APPENDIX E

Marxan with Zones Analysis

LIST OF FIGURES

LIST OF TABLES

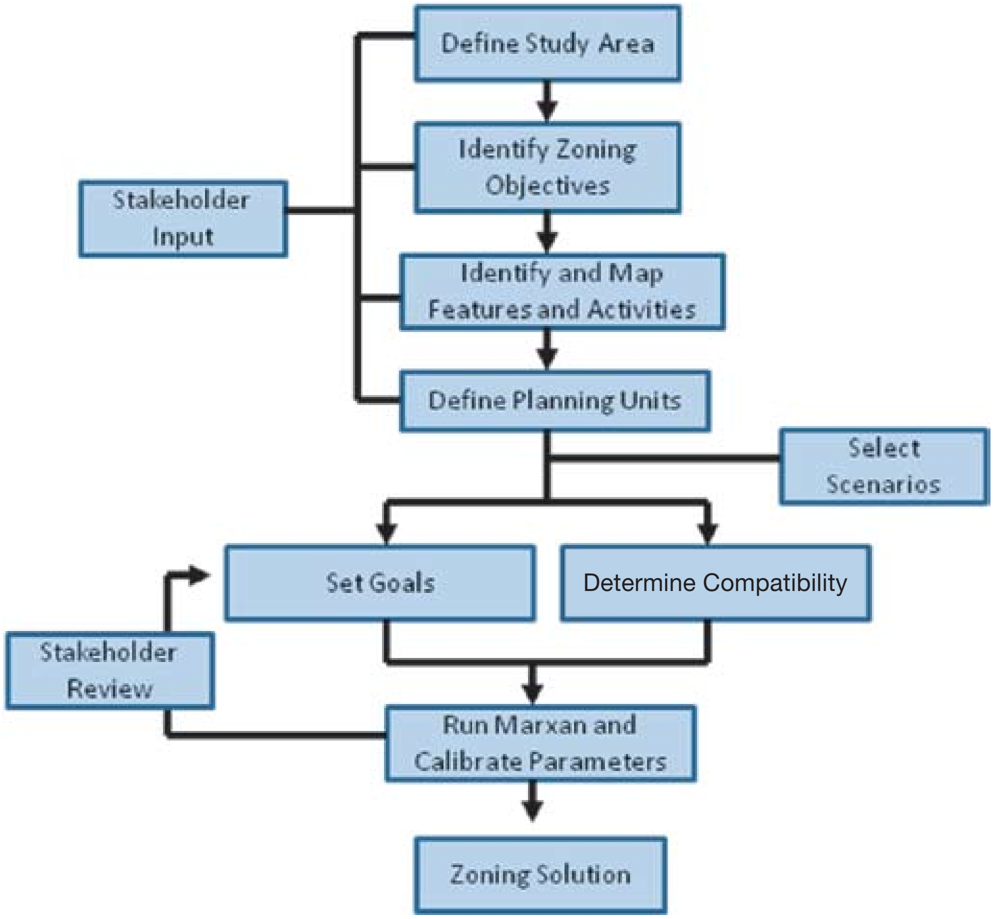


FIGURE E1. Flowchart of the process of implementing Marxan with Zones to generate possible zoning solutions.

INTRODUCTION

Marxan with Zones is an extension of the popular conservation planning decision support tool Marxan[1]. This free software allows users to consider a wide range of ecological and socioeconomic features when designing a portfolio of management areas or management approaches. Marxan is the most widely used conservation planning software in the world and it allows users to examine complex planning problems both on land and in the sea. The extension Marxan with Zones allows users to consider multiple features, objectives, or zones, within an analysis extent. In the case of multi-objective or multiple-use planning, this allows managers, decision makers, user groups, and stakeholders to spatially review tradeoffs in the planning process. Additionally, the systematic analysis allows key areas for each use or objective to be highlighted. Using Marxan with Zones in a participatory planning process illuminates important areas to each sector and facilitates the negotiation of tradeoffs in a zoning process.

Here we outline how Marxan with Zones was implemented in St. Kitts and Nevis in the eastern Caribbean to help inform the development of a multi-objective marine zoning design. We describe the inputs and parameters that were used in running the analysis and provide a brief discussion of model outputs. Figure E1 presents a flowchart of the process of implementing

[1] Ardron, J.A., H.P. Possingham, and C.J. Klein, (Eds). 2010. *Marxan Good Practices Handbook, Version 2*. Pacific Marine Analysis and Research Association, Victoria, BC, Canada. 165 pages. www.pacmara.org.

Marxan with Zones to generate possible zoning solutions. We refer the readers to Section 3.5 of the main report for a description of how analysis outputs were used to facilitate discussions with key decision makers about tradeoffs.

Model Inputs and Parameters

A zoning analysis using Marxan with Zones requires the following elements:

1. Analysis boundaries
2. Potential zone types
3. A spatial unit for the analysis
4. A specification of quantitative goals and spatial information on where they can potentially be achieved
5. A metric that summarizes factors to avoid
6. Spatial objectives that guide appropriate location of zones

The following is a description of how each of the model inputs and parameters listed above were defined for this project:

1. Analysis boundaries

   In defining the boundaries or maximum analysis extent for this project, several factors were considered. These included the jurisdictional reach of government (e.g., exclusive economic zone [EEZ]), the practical reach for enforcement activities, the location of marine activities throughout the seascape, and the existence of spatial data on marine activities and characteristics (features). Although the need for a zoning plan that extends out to the limits of the country's EEZ was recognized by both the project team and the stakeholders, the analysis extent was set to the limits of the benthic habitat map, an area extending to the 30-meter depth contour line. This area was chosen because it contains equal and uniform information across all sectors considered, an essential component of any spatial modeling effort as it helps deliver unbiased results.

2. Potential zone types

   In order to set up a Marxan with Zones run, the zone types to implement need to be defined based on knowledge of the marine area in question. Ideally the number of zones should be limited and determined in consultation with stakeholders. During the first workshop (Table 2 in main report), the four main zone types for the waters of St. Kitts and Nevis were defined as follows: i) a fishing priority zone; ii) a conservation priority zone; iii) a tourism priority zone; iv) an industrial/transportation priority zone. The overall vision that would frame activities within each of these zones was also defined at the first workshop (Appendix A).

3. A spatial unit for the analysis (planning units)

   Marxan with Zones requires that each characteristic (feature) and activity in the seascape be summarized into planning units. Planning units are a pre-defined suite of areas, typically hexagons, that house all the necessary information for Marxan with Zones. These units permit the program to run and allow comparison and selection between candidate zoning areas. Planning units must capture all the areas that can possibly be selected as part of the zoning design, and their size should be at a scale appropriate for both the ecological and socioeconomic features used as model inputs. In general, planning units should be no finer in resolution than the characteristics or activities mapped and no coarser than is realistic for management decisions. Other considerations include the number of planning units based on computing power, and the size of planning units in relation to the reliability of the mapping data for features and activities. For this project, it was determined that hexagons five hectares in size were suitable based on the scale and complexity of the input data, the spatial extent of the study area, and the computational resources for executing the model. A total of 7,651 planning units were created, covering the study area extent to the 30-meter depth contour, and storing the abundance or intensity level for each sector feature or activity at that particular location (Figure E2).

