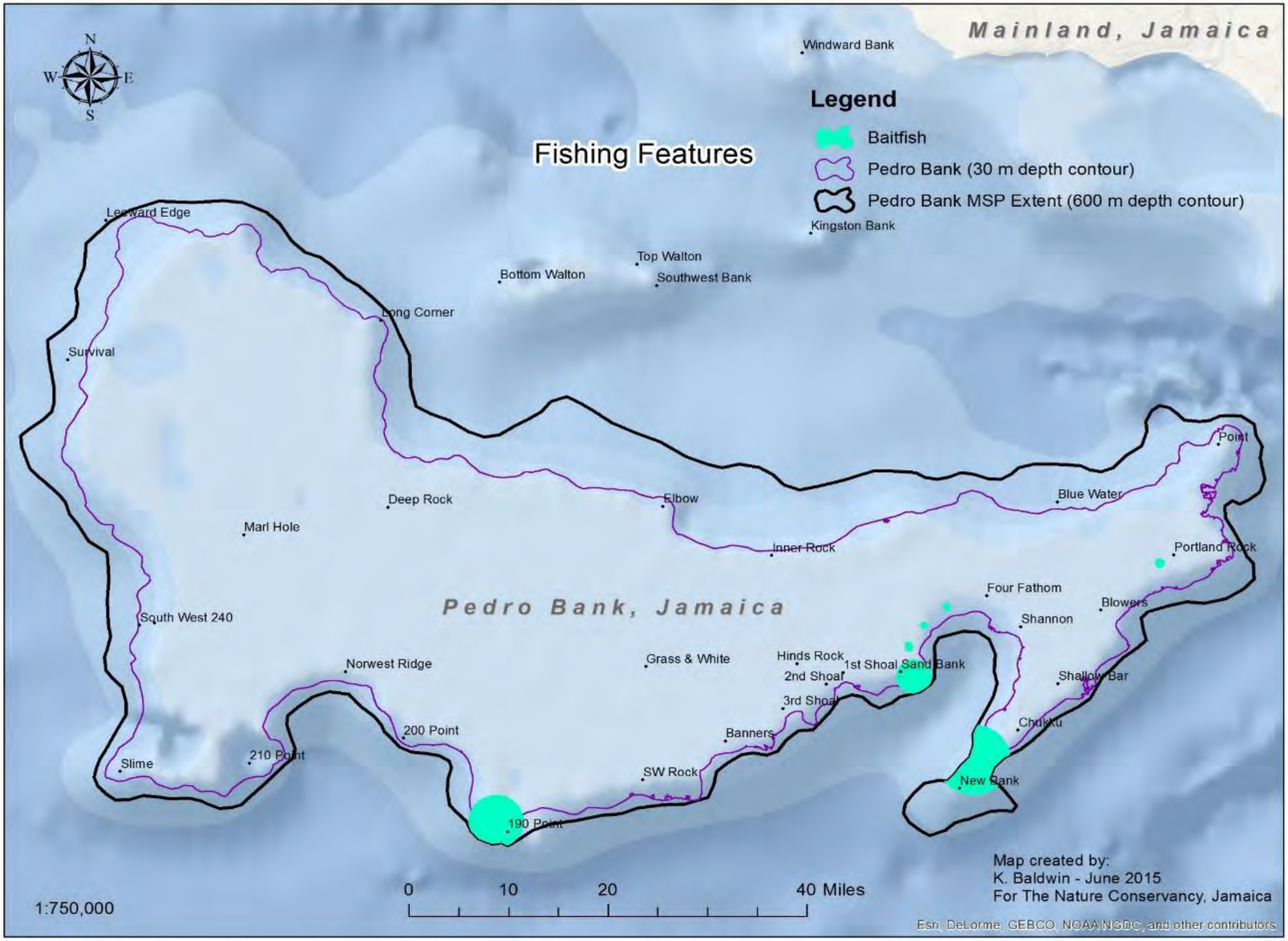

Mainland, Jamaica
N
W
E
S
Windward Bank
Legend
Shipwreck (Nautical Charts)
Pedro Bank MSP Extent (600 m depth contour)
Pedro Bank (30 m depth contour)
Conservation Features
Kingston Bank
Leeward Edge
Top Walton
Bottom Walton
Southwest Bank
Long Corner
Survival
Point
Deep Rock
Elbow
Blue Water
Marl Hole
Inner Rock
Portland Rock
Four Fathom
Pedro Bank, Jamaica
Blowers
South West 240
Shannon
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal
Sand Bank
2nd Shoal
Shallow Bar
3rd Shoal
200 Point
Banners
Chukku
210 Point
Slime
SW Rock
New Bank
190 Point
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
0
10
20
40 Miles
1:750,000
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

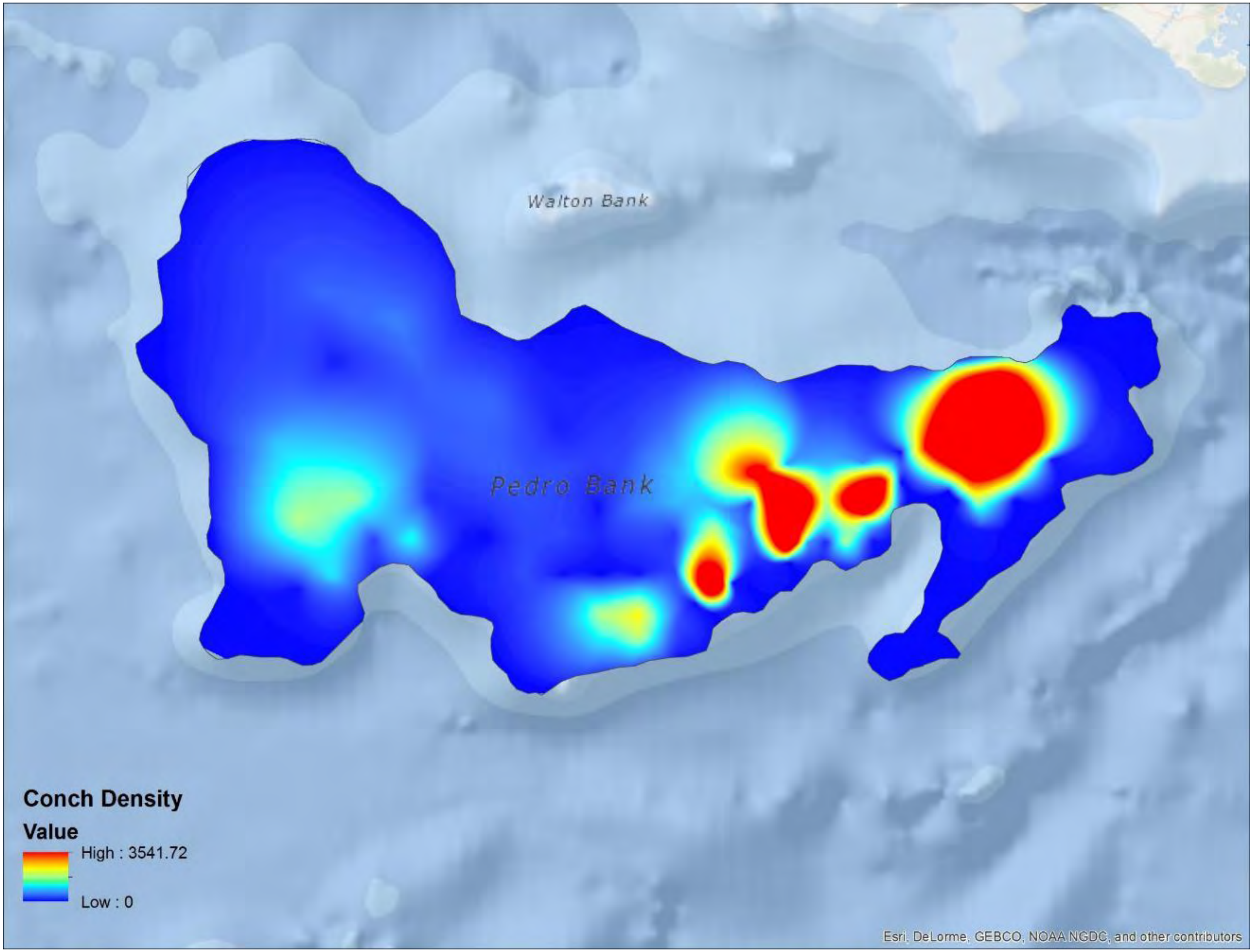

Conservation Features
Mainland, Jamaica
Legend
Nursery Grounds
Pedro Bank MSP Extent (600 m depth contour)
Pedro Bank (30 m depth contour)
Windward Bank
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Leeward Edge
Long Corner
Survival
Deep Rock
Marl Hole
Elbow
Inner Rock
Blue Water
Point
Portland Rock
Pedro Bank, Jamaica
Four Fathom
Blowers
Shannon
South West 240
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal
Sand Bank
2nd Shoal
3rd Shoal
Shallow Bar
Banners
Chukku
200 Point
210 Point
Slime
SW Rock
New Bank
190 Point
0
10
20
40 Miles
1:750,000
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

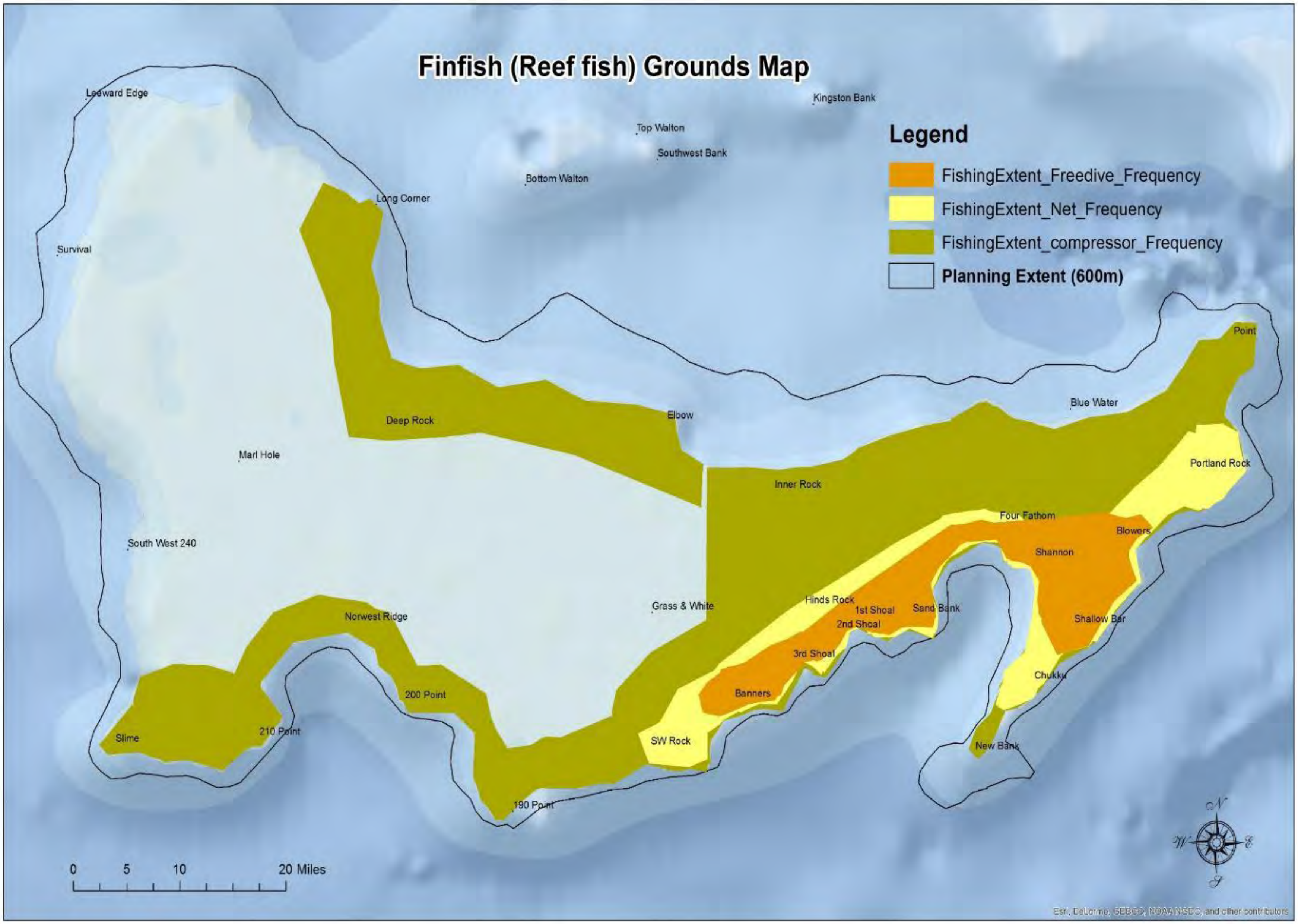


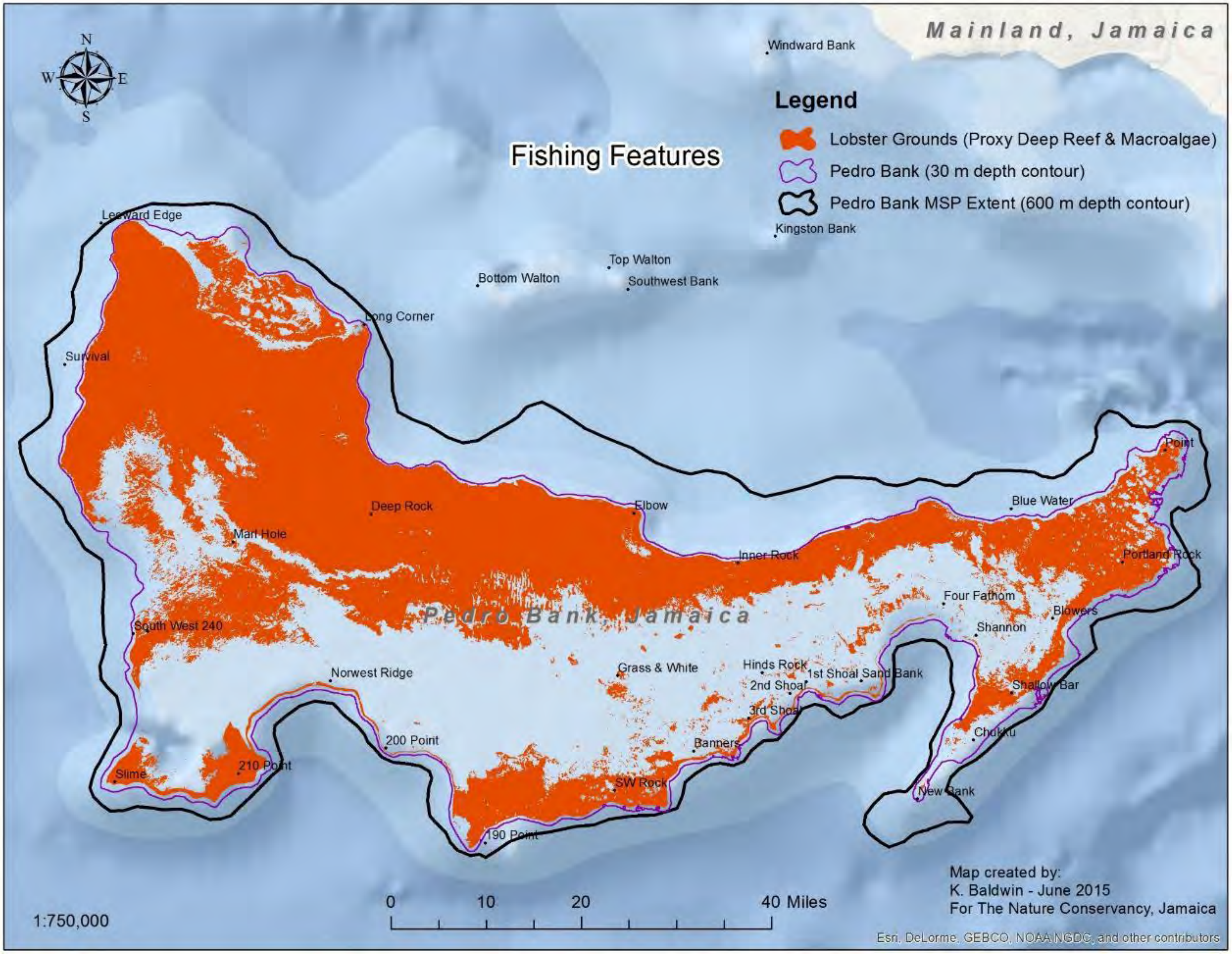
Conservation Feature Map
Legend
Kingston Bank
SPAGs
Mangrove
Salt Pond
SeaTurtle Nesting (Buffer1km)
SeaBird Nesting (Buffer1km)
Coral Reef
Seagrass <500m_Reef
Seagrass <500_DeepReef
Nursery Area
Seabird Foraging
SW Cay Sanctuary
Planning Extent (600m)
Leeward Edge
Top Walton
Southwest Bank
Bottom Walton
Long Corner
Survival
Deep Rock
Marl Hole
Elbow
Inner Rock
Blue Water
Point
Portland Rock
Four Fathom
Blowers
Shannon
South West 240
Grass & White
Hinds Rock
1st Shoal
2nd Shoal
Sand Bank
3rd Shoal
Shallow Bar
Norwest Ridge
Banners
Chukka
200 Point
SW Rock
New Bank
240 Point
Slime
190 Point
0 5 10 20 Miles

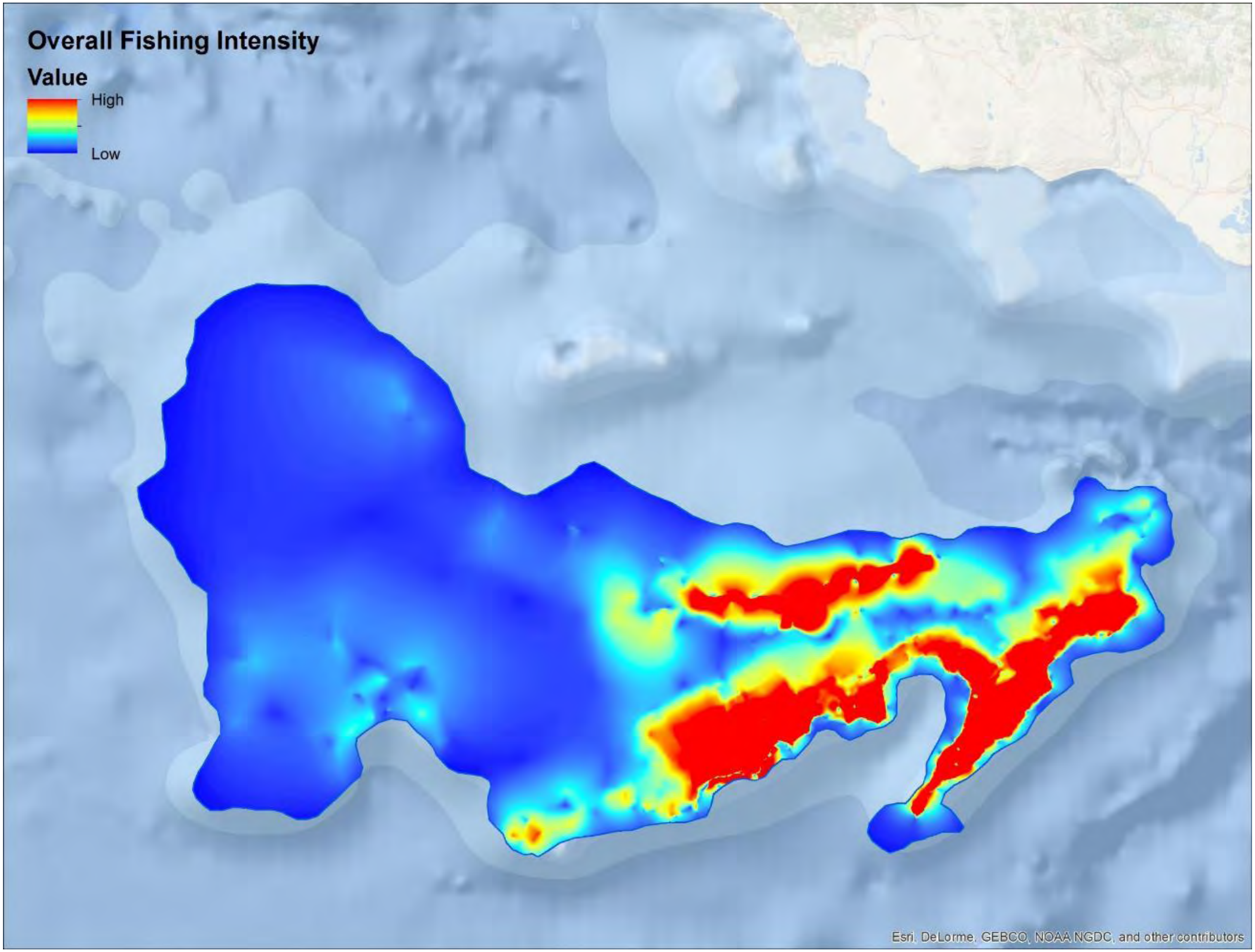
Maps of fishing features produced for use in the Pedro Bank Marine Spatial Planning project.

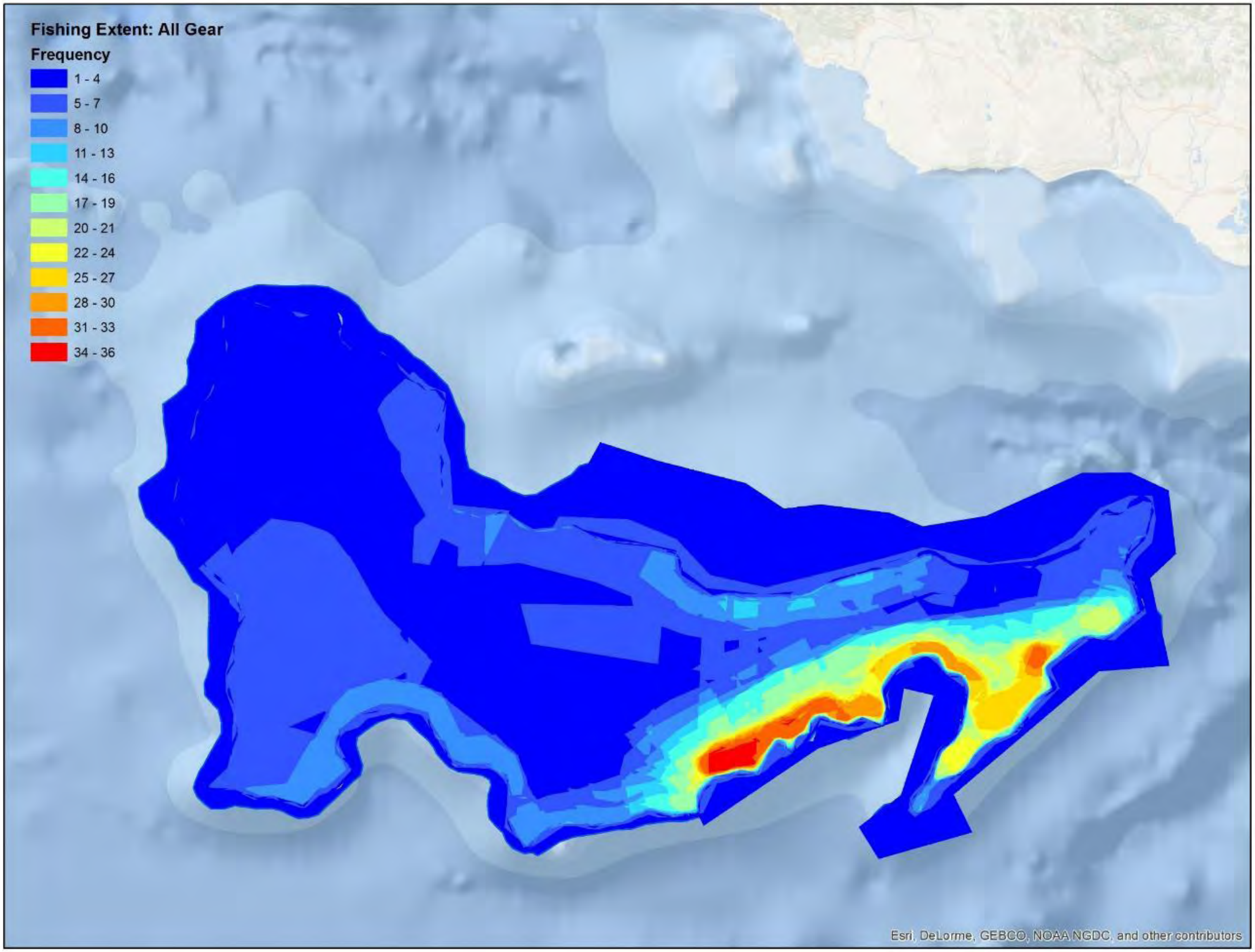


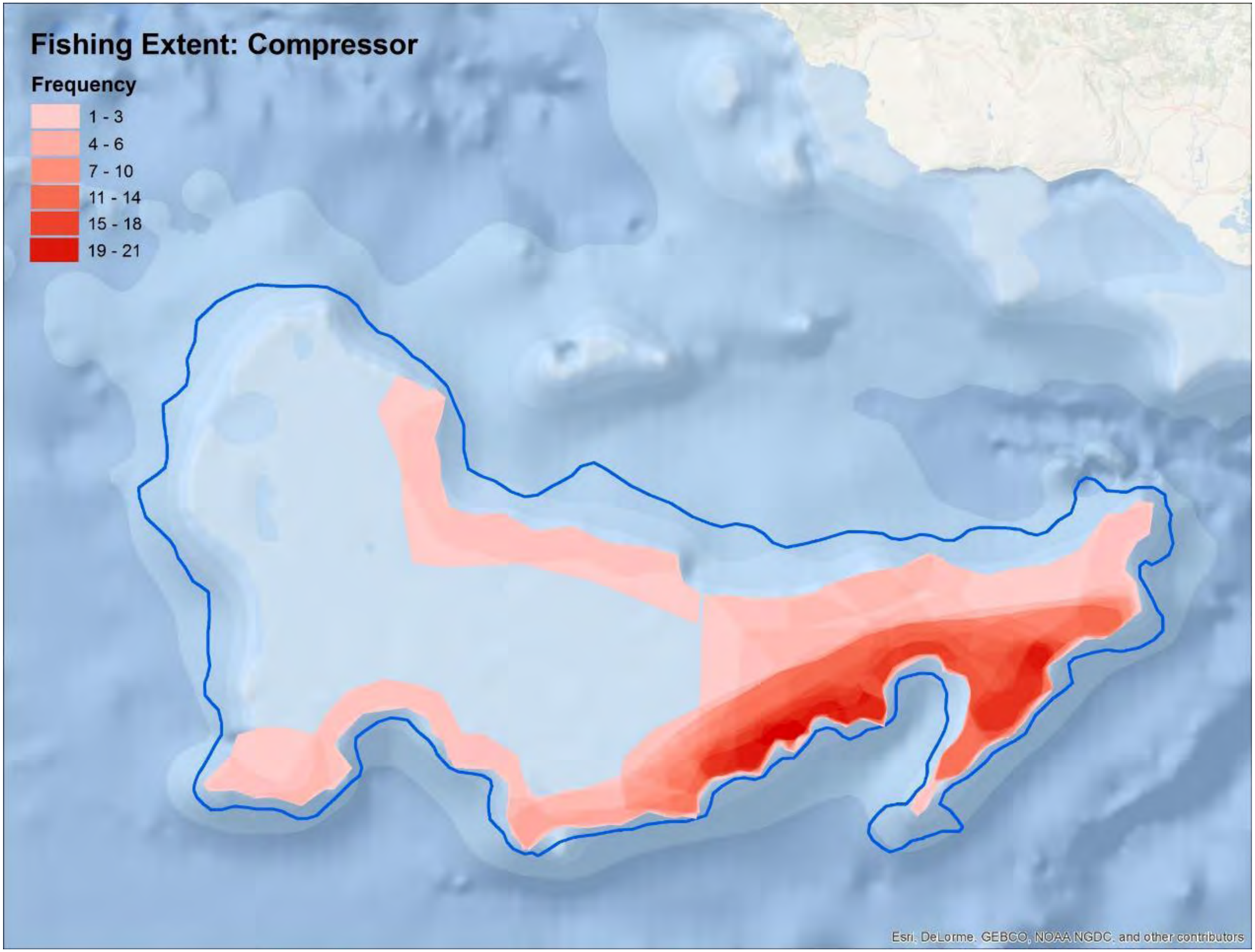

Walton Bank
Pedro Bank
Conch Density
Value
High : 3541.72
Low : 0
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

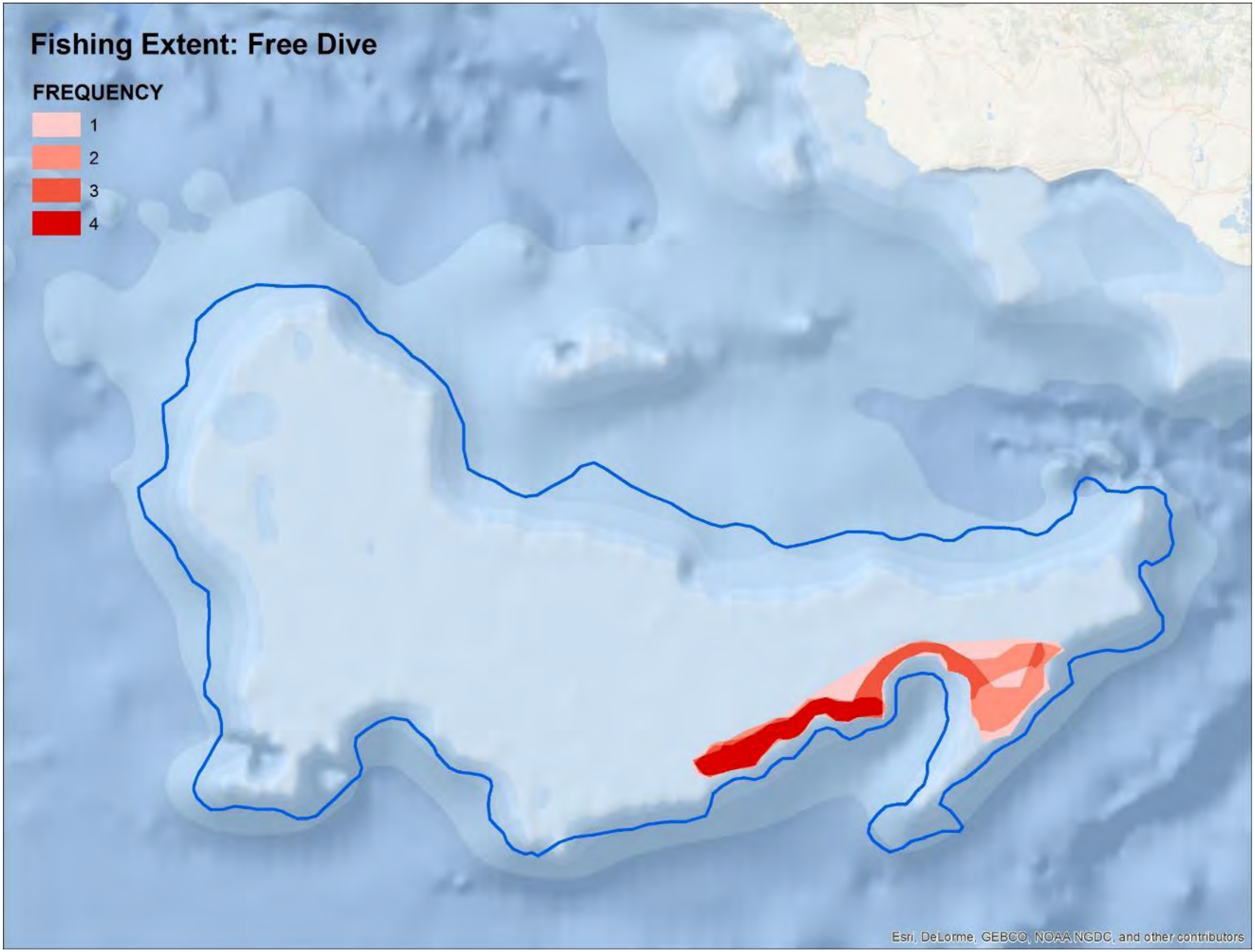

Finfish (Reef fish) Grounds Map
Legend
FishingExtent_Freedive_Frequency
FishingExtent_Net_Frequency
FishingExtent_compressor_Frequency
Planning Extent (600m)
Leeward Edge
Survival
Long Corner
Bottom Walton
Top Walton
Southwest Bank
Kingston Bank
Deep Rock
Elbow
Marl Hole
Inner Rock
Blue Water
Point
Portland Rock
Four Fathom
Blowers
Shannon
South West 240
Grass & White
Hinds Rock
1st Shoal
2nd Shoal
Sand Bank
Shallow Bar
3rd Shoal
Norwest Ridge
200 Point
Banners
Chukka
SW Rock
New Bank
Slime
210 Point
190 Point
0 5 10 20 Miles