4. A specification of quantitative goals and spatial information on where they can potentially be achieved.

   Specific characteristics (features) and activities that describe the study area in question within a Marxan with Zones platform and for which spatial data exist need to be selected as model inputs. Decisions on the amount of features or activity taking place in each zone (goals) also need to be made. Table E3 presents a list of spatial information selected to represent the study area in St. Kitts and Nevis. The choice of goals implemented in this analysis (Table E2) was guided by discussions with in-country partners, both at the first workshop outlined above and during informal meetings.

5. A metric that summarizes factors to avoid

   Different activities may affect each other, in addition to affecting ecosystem characteristics. These interactions are described in what is often called a cost matrix. The values in this matrix will ultimately influence where (i.e., which planning units) goals should be achieved. These values are used by Marxan with Zones to help identify and allocate an optimal selection of planning units to each zone, achieving the zone's goals at the minimum "cost." This optimal selection is referred to as the most efficient solution. For example, for a planning unit with a high cost of a specific activity, Marxan with Zones will try to avoid assigning a zone for that activity to that particular planning unit.

   Another way to consider these values is as a measure of potential conflict between marine features, activities, or interests. The cost, or in the St. Kitts and Nevis case, compatibility measures were generated at a stakeholder workshop (Table 2 in main report). Workshop participants reviewed each feature or activity to assess its compatibility with others. Based on group consensus, the interaction between each feature and/or activity was assigned one of four compatibility classes (Compatible, Somewhat Compatible, Rarely Compatible, and Incompatible) and entered into a compatibility matrix (Table 4 in main report). This matrix was used to create a series of GIS-based compatibility surfaces that were modeled for each marine-based feature and activity used in the project. These compatibility maps helped stakeholders visualize the level of compatibility between each feature or activity. For example, an area designated as a ferry route would have a low compatibility with a fishing area, while an area often used for snorkeling would have a higher compatibility score with coral reef conservation. Compatibility scores were assigned to each planning unit by taking the average value within the boundaries of the planning unit for each of the modeled compatibility surfaces. When attempting to meet the goals for each zone, Marxan with Zones uses the cost value of each planning unit as a

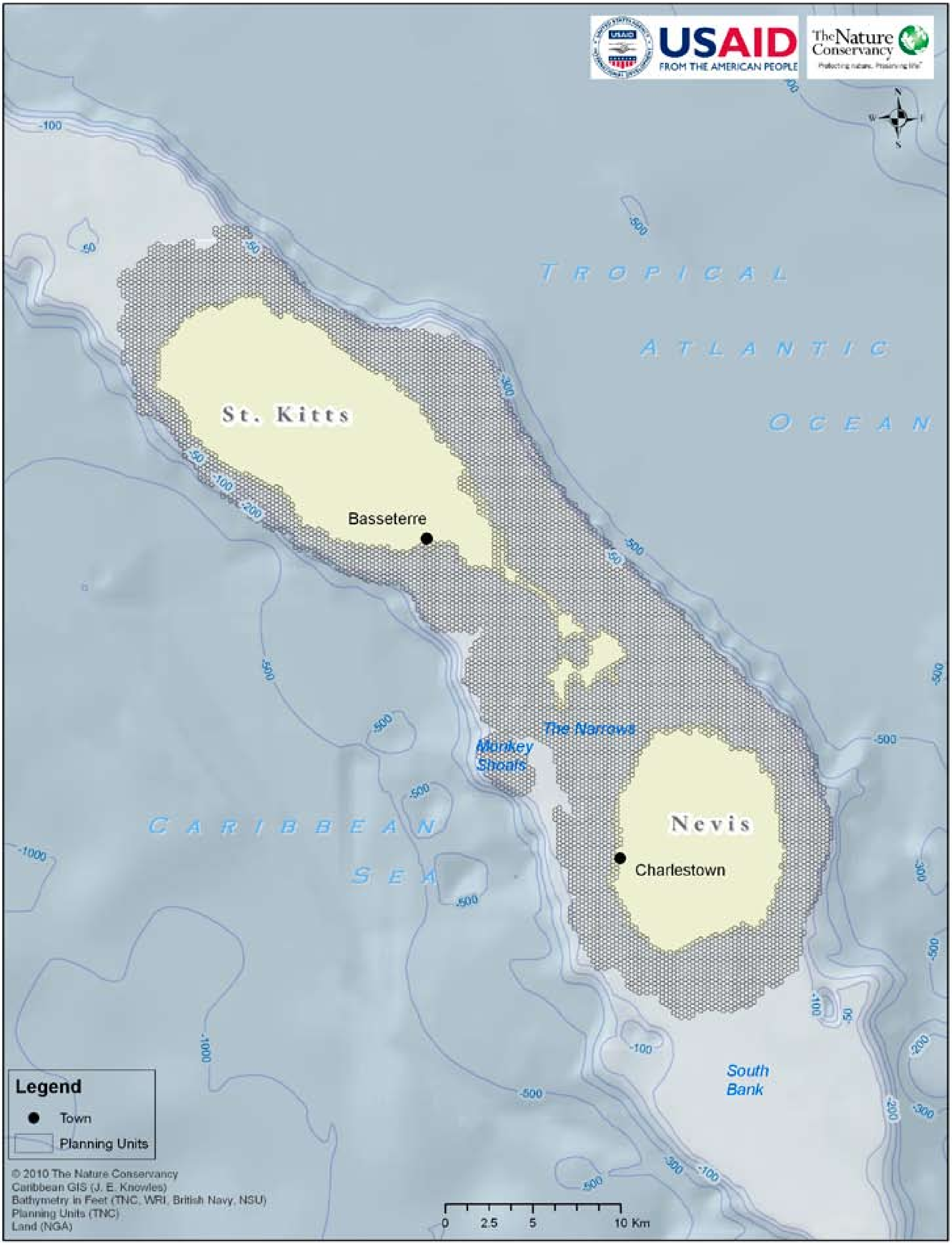


FIGURE E2. Planning units.

constraint for selecting the most optimal zoning configuration. In other words, the final zoning solutions represents an attempt to minimize the conflict by selecting the fewest planning units with the lowest total unit cost while meeting each of the pre-determined zone goals.

6. Spatial objectives that guide appropriate location of zones (zone boundary cost)

How fragmented a specific zone is has an impact on how costly implementing that zone will be from both an ecological as well as management perspective. Exploring the impact of varying levels of fragmentation is achieved by calibrating a parameter representing compactness (zone boundary cost). Too little compactness leads to highly fragmented zones that are unmanageable. Too much compactness results in an overly large and inefficient zoning design. Calibration makes it possible to find the most mathematically efficient value for zone boundary cost. The zone boundary cost can also function to encourage further separation of conflicting uses or to cluster zones that share compatible management objectives. This can be useful when trying to buffer potential conflict between activities taking place in different zones such as conservation and fishing.[2] Optimal parameters for spatial compactness and buffering of zones were derived through a calibration process as described in the *Marxan with Zones User Guide*.[3]

TABLE E1. Zone boundary cost values used in all scenarios.