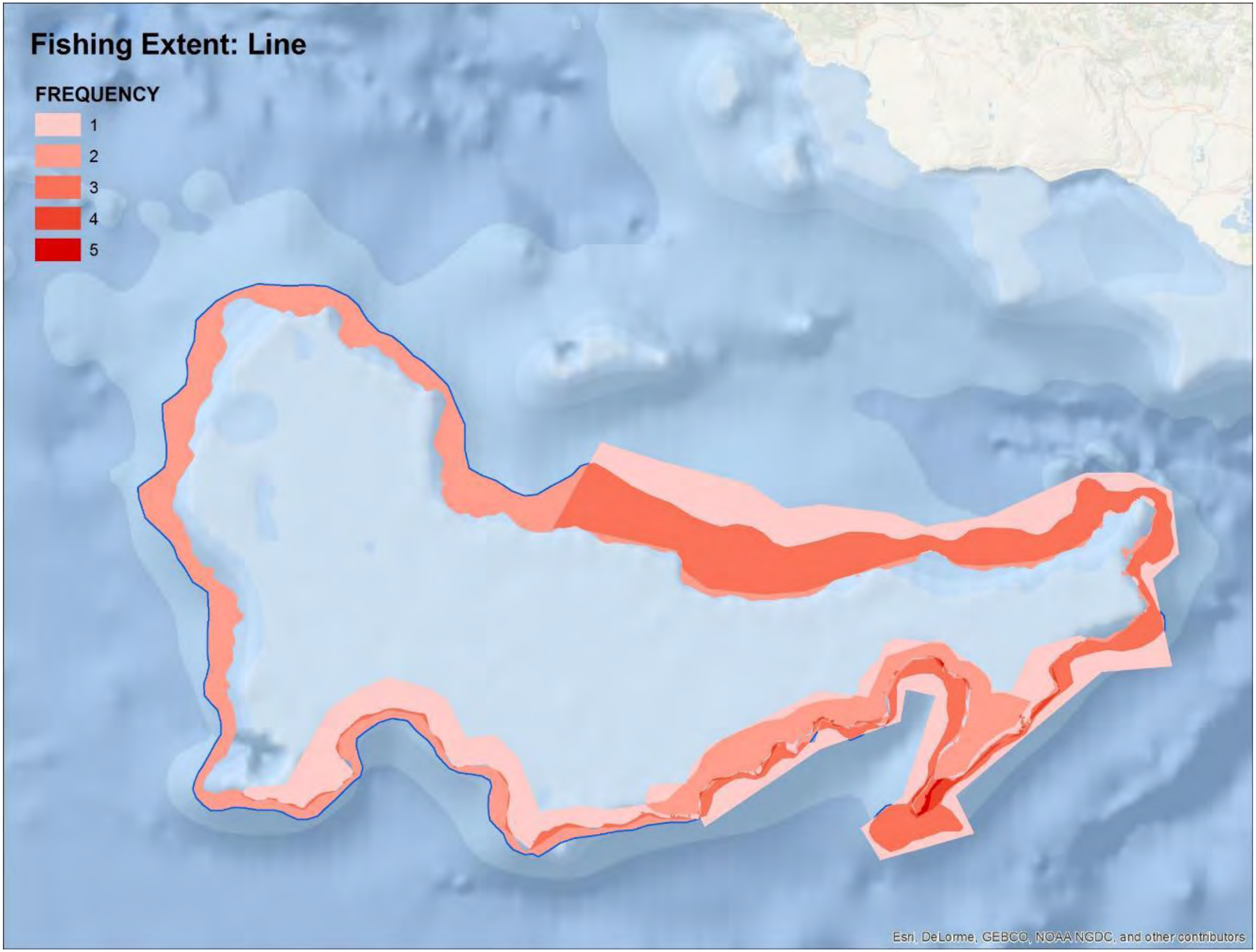

Mainland, Jamaica
Windward Bank
Legend
Lobster Grounds (Proxy Deep Reef & Macroalgae)
Pedro Bank (30 m depth contour)
Pedro Bank MSP Extent (600 m depth contour)
Fishing Features
Kingston Bank
Leeward Edge
Top Walton
Bottom Walton
Southwest Bank
Long Corner
Survival
Point
Deep Rock
Elbow
Blue Water
Marl Hole
Inner Rock
Portland Rock
Four Fathom
Pedro Bank, Jamaica
Blowers
South West 240
Shannon
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal Sand Bank
2nd Shoal
Shallow Bar
3rd Shoal
Chukku
200 Point
Banners
Slime
210 Point
SW Rock
New Bank
190 Point
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
0
10
20
40 Miles
1:750,000
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

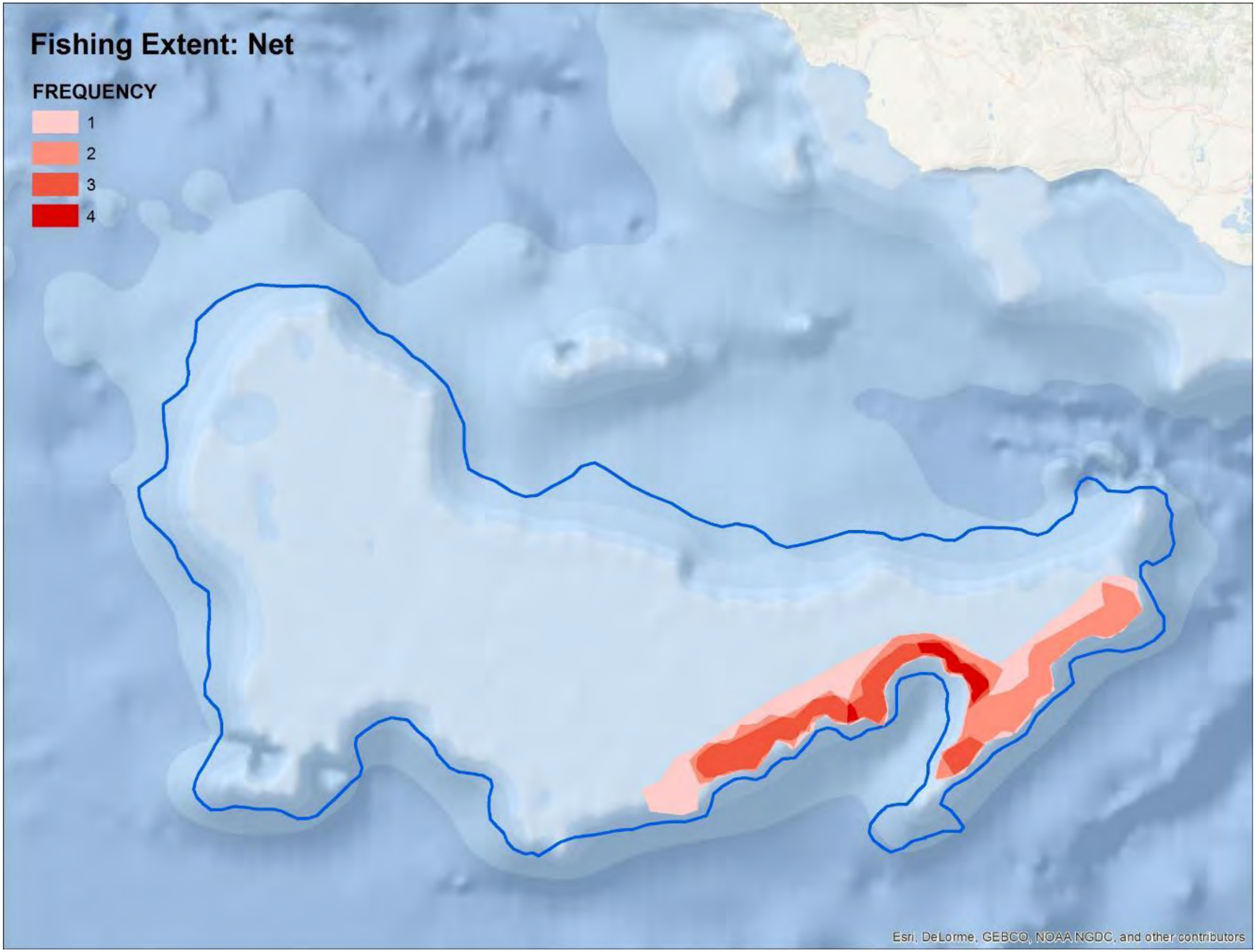

Overall Fishing Intensity
Value
High
Low
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

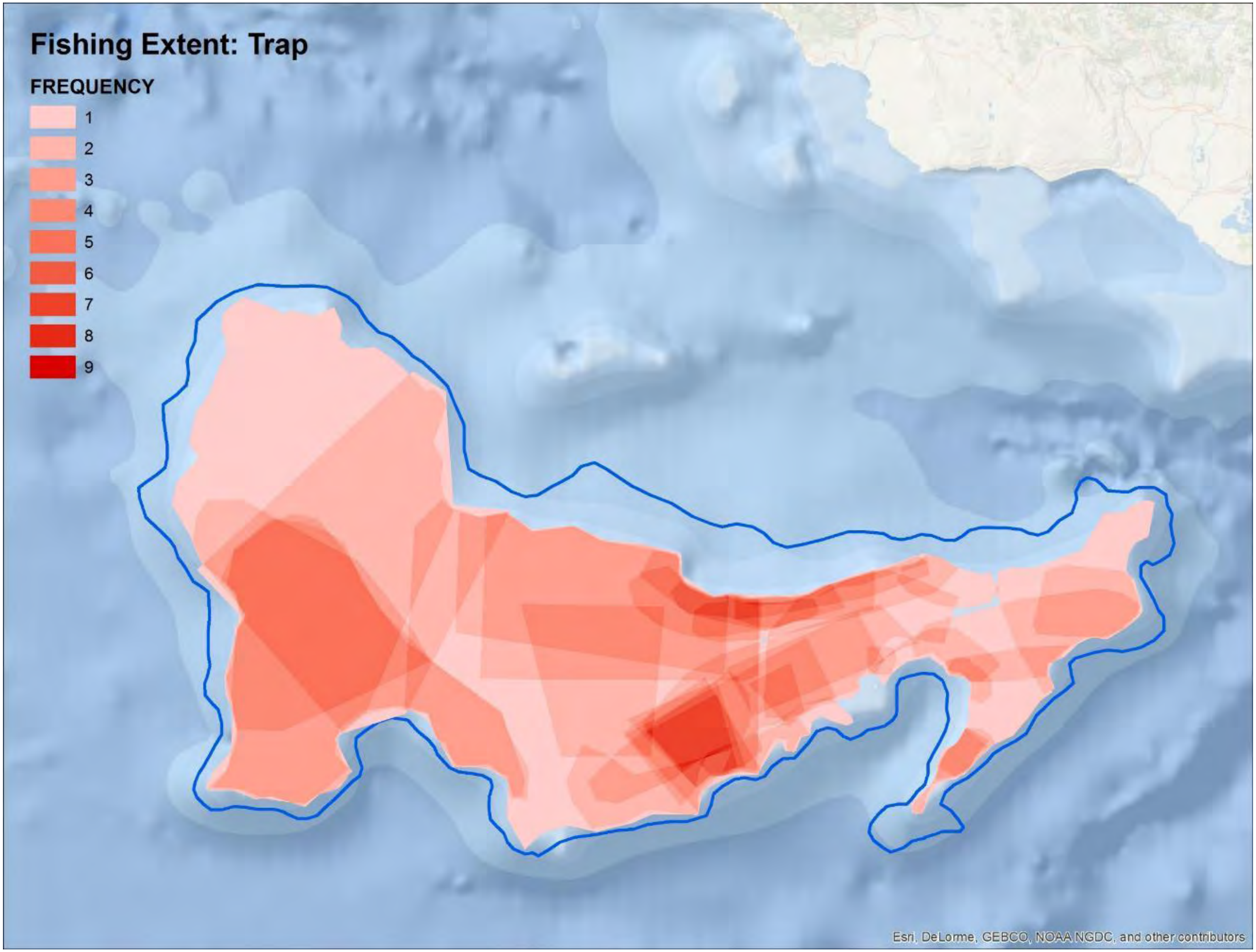

Fishing Extent: All Gear
Frequency
1 - 4
5 - 7
8 - 10
11 - 13
14 - 16
17 - 19
20 - 21
22 - 24
25 - 27
28 - 30
31 - 33
34 - 36
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

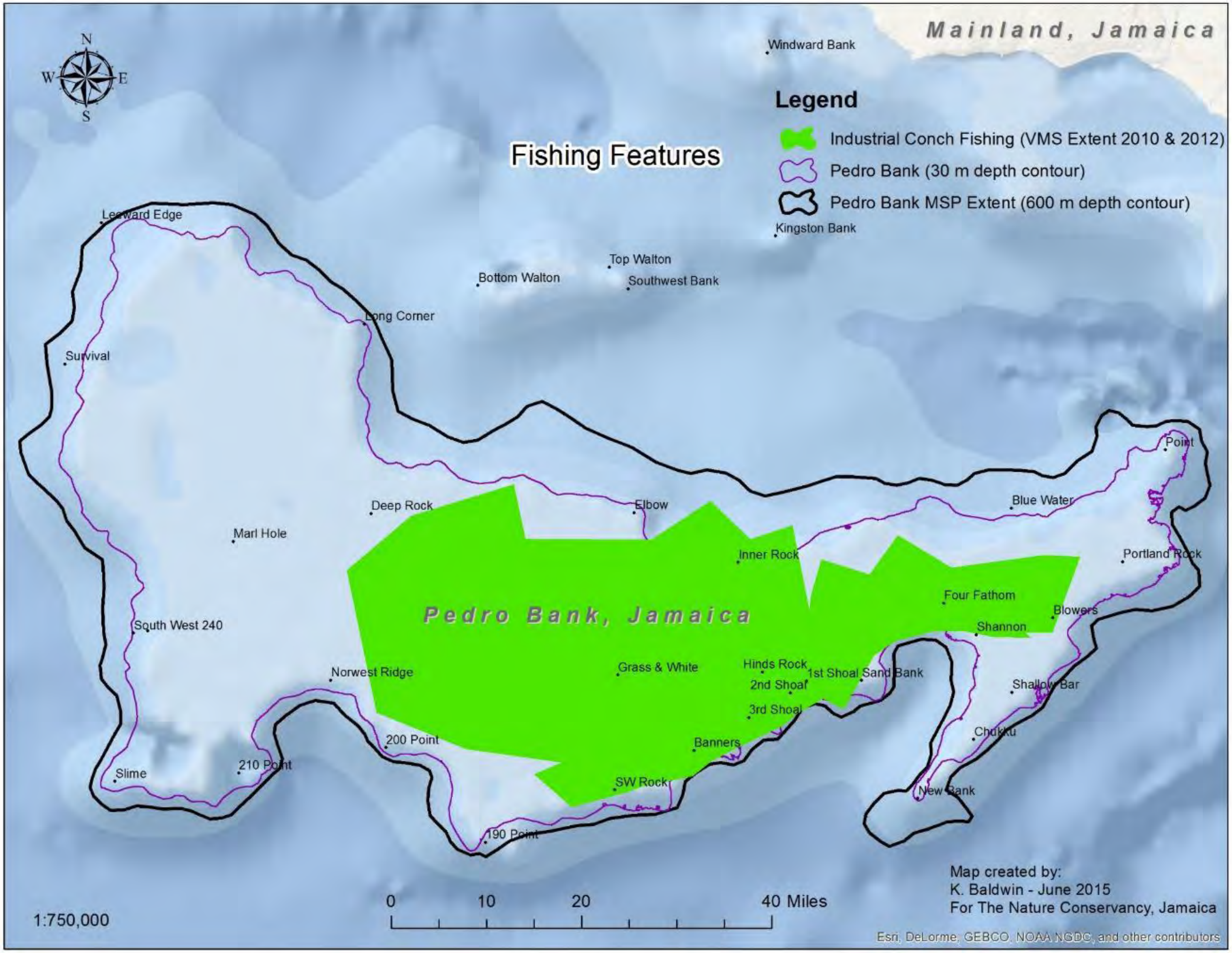

Fishing Extent: Compressor
Frequency
1 - 3
4 - 6
7 - 10
11 - 14
15 - 18
19 - 21
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Fishing Extent: Free Dive
FREQUENCY
1
2
3
4
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

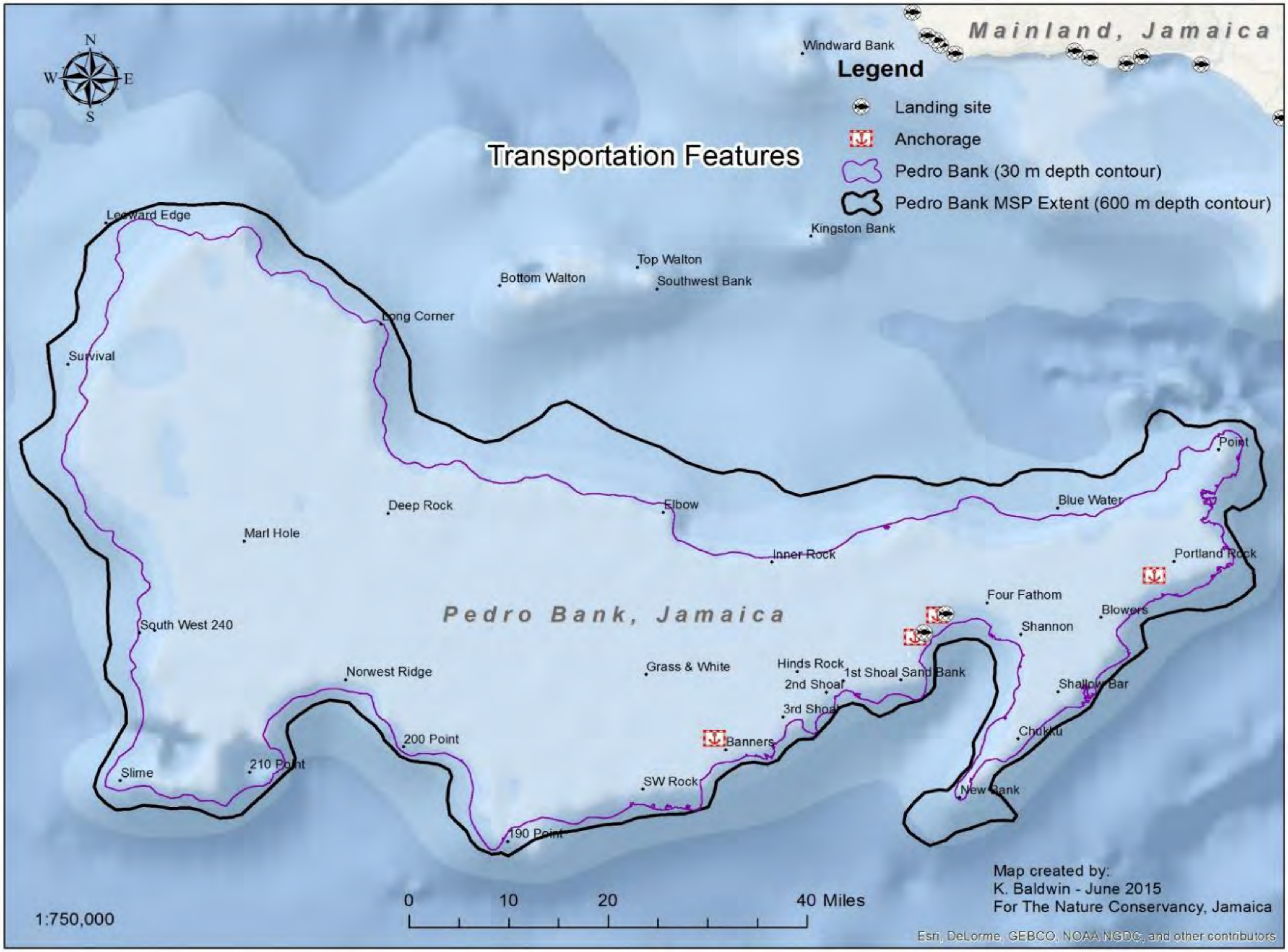

Fishing Extent: Line
FREQUENCY
1
2
3
4
5
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

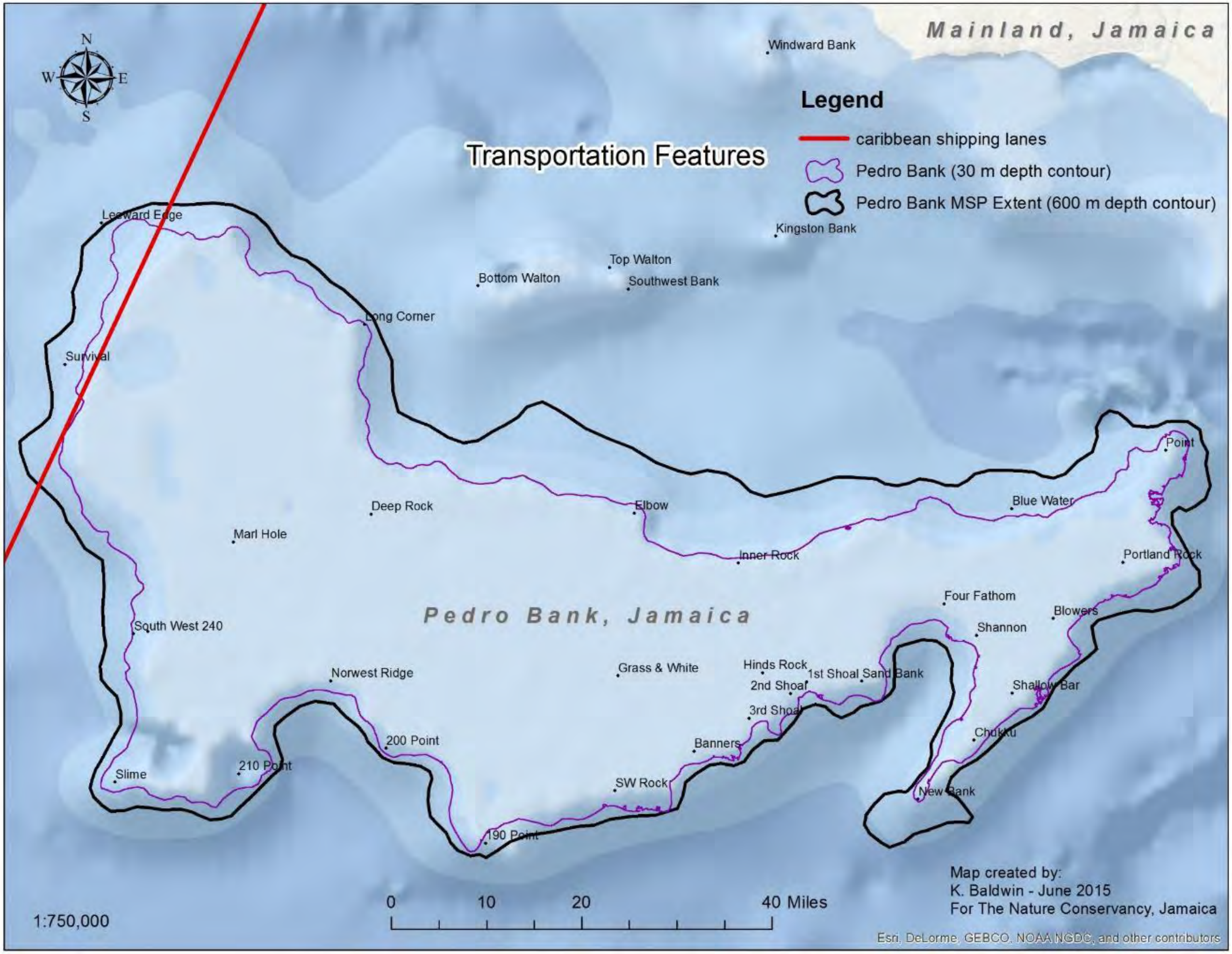

Fishing Extent: Net
FREQUENCY
1
2
3
4
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Fishing Extent: Trap
FREQUENCY
1
2
3
4
5
6
7
8
9
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

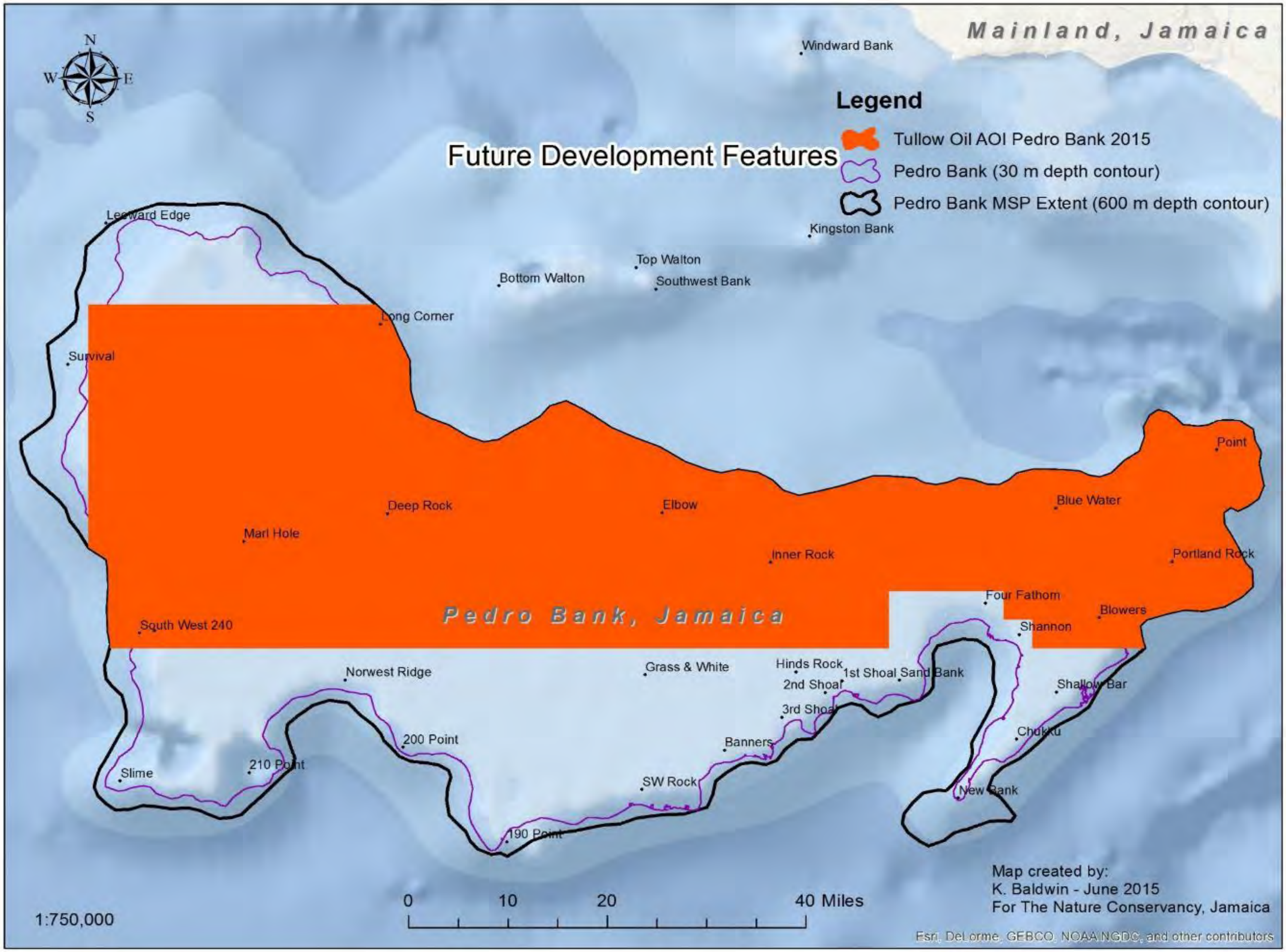

Mainland, Jamaica
Windward Bank
Legend
Industrial Conch Fishing (VMS Extent 2010 & 2012)
Pedro Bank (30 m depth contour)
Pedro Bank MSP Extent (600 m depth contour)
Fishing Features
Kingston Bank
Leeward Edge
Top Walton
Bottom Walton
Southwest Bank
Long Corner
Survival
Point
Deep Rock
Elbow
Blue Water
Marl Hole
Inner Rock
Portland Rock
Four Fathom
Pedro Bank, Jamaica
Blowers
South West 240
Shannon
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal
Sand Bank
2nd Shoal
Shallow Bar
3rd Shoal
200 Point
Chukku
Banners
210 Point
Slime
SW Rock
New Bank
190 Point
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
0
10
20
40 Miles
1:750,000
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

Maps of transportation features produced for use in the Pedro Bank Marine Spatial Planning project.



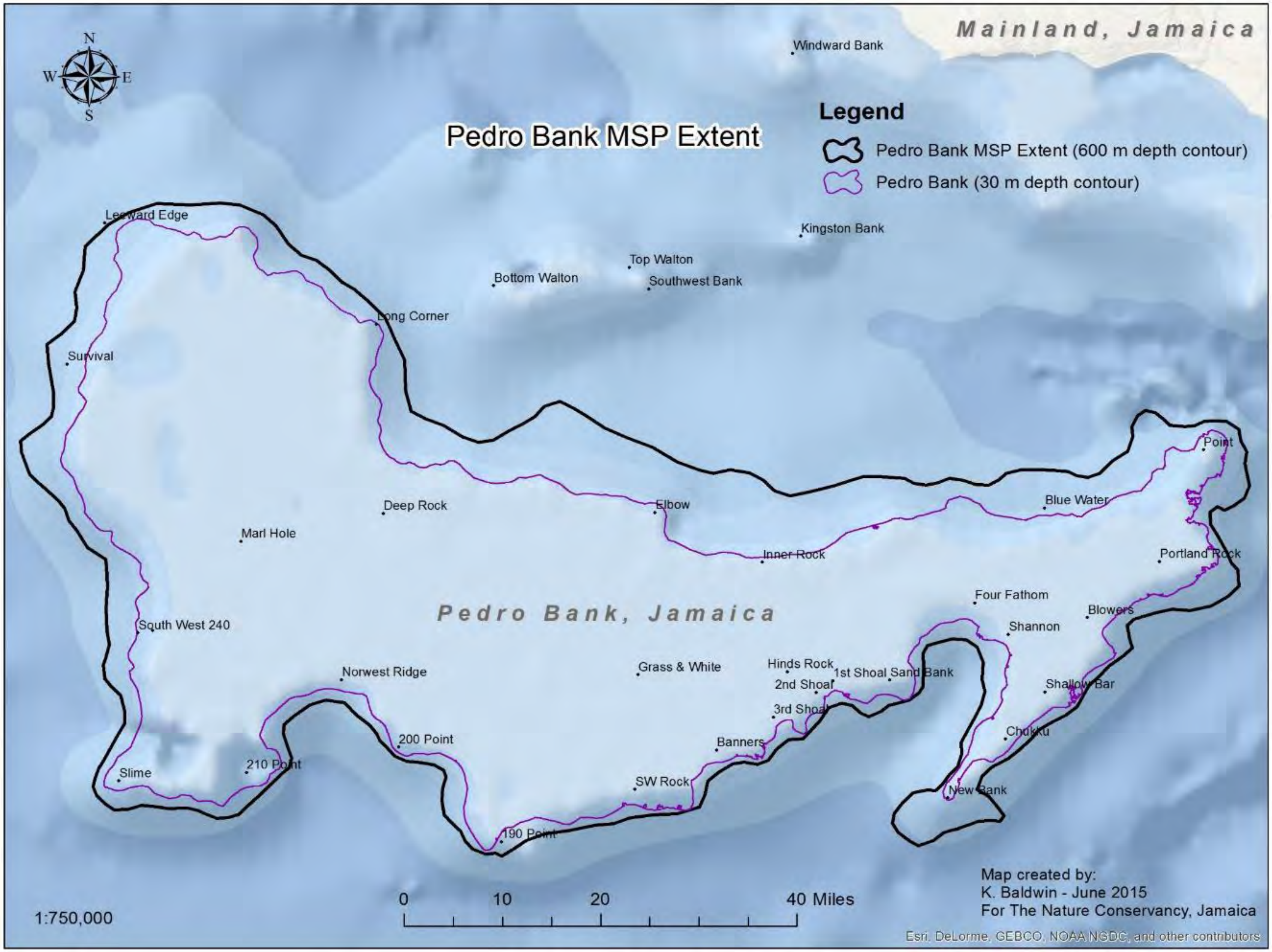

Mainland, Jamaica
Windward Bank
N
W
E
S
Legend
caribbean shipping lanes
Pedro Bank (30 m depth contour)
Pedro Bank MSP Extent (600 m depth contour)
Transportation Features
Leeward Edge
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Long Corner
Survival
Point
Deep Rock
Elbow
Blue Water
Marl Hole
Inner Rock
Portland Rock
Four Fathom
Pedro Bank, Jamaica
Blowers
South West 240
Shannon
Grass & White
Hinds Rock
Norwest Ridge
1st Shoal
Sand Bank
2nd Shoal
Shallow Bar
3rd Shoal
200 Point
Chukku
Banners
210 Point
Slime
SW Rock
New Bank
190 Point
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
0
10
20
40 Miles
1:750,000
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

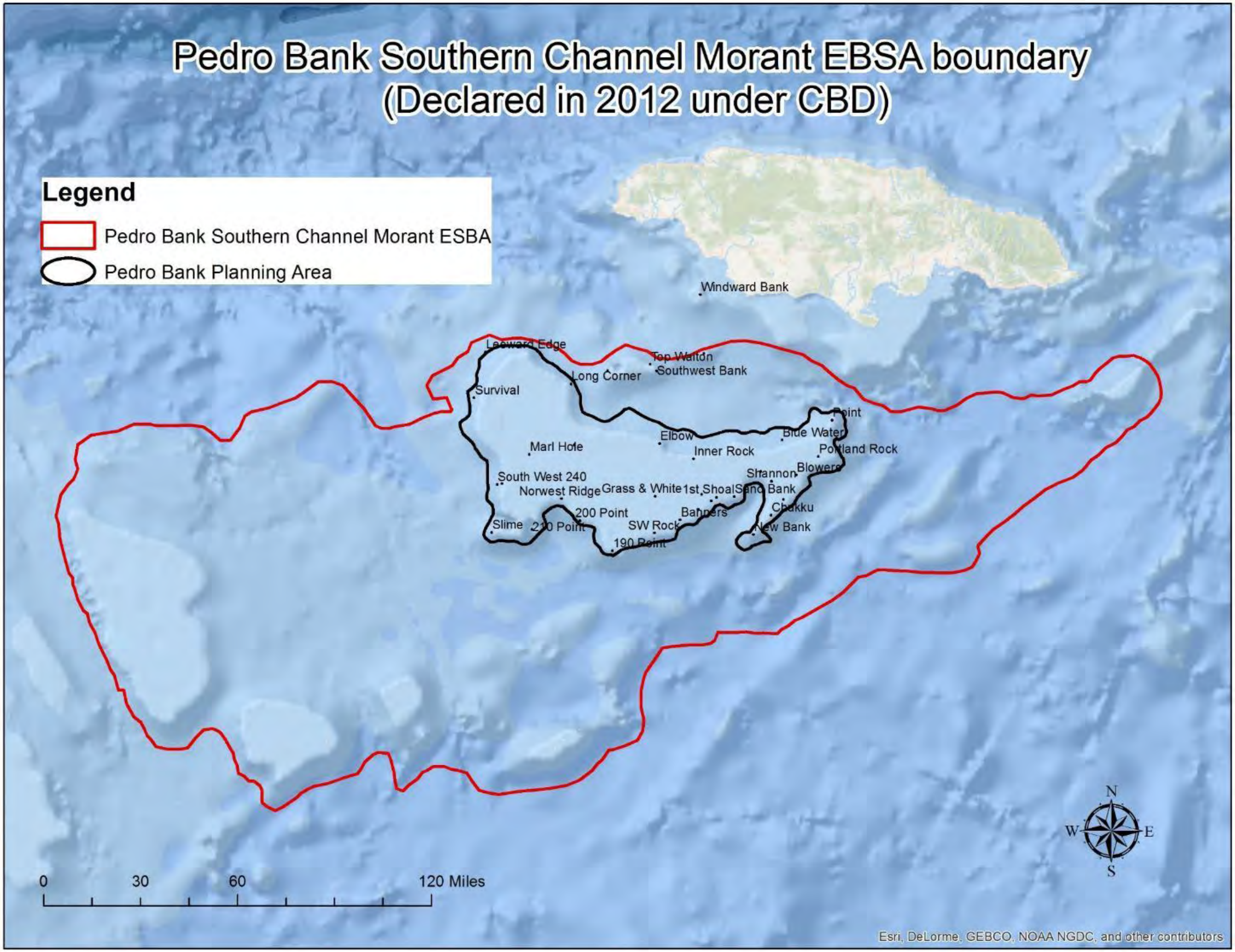
Maps of future development features produced for use in the Pedro Bank Marine Spatial Planning project.