Zone Objective	Fishing	Conservation	Tourism	Industrial/ Transportation
Fishing	0			
Conservation	100000	0		
Tourism	300	300	0	
Industrial/Transportation	300	300	300	0

Scenarios

After calibration and in order to assess the impact of different decisions on the potential configuration of zones, some of the parameters described above were modified to generate different scenarios. Three zoning scenarios were implemented in this analysis, each with different zone-specific requirements as defined in Table E2. For each of the scenarios, Marxan with Zones was run using 100 repetitions, each repetition having 1 million iterations. These scenarios were chosen to represent a variety of potential planning perspectives, so as to best assist decision makers in considering trade-offs and variations in zoning design.

Scenario 1: Flat 30 Goal Lock. In the first scenario, a flat goal of 30% was assigned to both the fishing and conservation zones. This means the model was asked to locate the most optimal 30% of the fishing activities and benthic habitats based on the distribution of these features and corresponding underlying constraints. This scenario was an attempt to identify

[2] Watts, M. E., C.J. Klein, R. R. Stewart, I. R. Ball, and H. P. Possingham. 2008. Marxan with Zones (V1.0.1): Conservation Zoning Using Spatially Explicit Annealing, A Manual. University of Queensland, Brisbane. http://www.uq.edu.au/marxan.

[3] Watts, M. E., I. A. Ball, R. S. Stewart, C. J. Klein, K. Wilson, C. Steinback, R. Lourival, L. Kircher, and H. P. Possingham. 2009. Marxan with Zones: Software for optimal conservation based land- and sea-use zoning. Environmental Modelling & Software 24(12):1513–1521.

the highest priority fishing and conservation areas by constraining the model to identify the top 30% of fishing activities and benthic habitats for each zone. For this scenario, all tourism and industrial/transportation activities were "locked" into the best solution, since these activities are largely constrained to discrete locations (e.g., hotel areas, ferry lanes) and represent a relatively small spatial footprint on the marine environment. In other words, these areas were automatically assigned to their corresponding zones and not made available for possible selection into other zones. Because these planning units were locked into their respective zones, they were not considered candidate sites for meeting fishing and conservation goals.

Scenario 2: Flat 60 Goal No Lock. In the second scenario, no planning units were locked into predefined zones, permitting the model to freely choose among all planning units for allocating the optimal zone configuration based on a flat 60% goal assigned across all zone activities and features.

Scenario 3: Variable Goals Reduced Lock. In the third scenario, different goals were assigned to each activity or feature based on consultation with in-country partners and stakeholders during the first workshop and informal meetings. Many of the recommended goals were very high (i.e., 90-100%) and consequently the software had trouble finding a solution that would meet all goals. In order to allow the software to adequately meet the goals in the output solution, all goals that were 90% or above were reduced by 20%. As in the first scenario, both the tourism and industrial/transportation activities were locked in.

TABLE E2. Scenarios used in Marxan with Zones and associated run parameters.

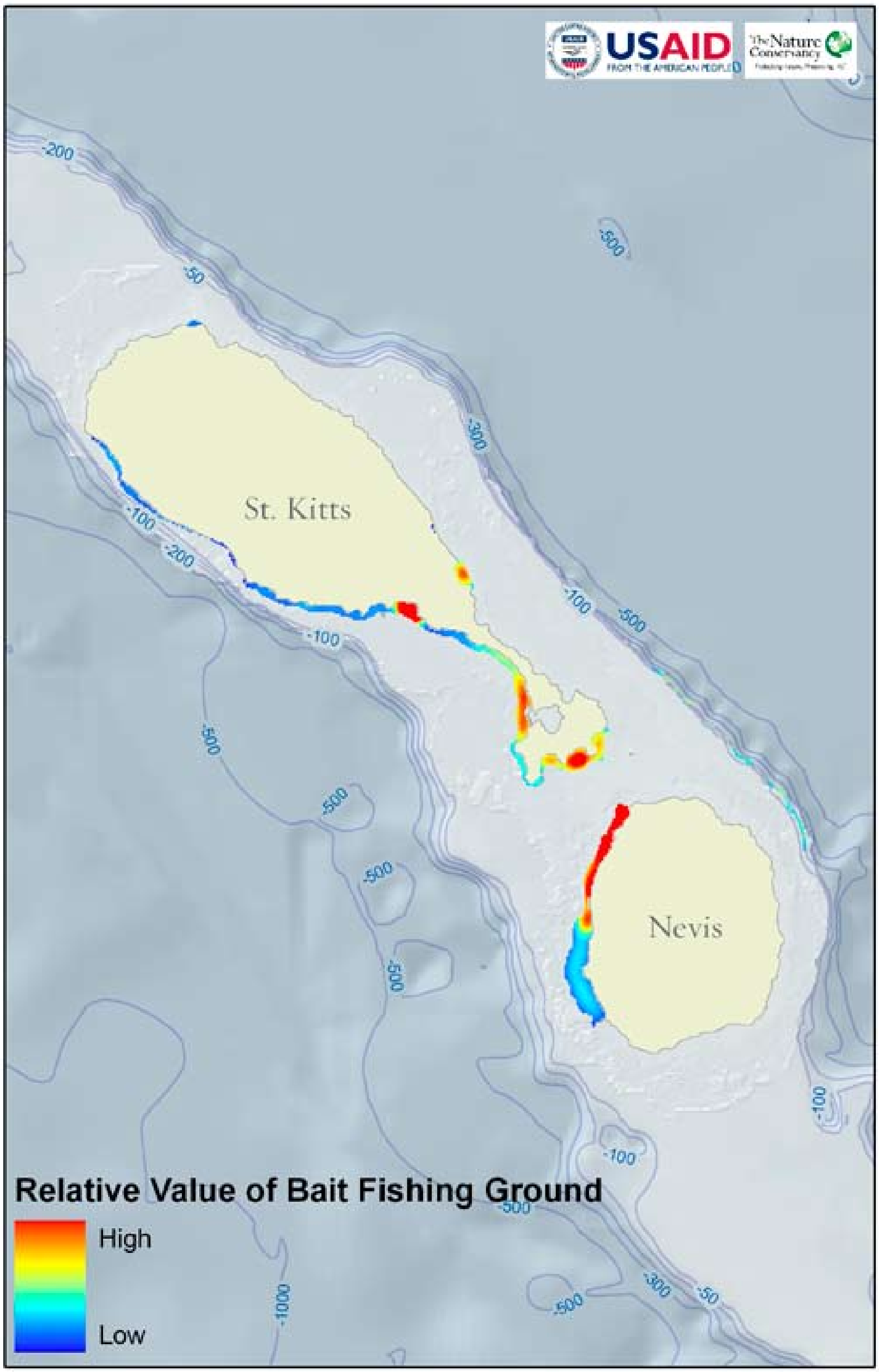
Scenario	# Runs	Goals	Locked	Goals Met?
1. Flat 30 Goal - Lock	100	30% for fishing and conservation objectives	Tourism and Industrial/ Transportation objectives	Yes
2. Flat 60 Goal - No Lock	100	60% for all objectives	No objectives locked	Yes
3. Variable Goals Reduced - Lock	100	Tourism Anchoring 50% Tourism Mooring 60% Tourism Swimming/Snorkeling 80% Tourism Scuba Diving 80% Tourism Jet Ski 80% Tourism Surfing 15% Tourism Kite Boarding 80% Tourism Wind Surfing 15% Tourism Bird Watching 70% Fishing Coastal Pelagics 70% Fishing Coastal Demersals 70% Fishing Demersal Shelf 70% Fishing Lobster 70% Fishing Conch 70% Fishing Bait 70% Conservation Coastal Lagoons 60% Conservation Coral Reef Good 80% Conservation Coral Reef Poor 30% Conservation Mangroves 60% Conservation Sandy Bottom 40% Conservation Seagrass Dense 20% Conservation Seagrass Sparse 20% Conservation Turtle Nesting Sites 70% Conservation Nursery Areas 60% Transportation Cruise Ship Port 20% Industrial Ports 20% Industrial Geothermal Vents 15% Industrial Sand Mining 15%	Tourism and Industrial/ Transportation objectives	Yes