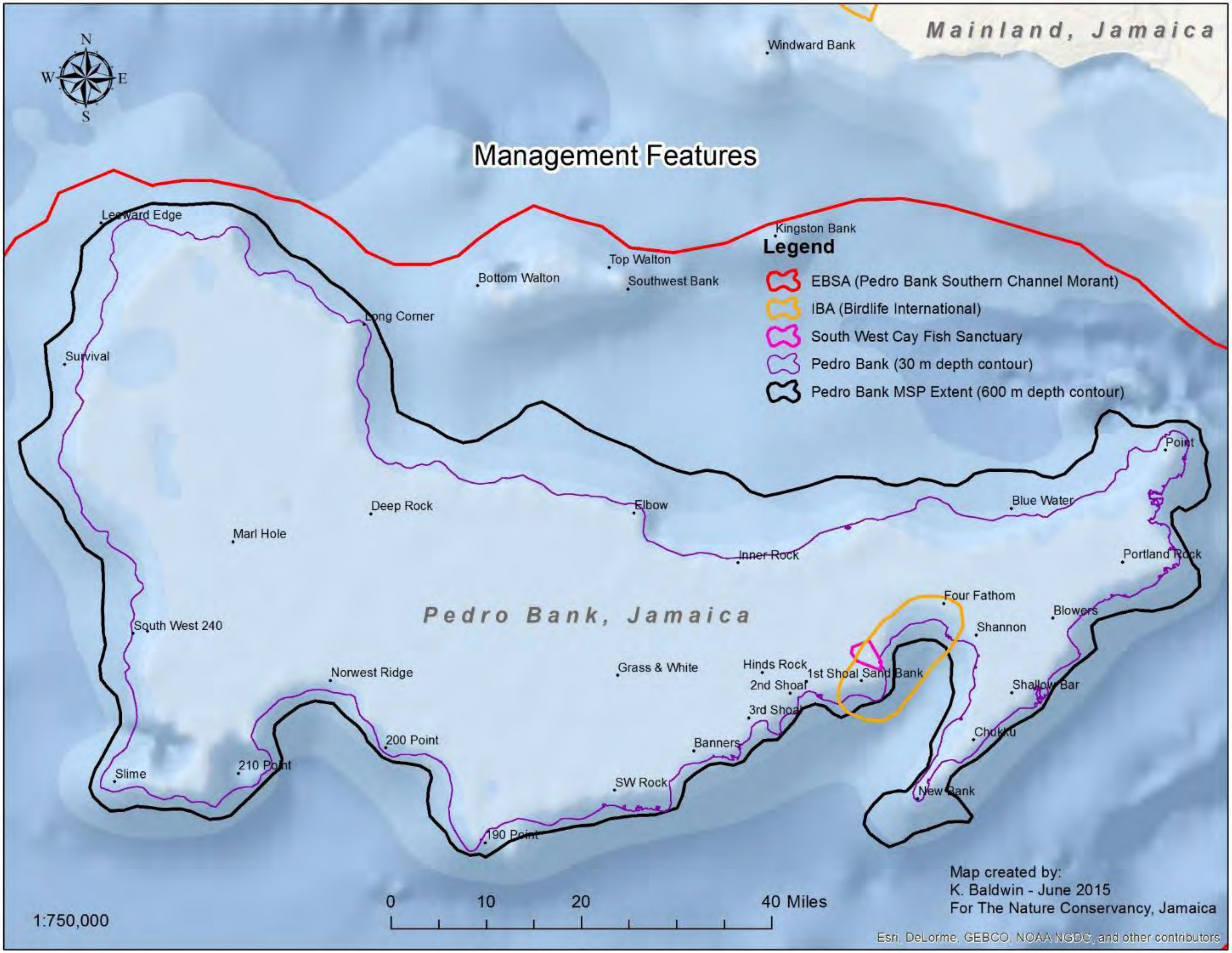


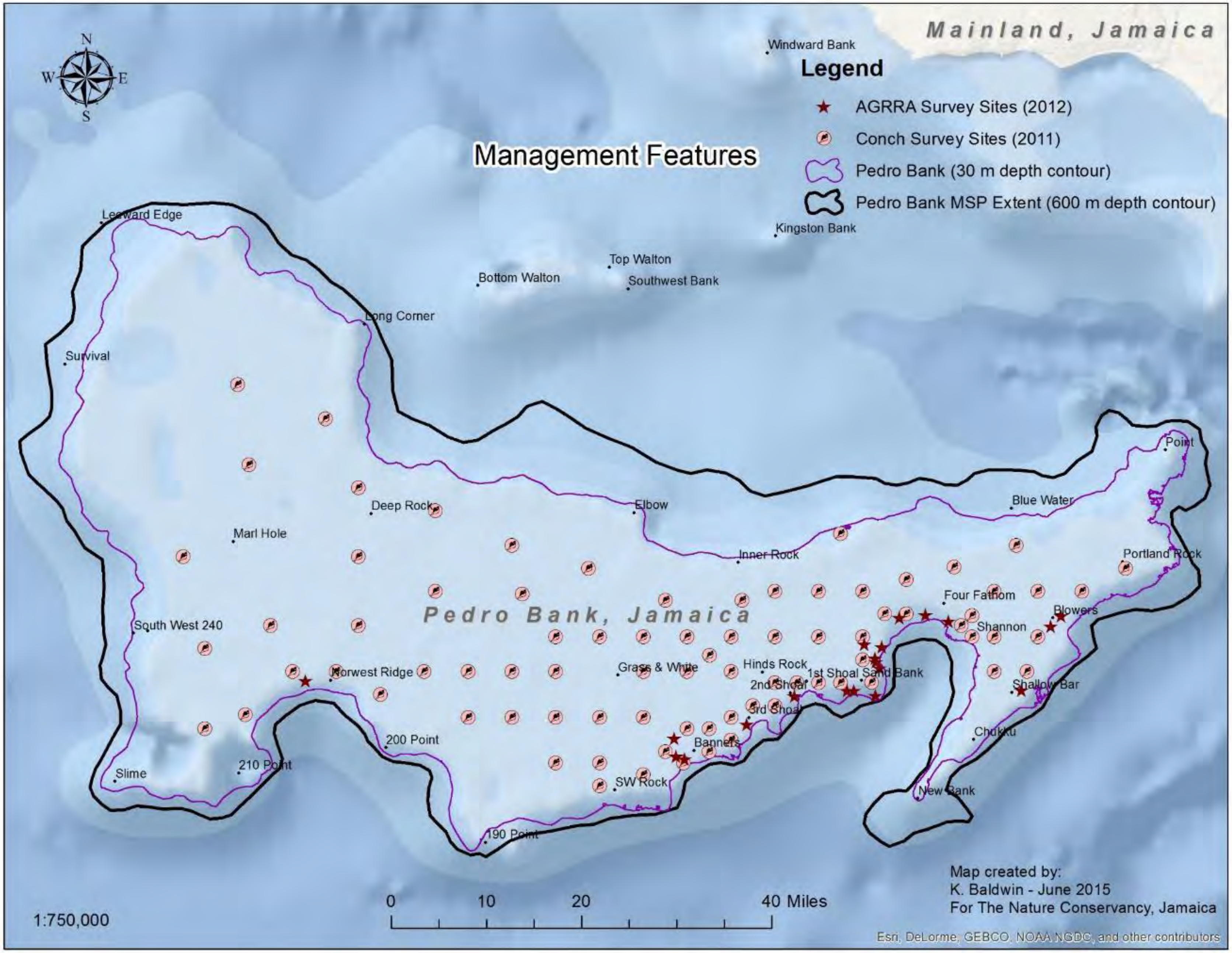
Mainland, Jamaica
Future Development Features
Legend
Ecotourism Potential
Pedro Bank (30 m depth contour)
Pedro Bank MSP Extent (600 m depth contour)
N
S
E
W
Windward Bank
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Leeward Edge
Long Corner
Survival
Deep Rock
Marl Hole
Elbow
Inner Rock
Blue Water
Point
Portland Rock
Four Fathom
Blowers
Shannon
Pedro Bank, Jamaica
South West 240
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal
Sand Bank
2nd Shoal
3rd Shoal
Shallow Bar
Chukku
Banners
200 Point
210 Point
Slime
SW Rock
New Bank
190 Point
0
10
20
40 Miles
1:750,000
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

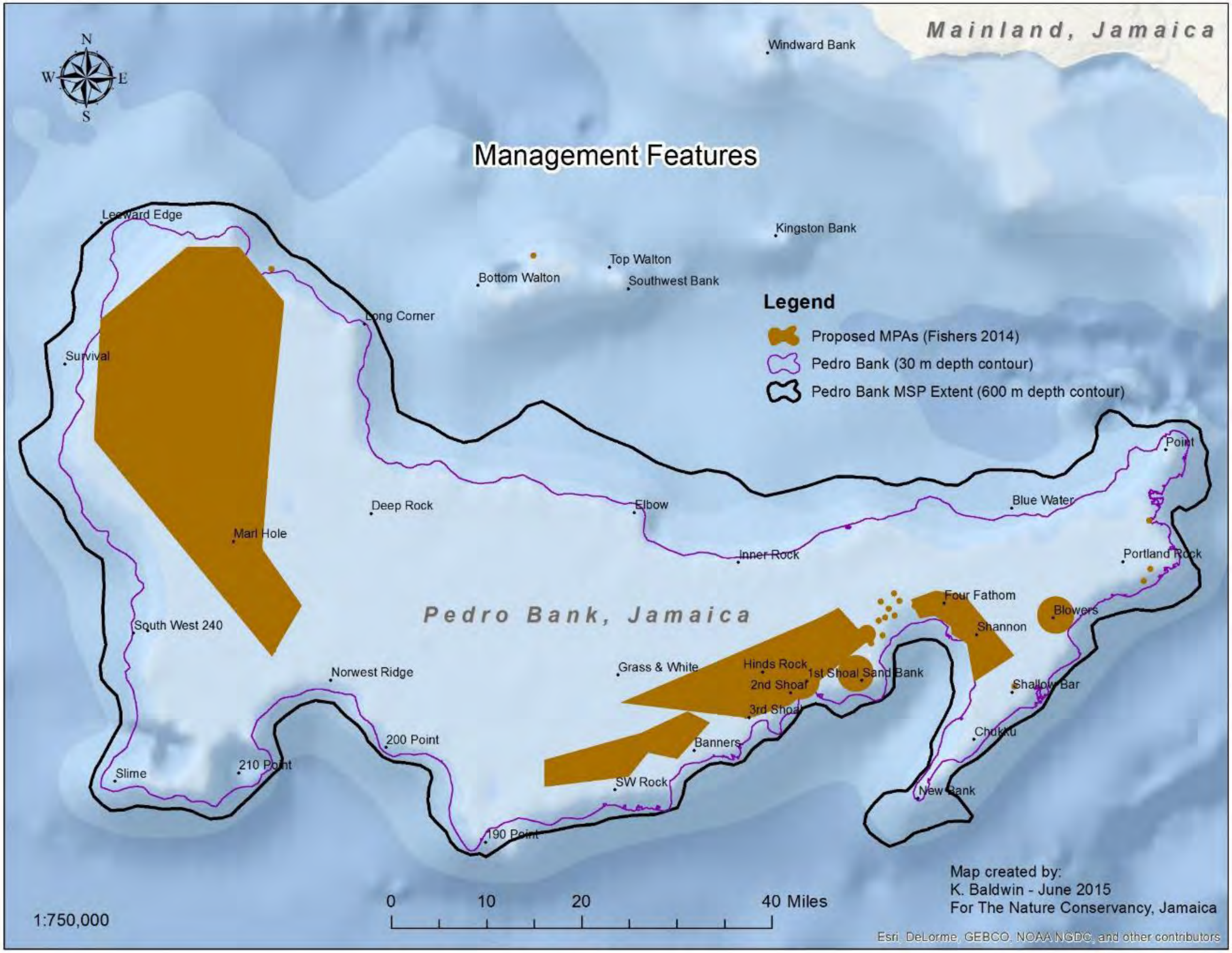
Maps of management features produced for use in the Pedro Bank Marine Spatial Planning project.

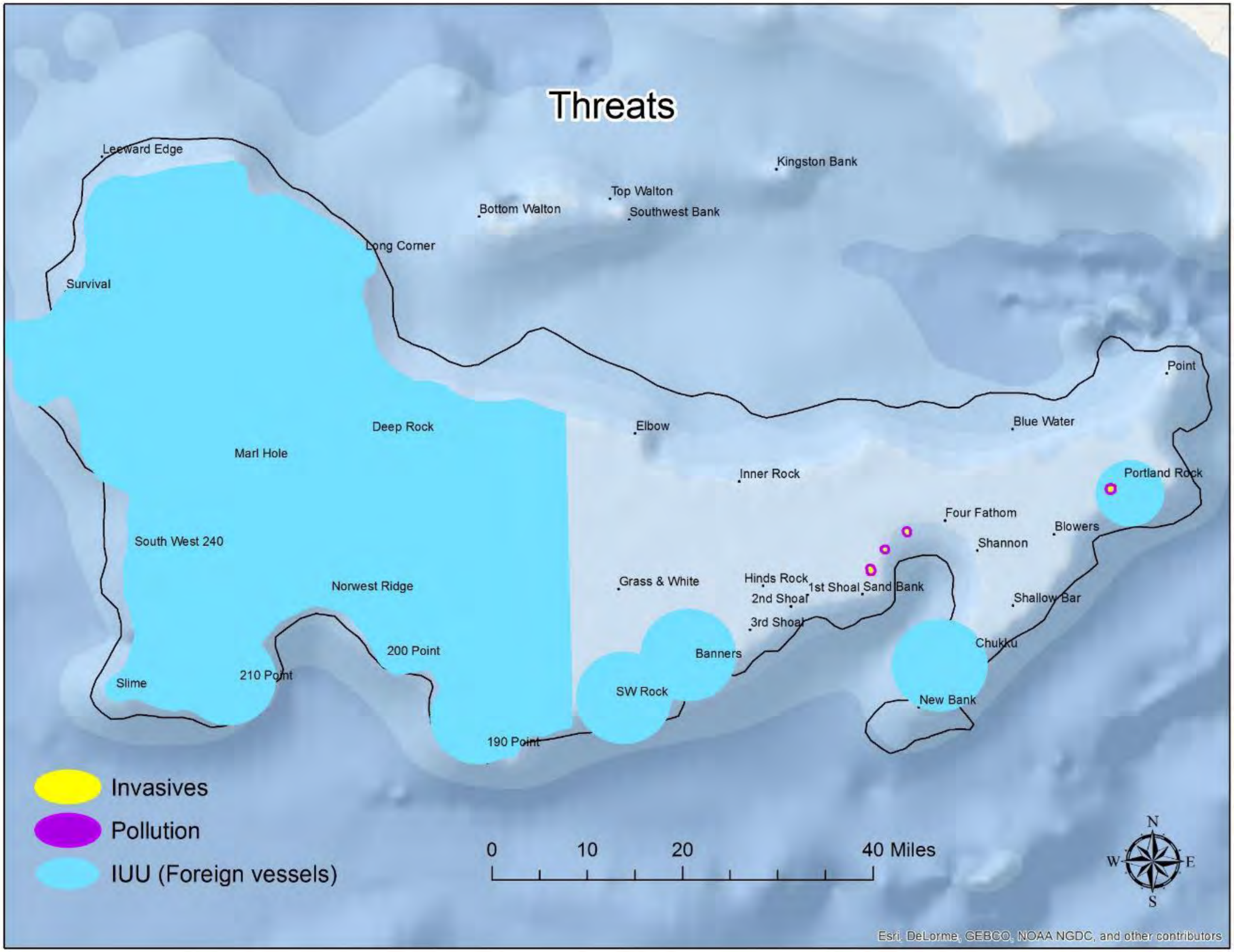



Pedro Bank Southern Channel Morant EBSA boundary
(Declared in 2012 under CBD)
Legend
Pedro Bank Southern Channel Morant ESBA
Pedro Bank Planning Area
Windward Bank
Leeward Edge
Top Walton
Southwest Bank
Long Corner
Survival
Point
Blue Water
Elbow
Marl Hole
Inner Rock
Portland Rock
Blowers
Shannon
South West 240
Norwest Ridge
Grass & White
1st Shoal
Sand Bank
Chukku
200 Point
Banners
Slime
210 Point
SW Rock
New Bank
190 Point
0
30
60
120 Miles
N
W
E
S
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