BLM = Boundary Length Modifier, used for specifying the level of compactness of solutions.
# Runs = Number of repeat independent runs in Marxan using identical parameters. In other words, the number of solutions Marxan generates.

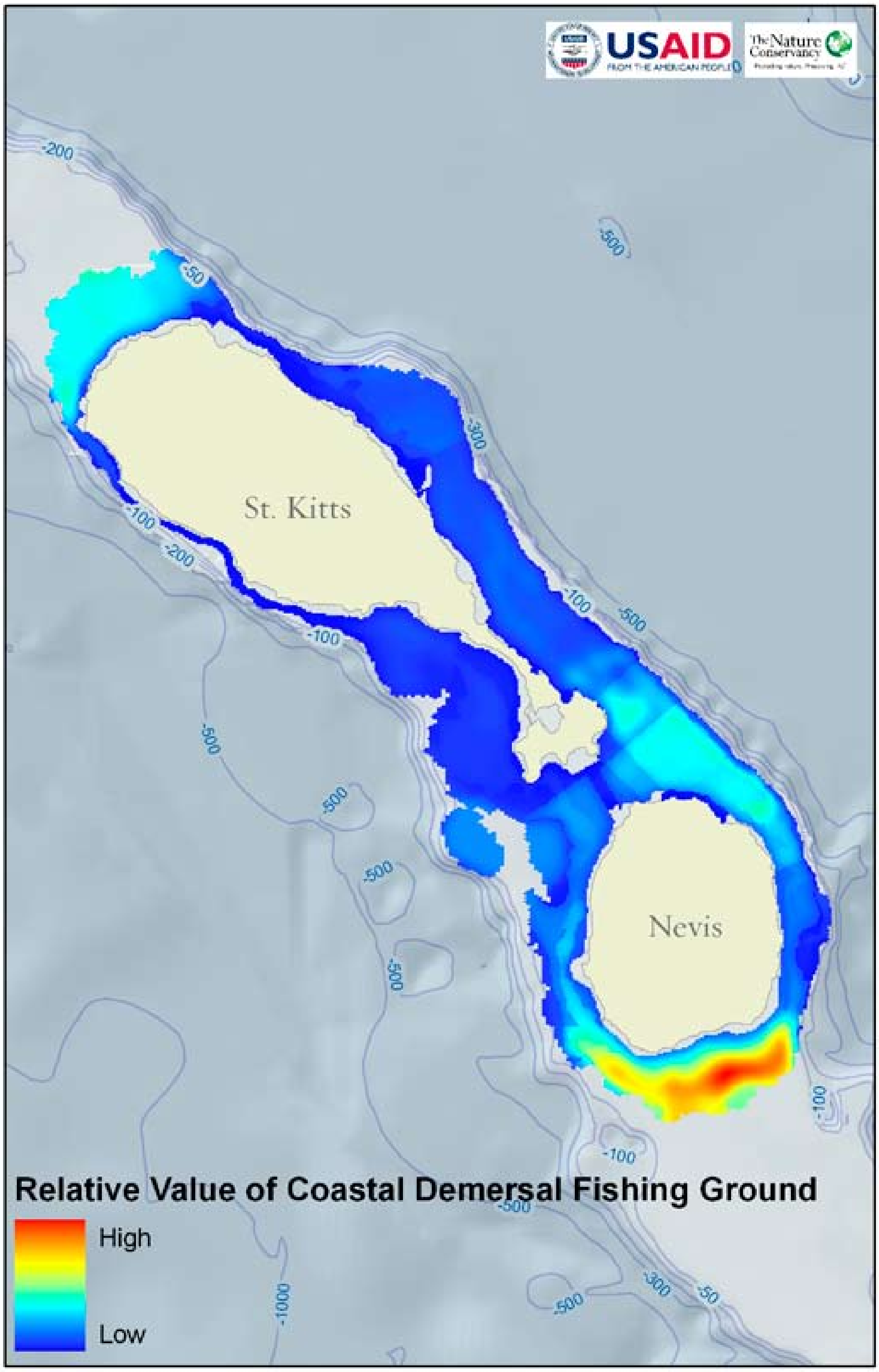
Data Inputs and Outputs

A Marxan with Zones analysis generates a number of mapped products and results, which are useful for understanding the complexity of interactions between uses and to assist the decision-making process. Here we include a series of maps that depict all model inputs and outputs (Figures E3-E7).

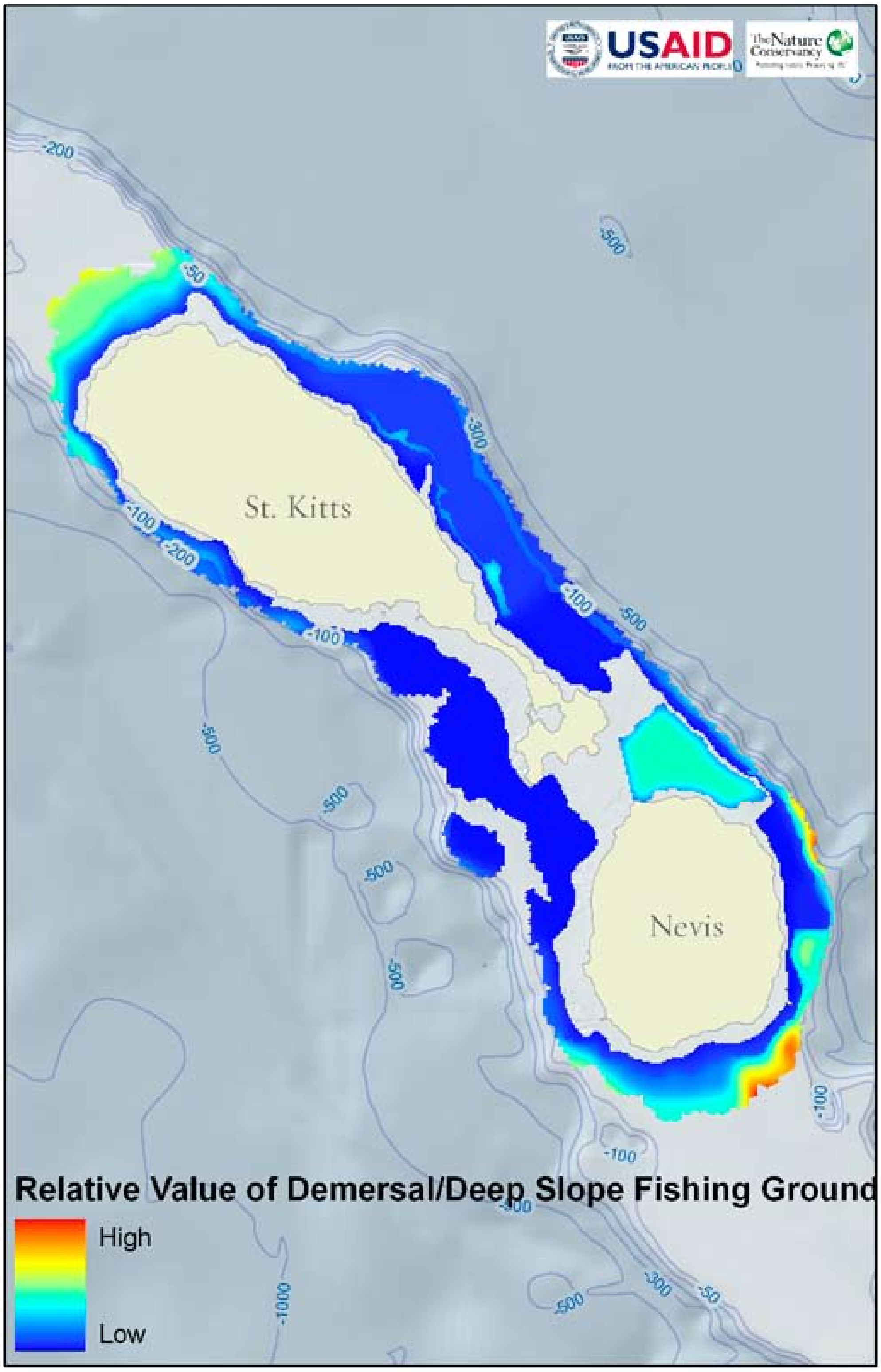
FIGURE E3. Features and Activities: These maps show the spatial distribution of all marine-based features and activities that were used in this analysis. These features and activities were summed at the planning-unit level for use in the model.



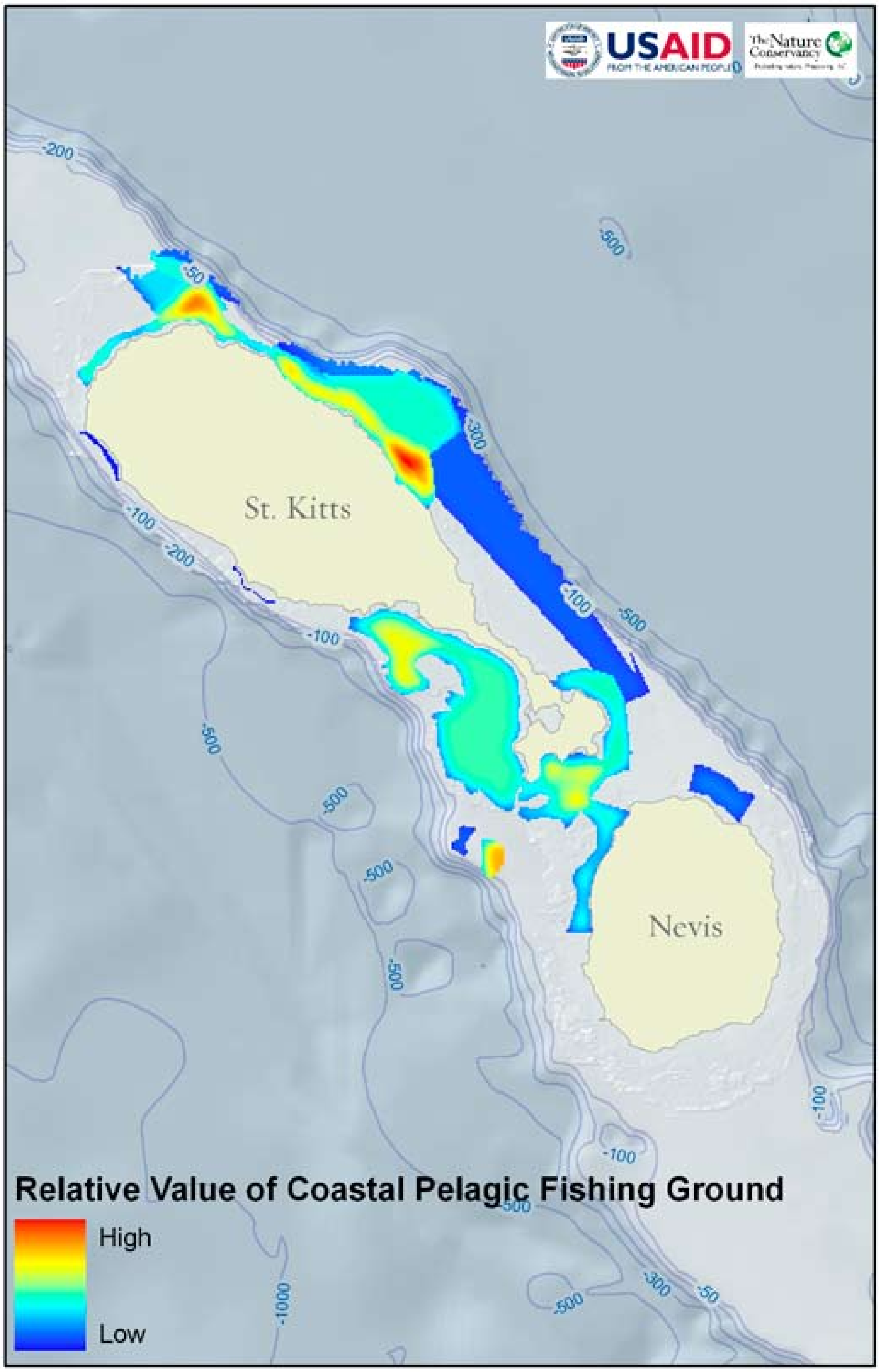
(a) Fishing Activity – Bait Fishing: The relative value of bait fishing grounds (based on fisher surveys) in St. Kitts and Nevis used for modeling fishing-priority zones. Areas in red and yellow indicate areas where bait fishing is most likely to take place.