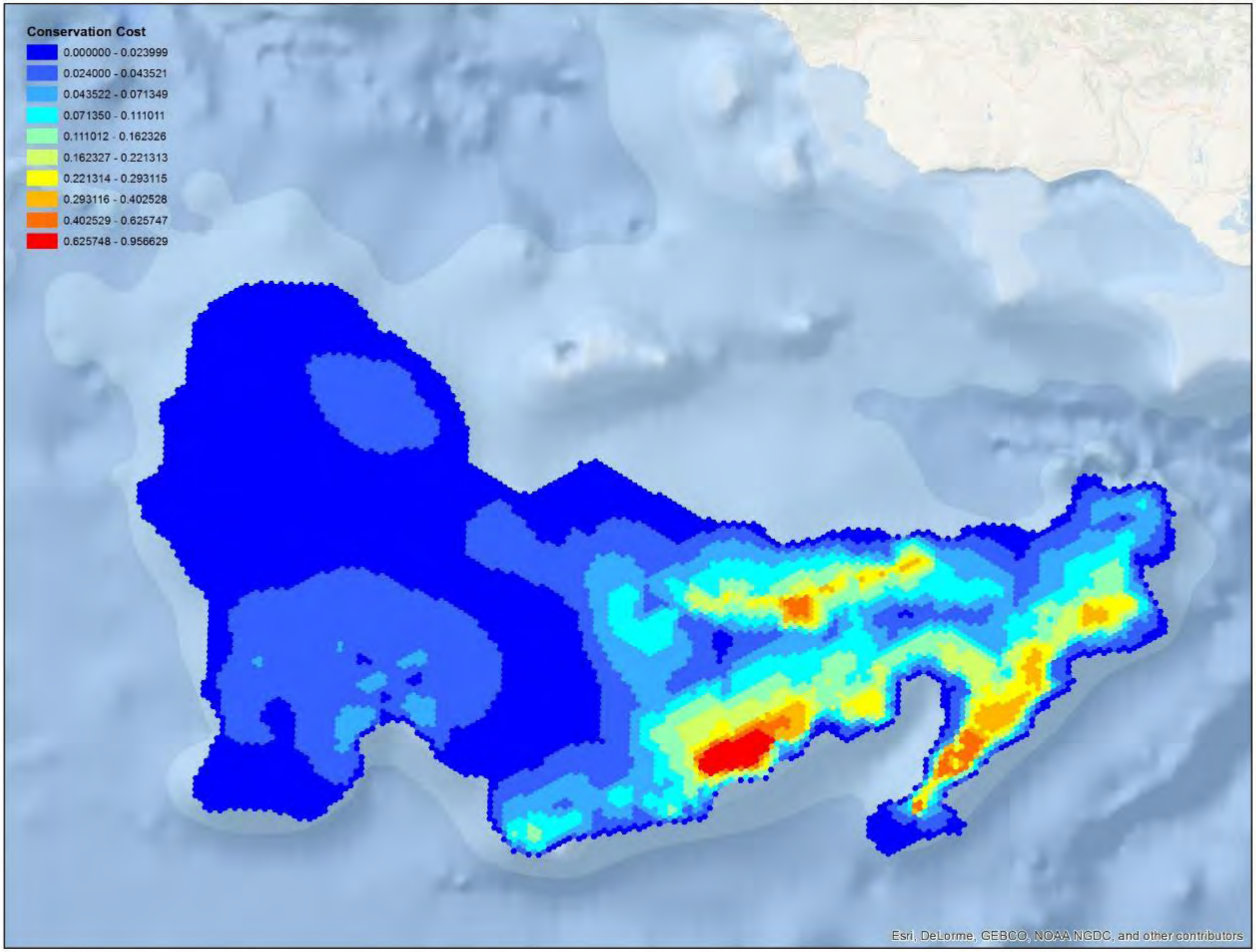

Mainland, Jamaica
Windward Bank
Management Features
Leeward Edge
Kingston Bank
Legend
Top Walton
Bottom Walton
Southwest Bank
EBSA (Pedro Bank Southern Channel Morant)
IBA (Birdlife International)
South West Cay Fish Sanctuary
Pedro Bank (30 m depth contour)
Pedro Bank MSP Extent (600 m depth contour)
Long Corner
Survival
Point
Deep Rock
Elbow
Blue Water
Marl Hole
Inner Rock
Portland Rock
Four Fathom
Pedro Bank, Jamaica
Blowers
South West 240
Shannon
Hinds Rock
Grass & White
Norwest Ridge
1st Shoal
Sand Bank
2nd Shoal
Shallow Bar
3rd Shoal
Chukku
200 Point
Banners
210 Point
Slime
SW Rock
New Bank
190 Point
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
0
10
20
40 Miles
1:750,000
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

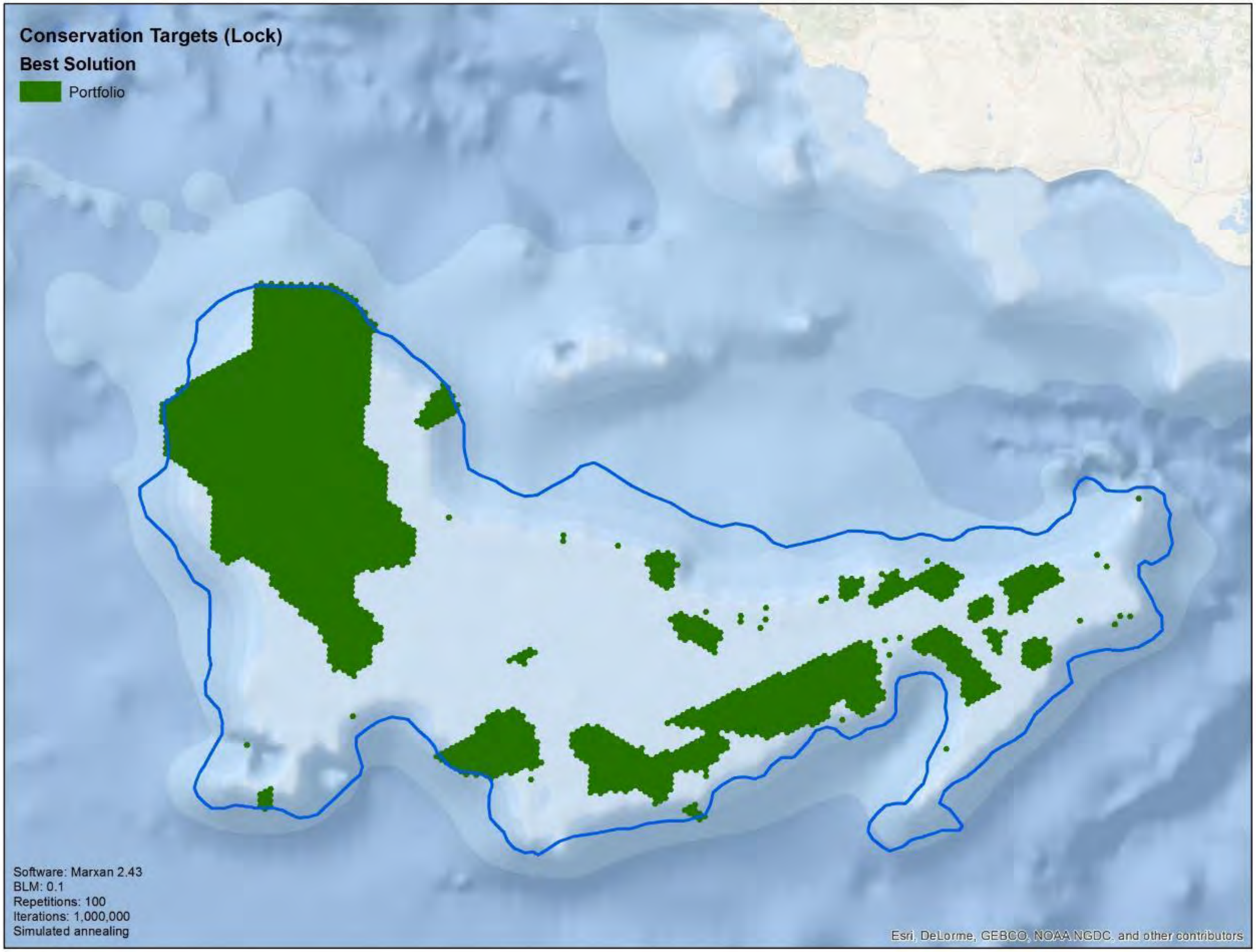

Management Features
Mainland, Jamaica
Legend
AGRRA Survey Sites (2012)
Conch Survey Sites (2011)
Pedro Bank (30 m depth contour)
Pedro Bank MSP Extent (600 m depth contour)
Pedro Bank, Jamaica
Windward Bank
Kingston Bank
Top Walton
Southwest Bank
Bottom Walton
Leeward Edge
Long Corner
Survival
Deep Rock
Marl Hole
Elbow
Inner Rock
Blue Water
Point
Portland Rock
Four Fathom
Shannon
Blowers
South West 240
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal
Sand Bank
2nd Shoal
3rd Shoal
Shallow Bar
Bannets
Chukku
200 Point
210 Point
Slime
SW Rock
New Bank
190 Point
0
10
20
40 Miles
1:750,000
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

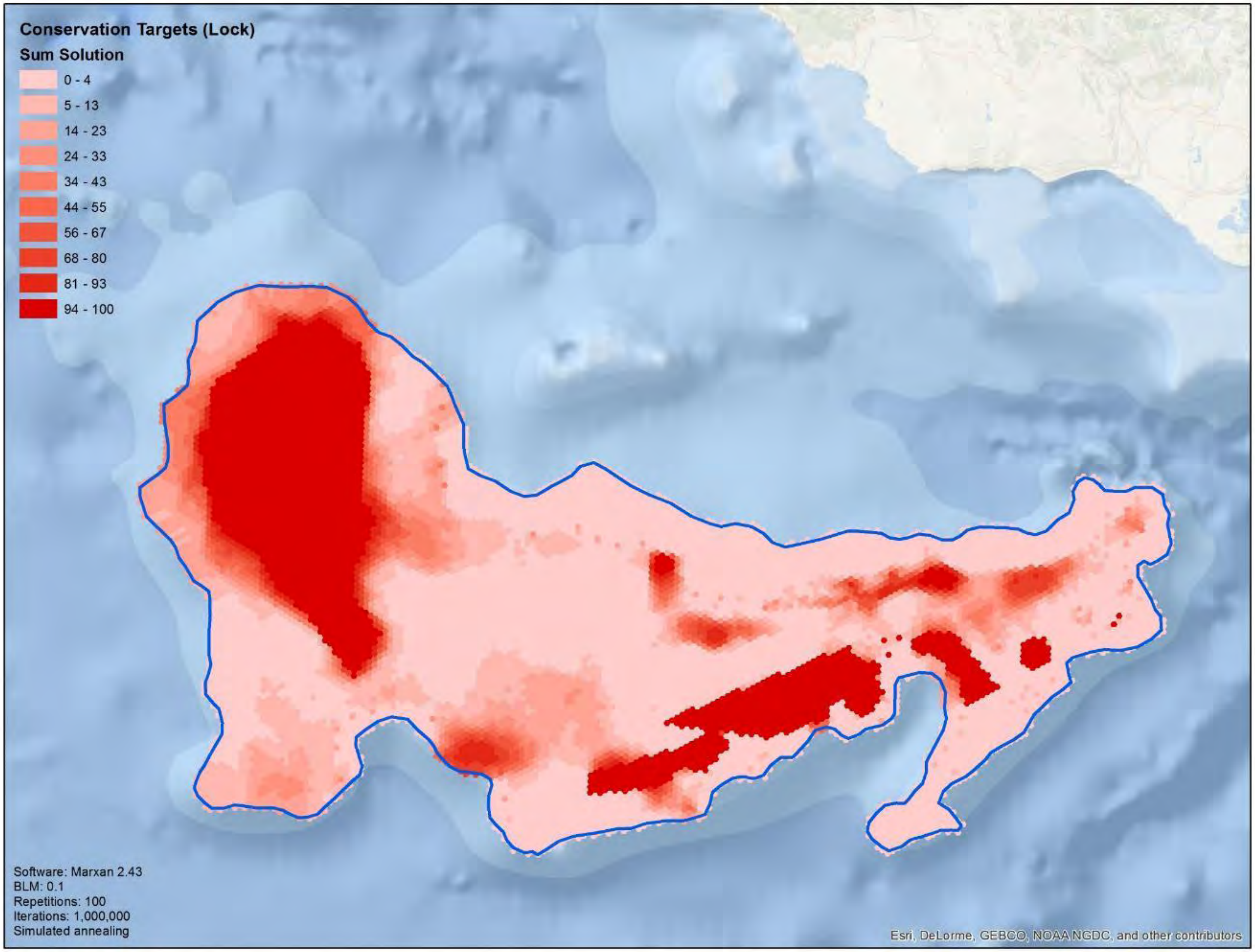

Mainland, Jamaica
Management Features
Windward Bank
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Leeward Edge
Long Corner
Survival
Legend
Proposed MPAs (Fishers 2014)
Pedro Bank (30 m depth contour)
Pedro Bank MSP Extent (600 m depth contour)
Point
Blue Water
Deep Rock
Elbow
Marl Hole
Inner Rock
Portland Rock
Four Fathom
Pedro Bank, Jamaica
Blowers
South West 240
Shannon
Grass & White
Hinds Rock
1st Shoal
Sand Bank
Norwest Ridge
2nd Shoal
Shallow Bar
3rd Shoal
200 Point
Banners
Chukku
210 Point
Slime
SW Rock
New Bank
190 Point
Map created by:
K. Baldwin - June 2015
For The Nature Conservancy, Jamaica
0
10
20
40 Miles
1:750,000
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

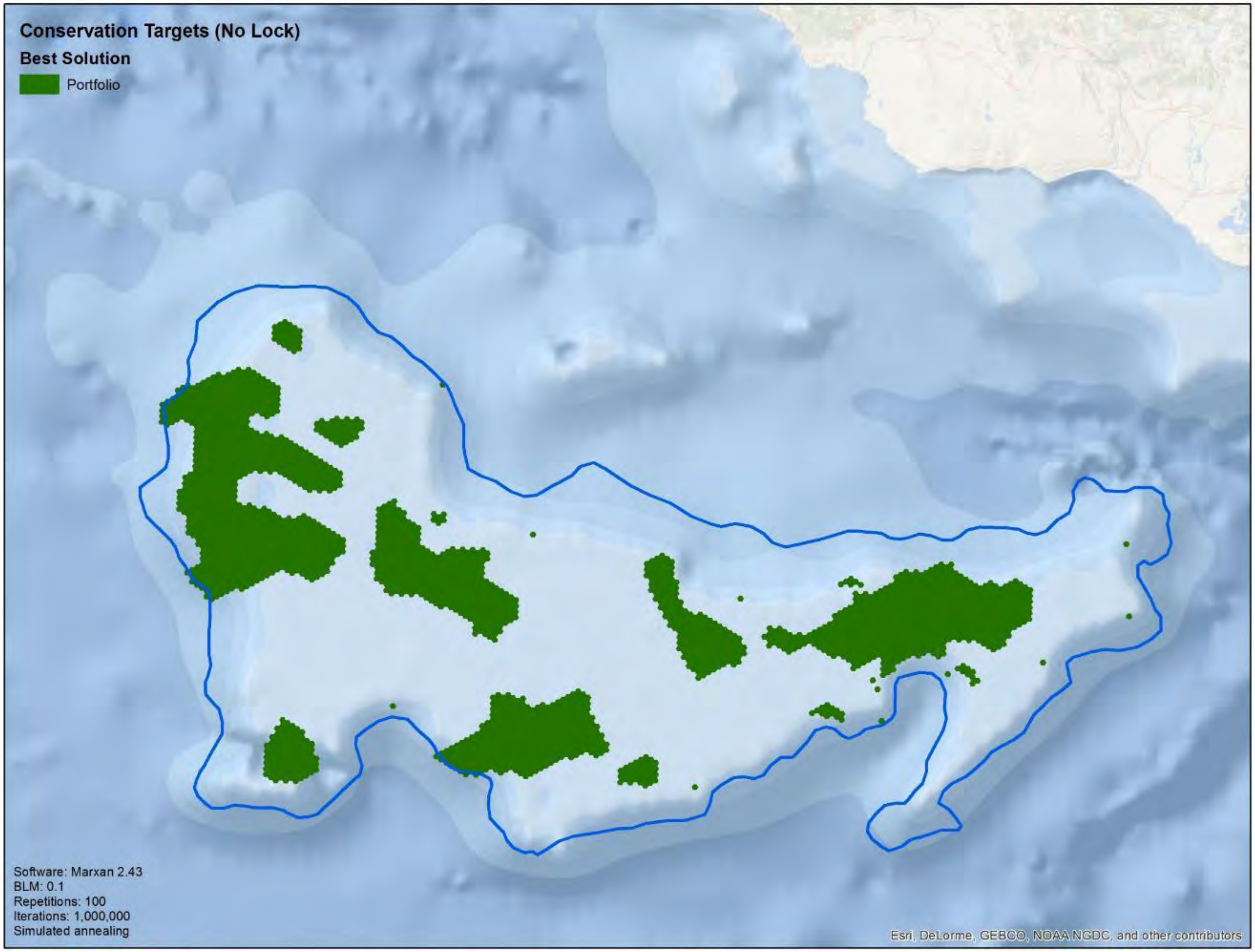

Threats
Leeward Edge
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Long Corner
Survival
Point
Deep Rock
Elbow
Blue Water
Marl Hole
Inner Rock
Portland Rock
Four Fathom
Blowers
Shannon
South West 240
Grass & White
Hinds Rock
1st Shoal
Sand Bank
Norwest Ridge
2nd Shoal
Shallow Bar
3rd Shoal
Chukku
200 Point
Banners
210 Point
Slime
SW Rock
New Bank
190 Point
Invasives
Pollution
IUU (Foreign vessels)
0
10
20
40 Miles
N
W
E
S
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