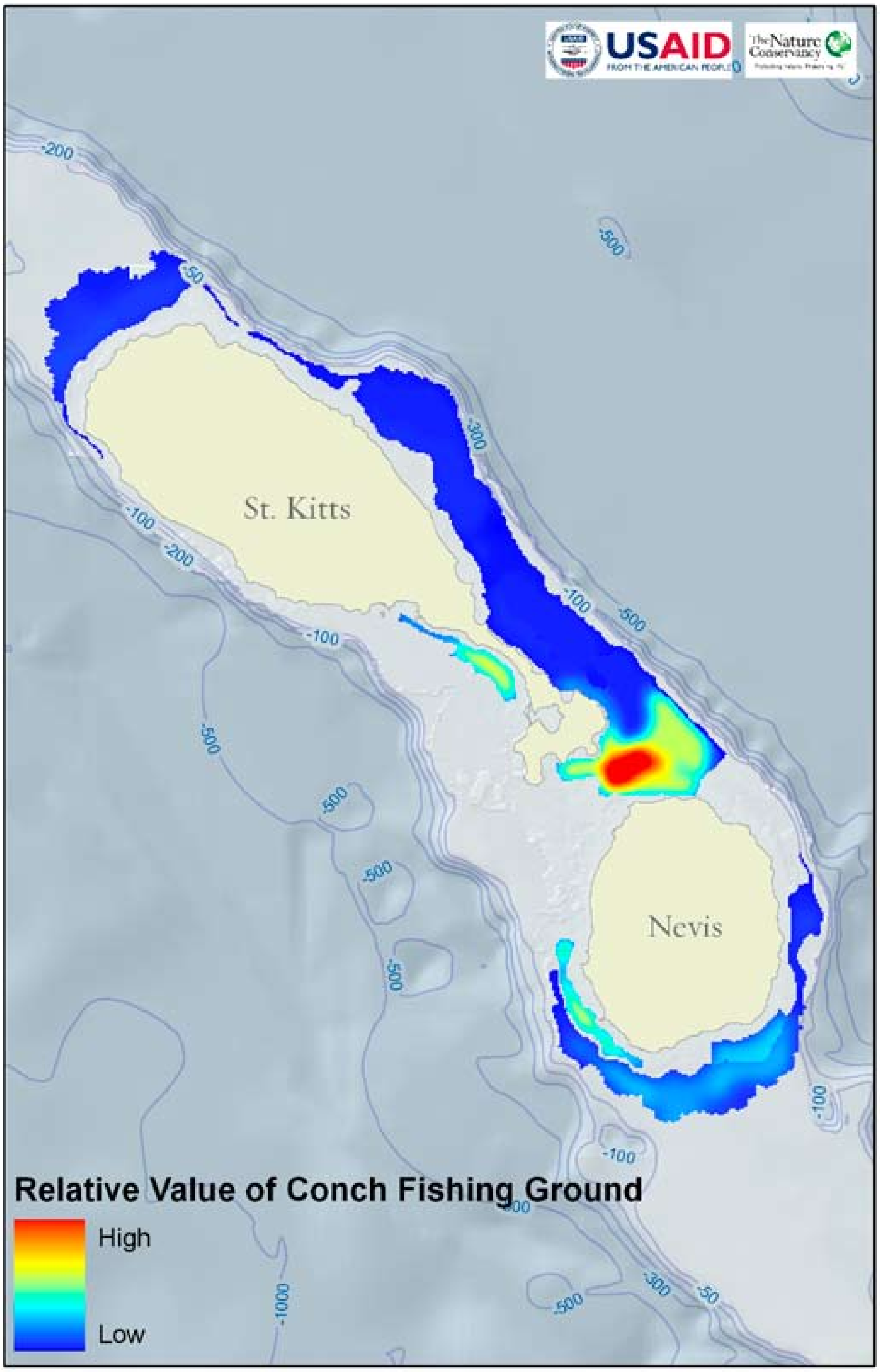
(b) Fishing Activity – Coastal Demersal Fishing: The relative value of coastal demersal fishing grounds (based on fisher surveys) in St. Kitts and Nevis used for modeling fishing-priority zones. Areas in red and yellow indicate areas where coastal demersal fishing is most likely to take place.



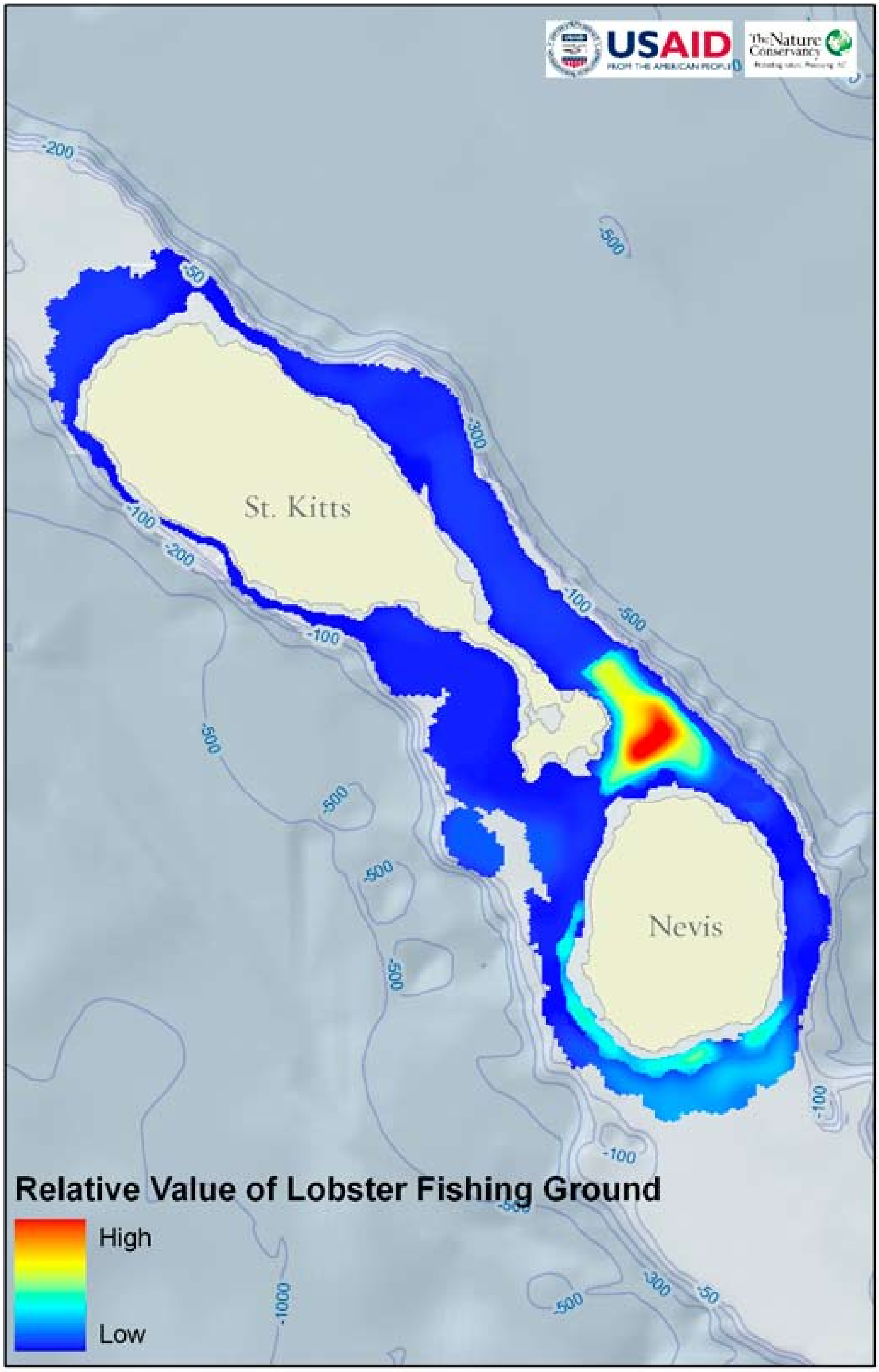
(c) Fishing Activity – Demersal/Deep Slope Fishing: The relative value of demersal/deep-slope fishing grounds (based on fisher surveys) in St. Kitts and Nevis used for modeling fishing-priority zones. Areas in red and yellow indicate areas where demersal/deep-slope fishing is most likely to take place.



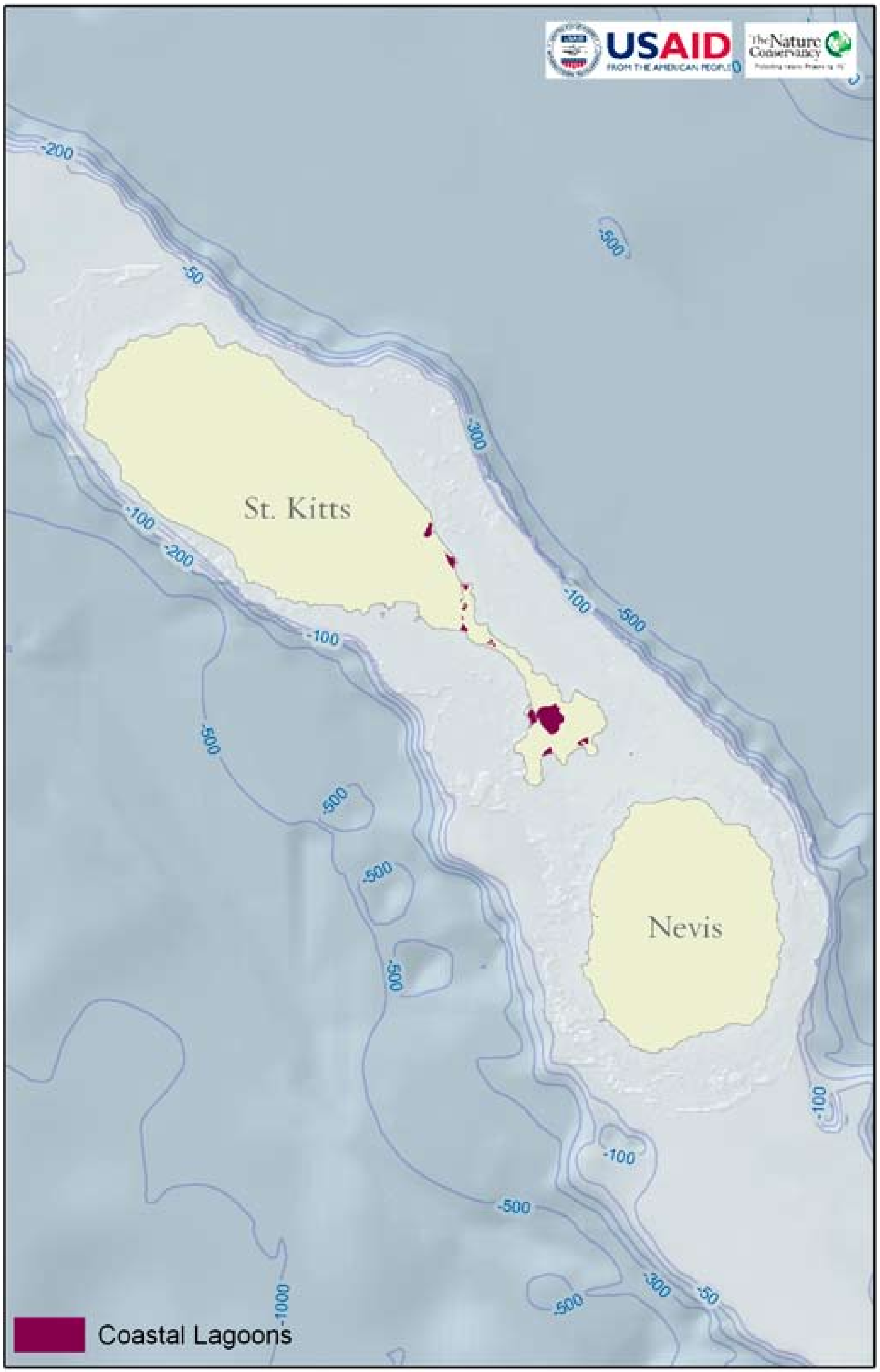
(d) Fishing Activity – Pelagic Fishing: The relative value of pelagic fishing grounds (based on fisher surveys) in St. Kitts and Nevis used for modeling fishing-priority zones. Areas in red and yellow indicate areas where pelagic fishing is most likely to take place.