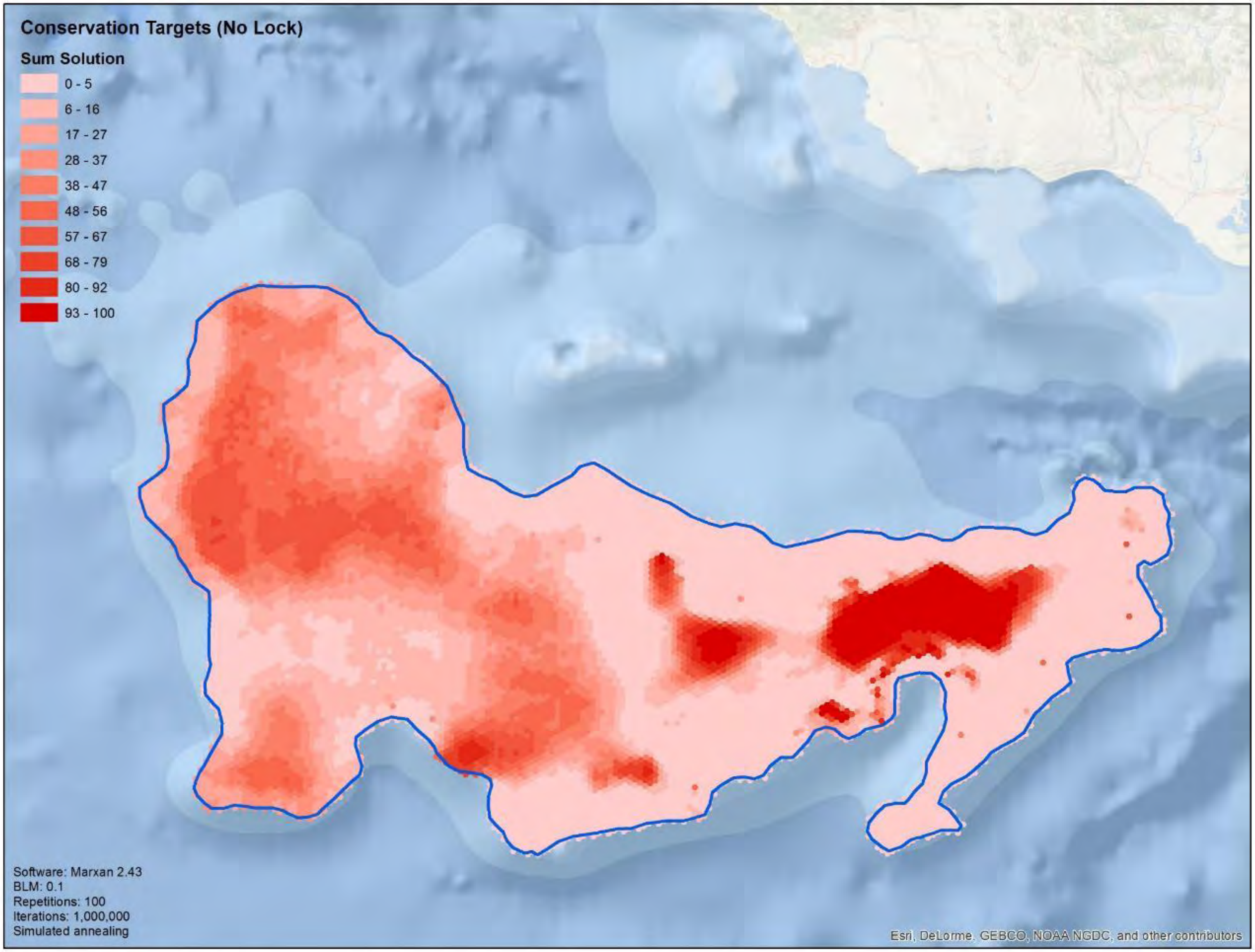
Marxan DST input parameter and scenario maps produced for the Pedro Bank Marine Spatial Planning project.

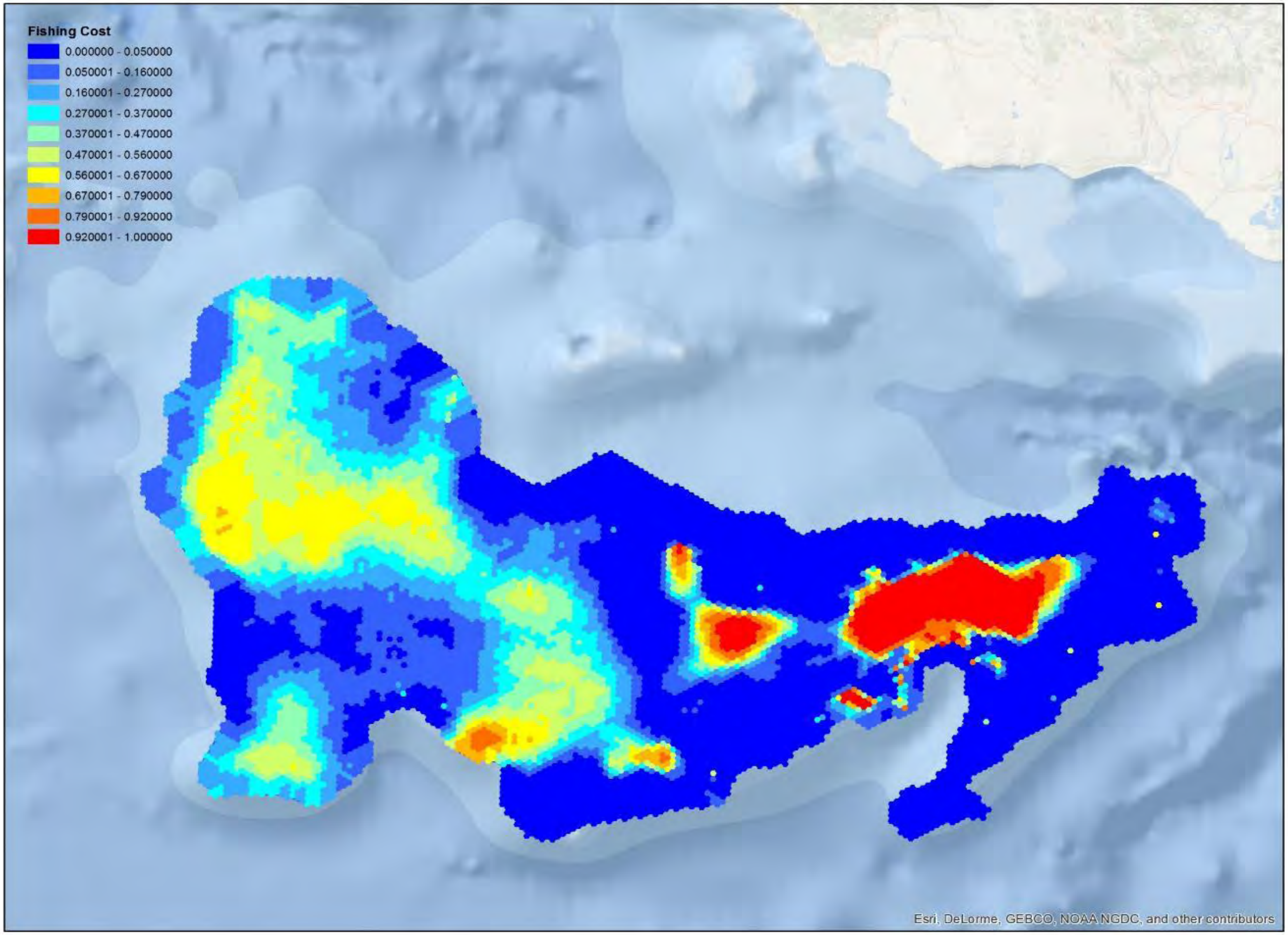

Conservation Cost
0.000000 - 0.023999
0.024000 - 0.043521
0.043522 - 0.071349
0.071350 - 0.111011
0.111012 - 0.162326
0.162327 - 0.221313
0.221314 - 0.293115
0.293116 - 0.402528
0.402529 - 0.625747
0.625748 - 0.956629
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

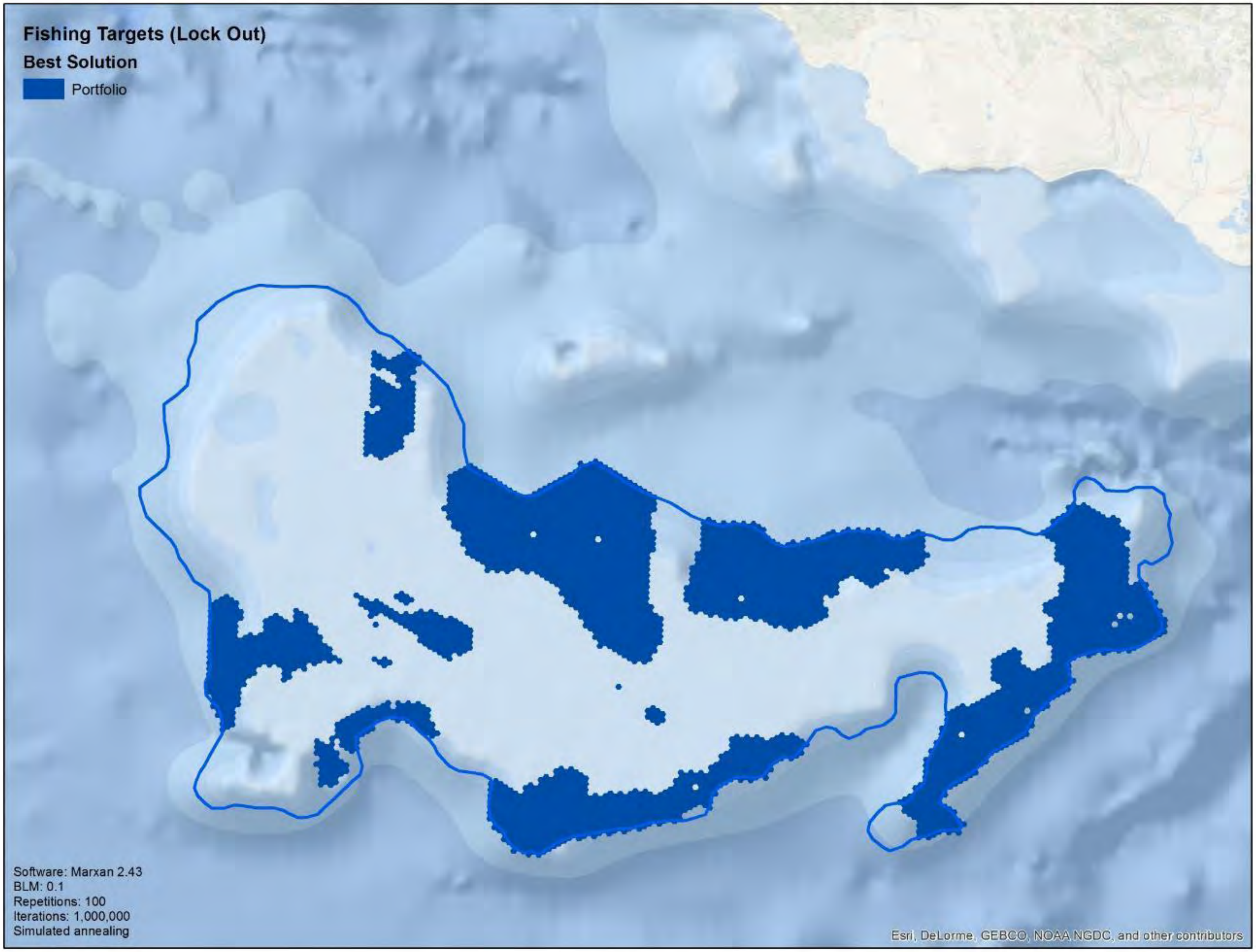

Conservation Targets (Lock)
Best Solution
Portfolio
Software: Marxan 2.43
BLM: 0.1
Repetitions: 100
Iterations: 1,000,000
Simulated annealing
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Conservation Targets (Lock)
Sum Solution
0 - 4
5 - 13
14 - 23
24 - 33
34 - 43
44 - 55
56 - 67
68 - 80
81 - 93
94 - 100
Software: Marxan 2.43
BLM: 0.1
Repetitions: 100
Iterations: 1,000,000
Simulated annealing
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors

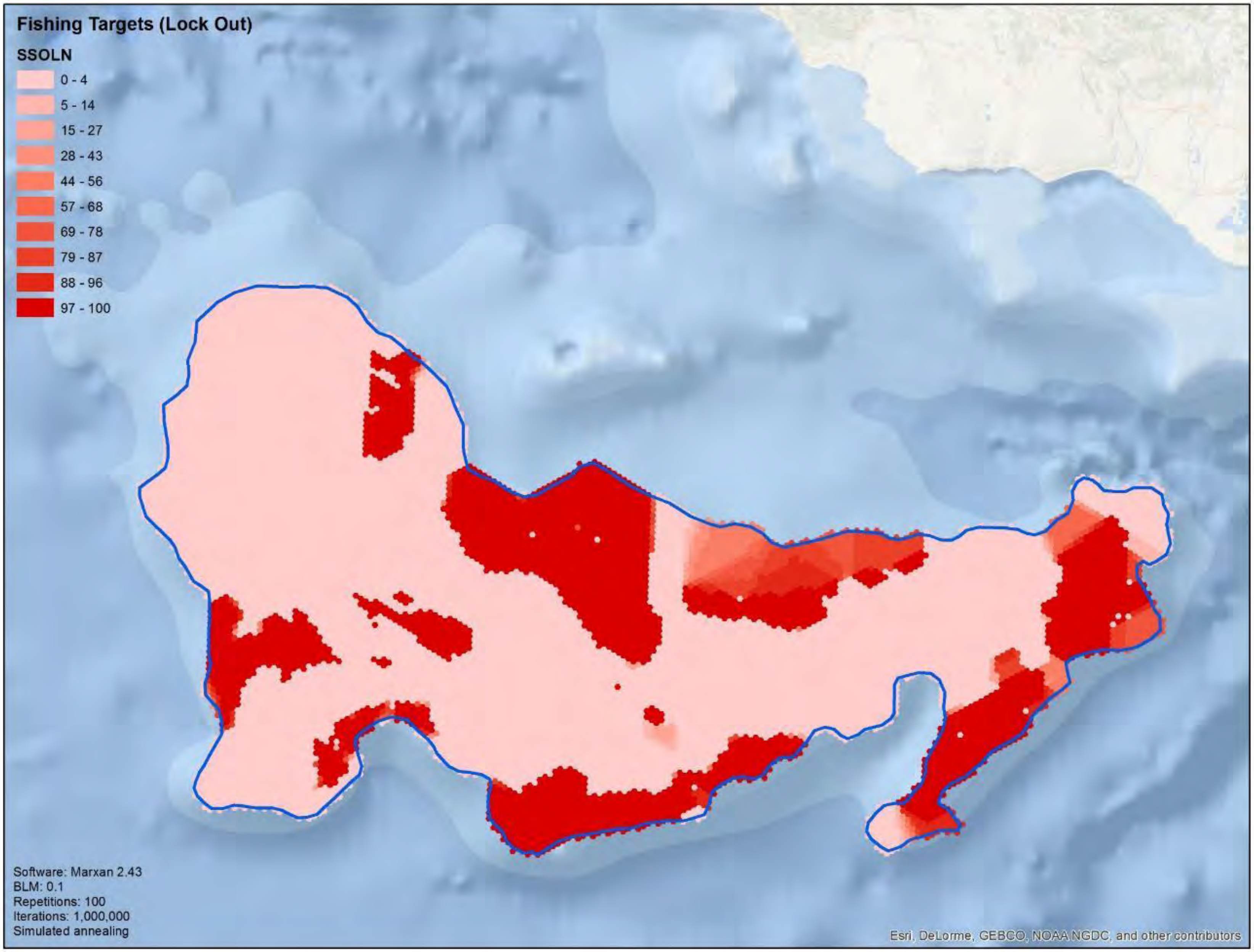

Conservation Targets (No Lock)
Best Solution
Portfolio
Software: Marxan 2.43
BLM: 0.1
Repetitions: 100
Iterations: 1,000,000
Simulated annealing
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Conservation Targets (No Lock)
Sum Solution
0 - 5
6 - 16
17 - 27
28 - 37
38 - 47
48 - 56
57 - 67
68 - 79
80 - 92
93 - 100
Software: Marxan 2.43
BLM: 0.1
Repetitions: 100
Iterations: 1,000,000
Simulated annealing
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Fishing Cost
0.000000 - 0.050000
0.050001 - 0.160000
0.160001 - 0.270000
0.270001 - 0.370000
0.370001 - 0.470000
0.470001 - 0.560000
0.560001 - 0.670000
0.670001 - 0.790000
0.790001 - 0.920000
0.920001 - 1.000000
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors



Fishing Targets (Lock Out)
Best Solution
Portfolio
Software: Marxan 2.43
BLM: 0.1
Repetitions: 100
Iterations: 1,000,000
Simulated annealing
Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors


Fishing Targets (Lock Out)
SSOLN
0 - 4
5 - 14
15 - 27
28 - 43
44 - 56
57 - 68
69 - 78
79 - 87
88 - 96
97 - 100
Software: Marxan 2.43
BLM: 0.1
Repetitions: 100
Iterations: 1,000,000
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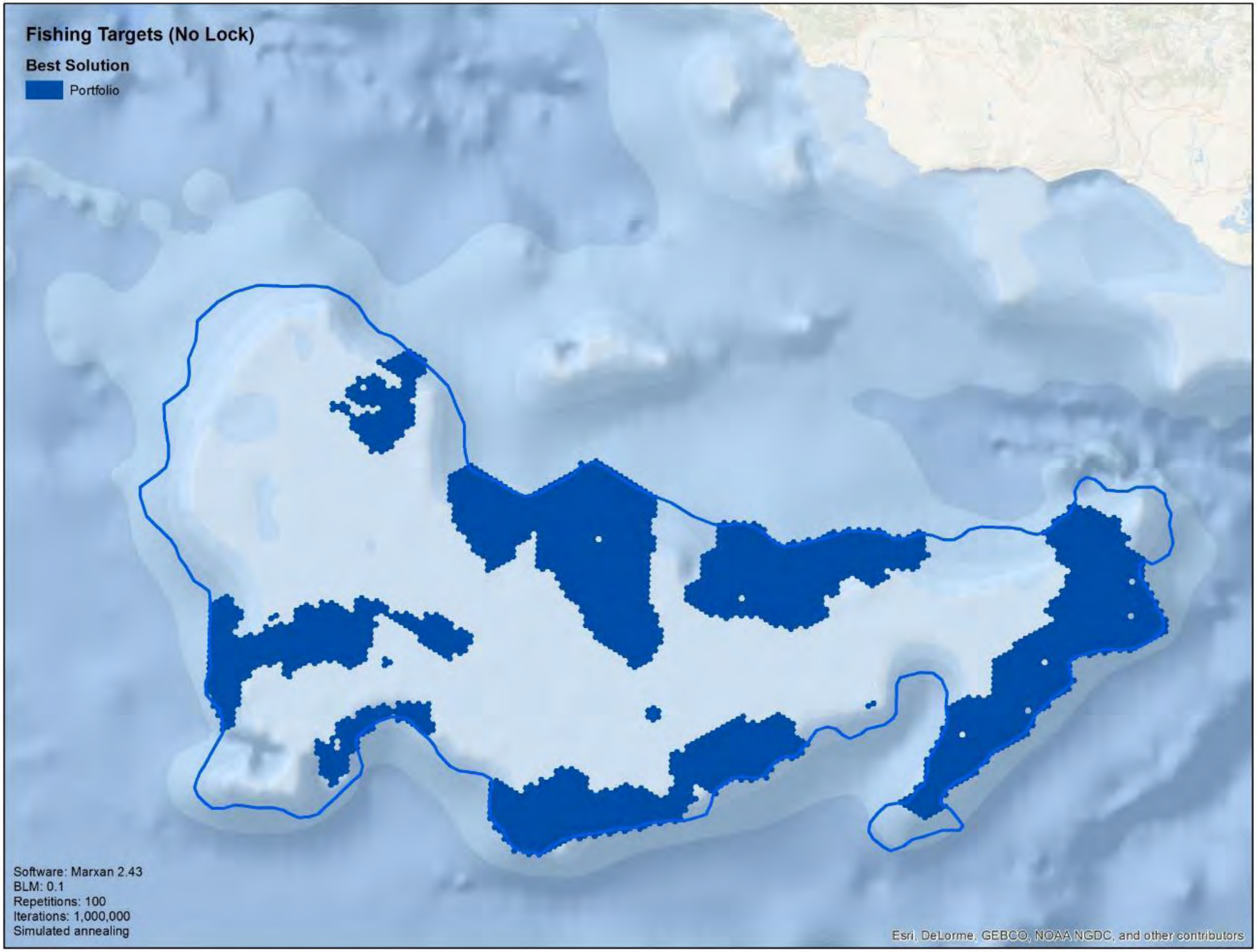
Fishing Targets (No Lock)
Best Solution
Portfolio
Software: Marxan 2.43
BLM: 0.1
Repetitions: 100
Iterations: 1,000,000
Simulated annealing
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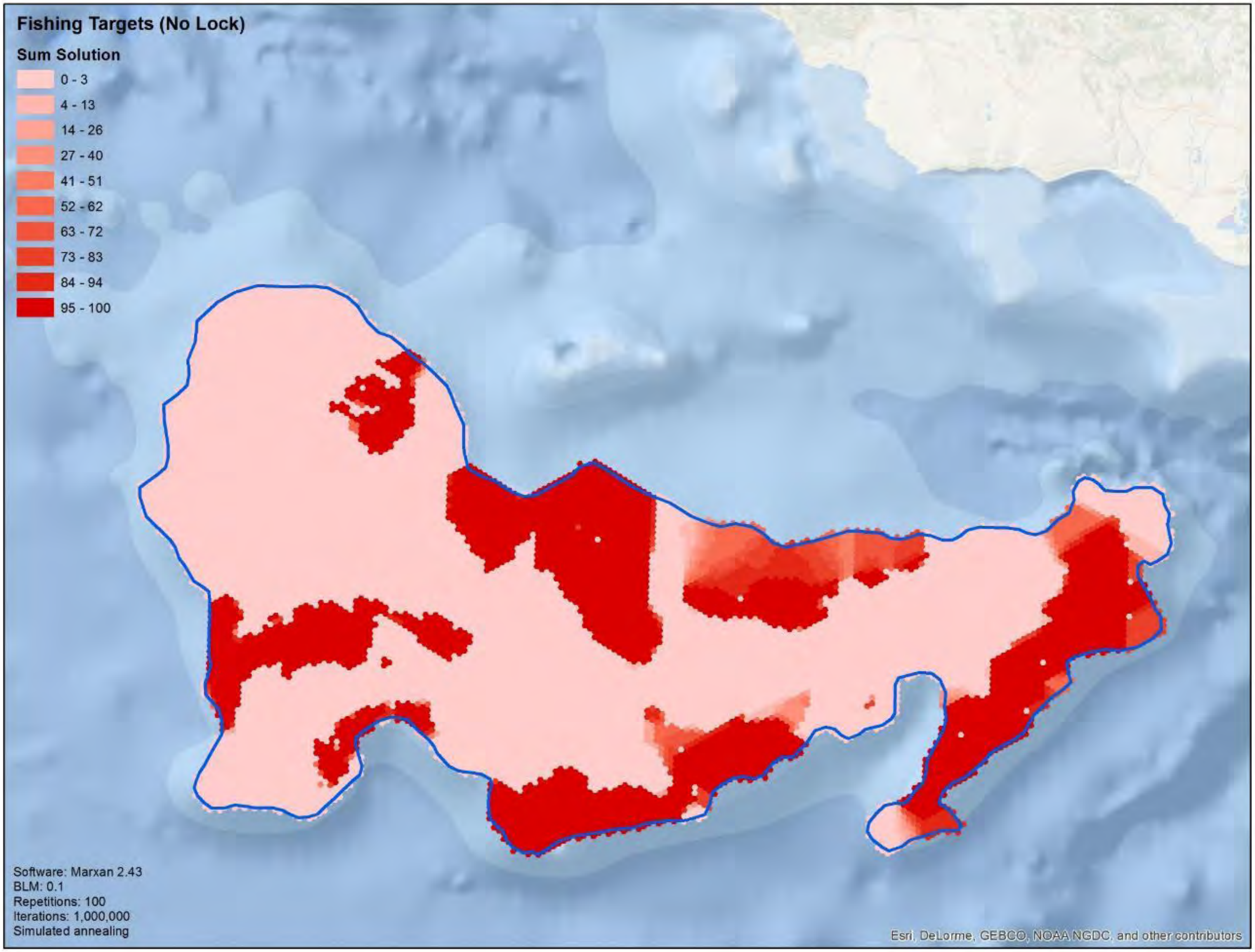
Fishing Targets (No Lock)
Sum Solution
0 - 3
4 - 13
14 - 26
27 - 40
41 - 51
52 - 62
63 - 72
73 - 83
84 - 94
95 - 100
Software: Marxan 2.43
BLM: 0.1
Repetitions: 100
Iterations: 1,000,000
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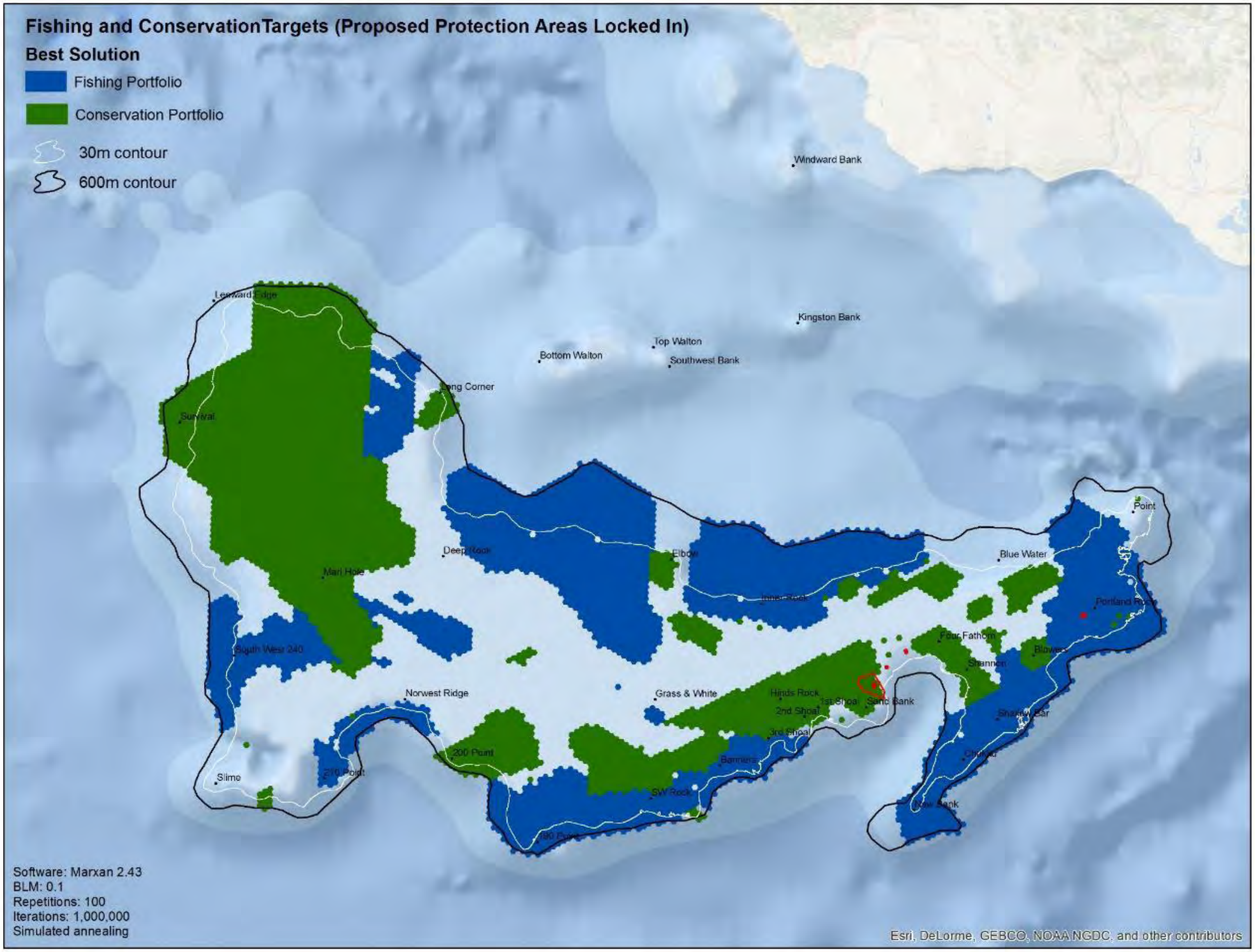
Fishing and ConservationTargets (Proposed Protection Areas Locked In)
Best Solution
Fishing Portfolio
Conservation Portfolio
30m contour
600m contour
Windward Bank
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Deep Rock
Blue Water
Norwest Ridge
Grass & White
Hinds Rock
1st Shoal
2nd Shoal
3rd Shoal
200 Point
210 Point
Slimo
SW Rock
Software: Marxan 2.43
BLM: 0.1
Repetitions: 100
Iterations: 1,000,000
Simulated annealing
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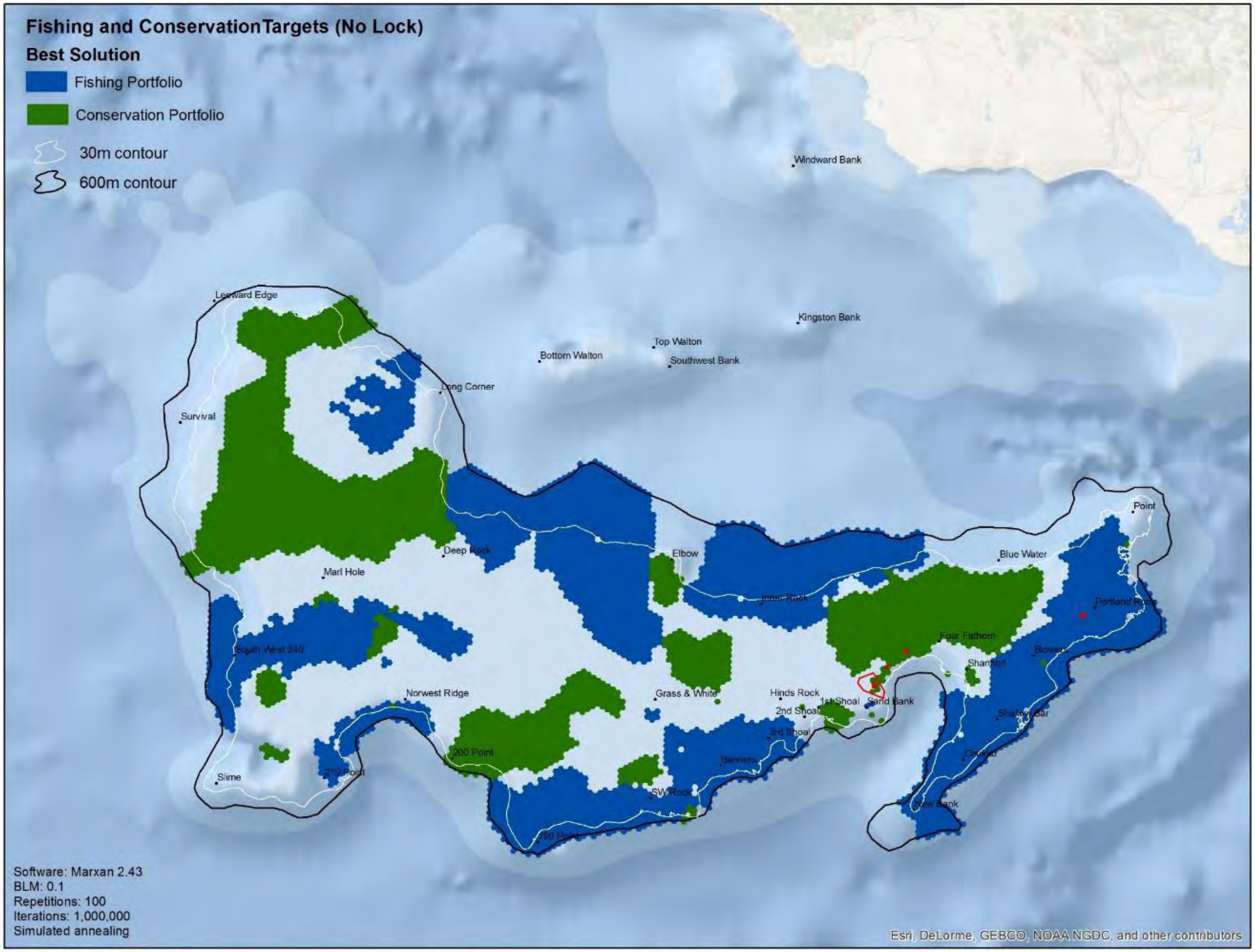
Fishing and Conservation Targets (No Lock)
Best Solution
Fishing Portfolio
Conservation Portfolio
30m contour
600m contour
Windward Bank
Kingston Bank
Top Walton
Bottom Walton
Southwest Bank
Survival
Deep Rock
Marl Hole
Elbow
Blue Water
Point
Four Fathom
Norwest Ridge
Grass & White
Hinds Rock
2nd Shoal
1st Shoal
Slime
200 Point
SW Rock
Software: Marxan 2.43
BLM: 0.1
Repetitions: 100
Iterations: 1,000,000
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