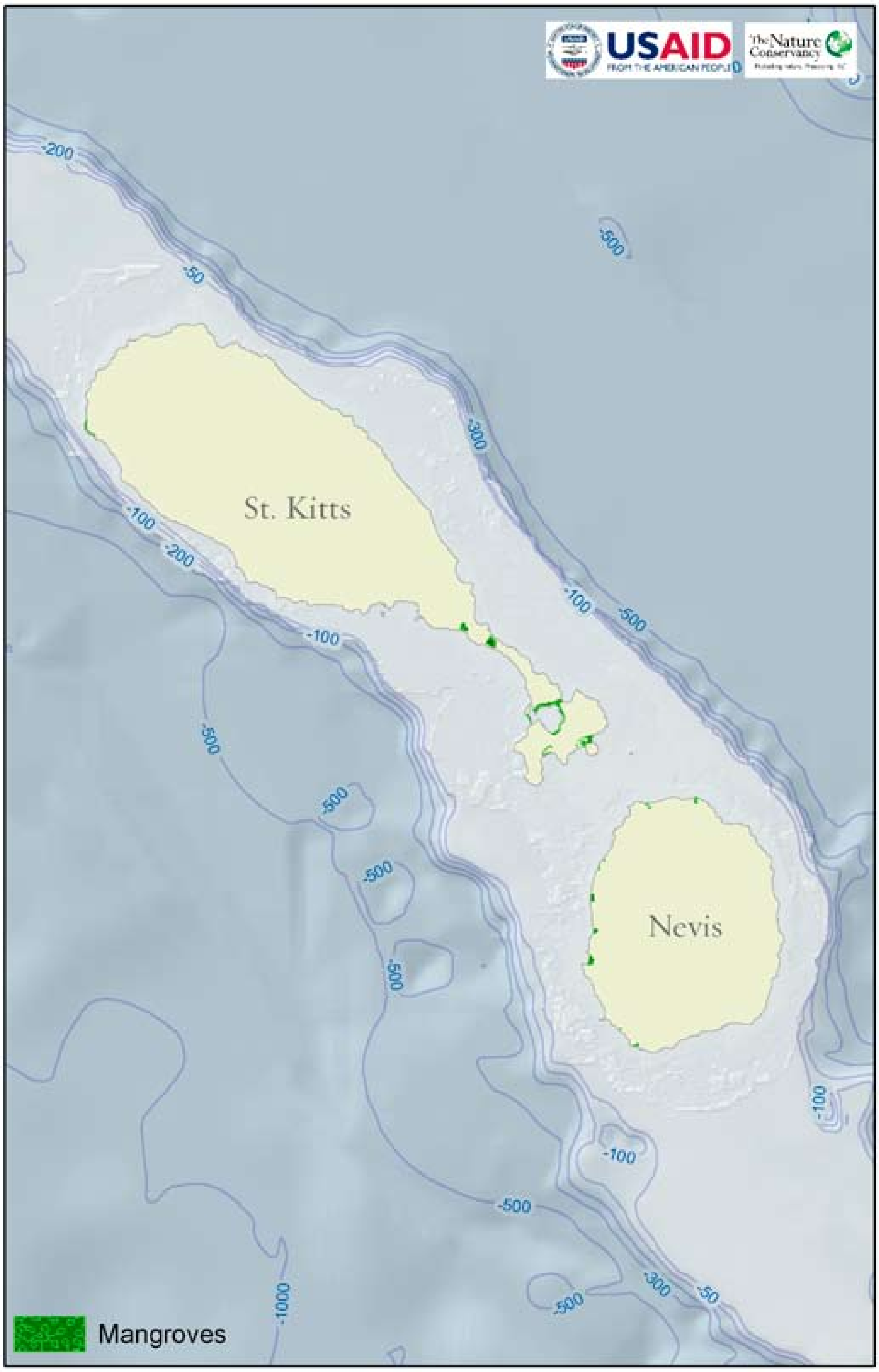
(e) Fishing Activity – Conch Fishing: The relative value of conch fishing grounds (based on fisher surveys) in St. Kitts and Nevis used for modeling fishing-priority zones. Areas in red and yellow indicate areas where conch fishing is most likely to take place.



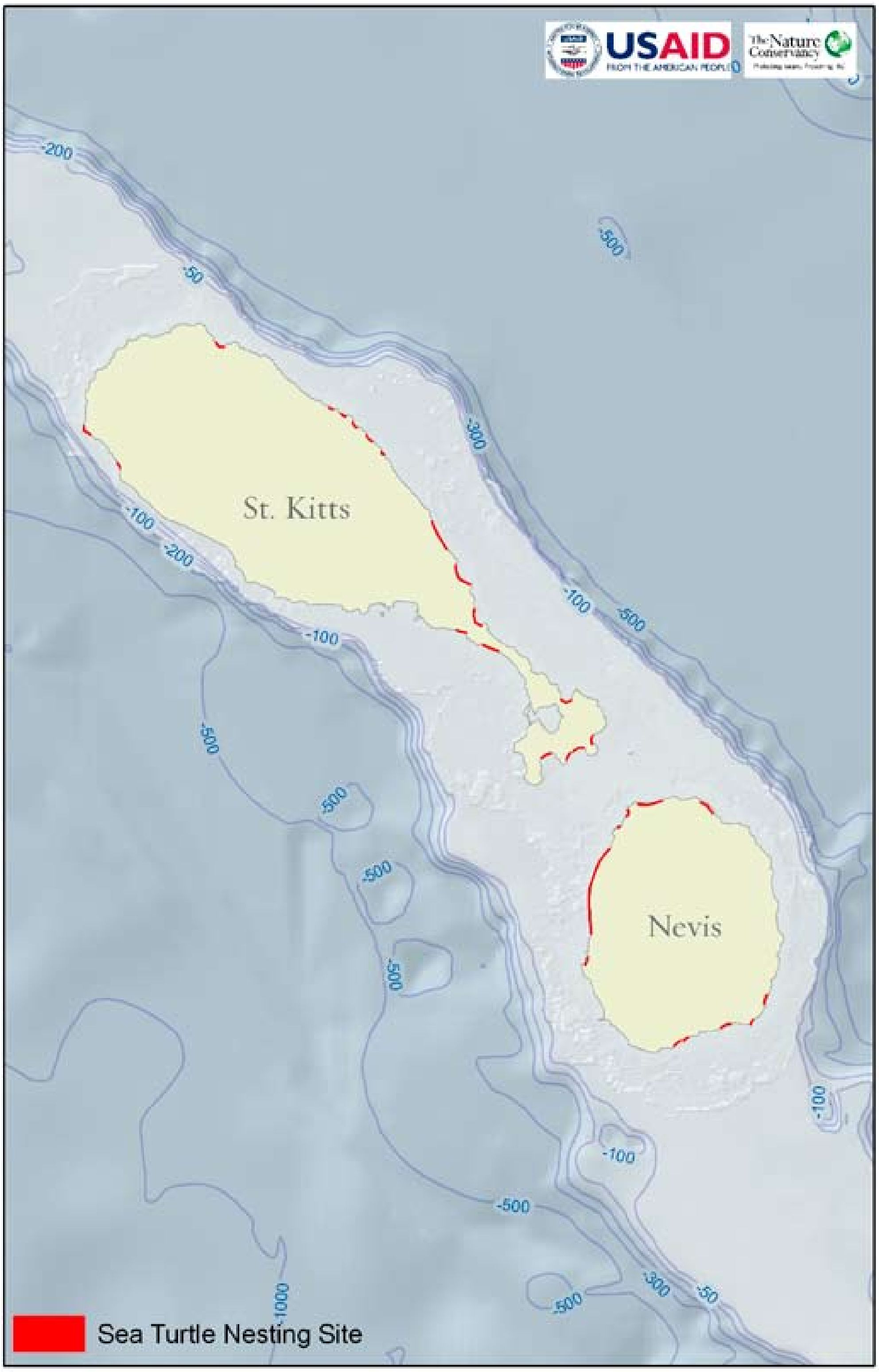
(f) Fishing Activity – Lobster Fishing: The relative value of lobster fishing grounds (based on fisher surveys) in St. Kitts and Nevis used for modeling fishing-priority zones. Areas in red and yellow indicate areas where lobster fishing is most likely to take place.



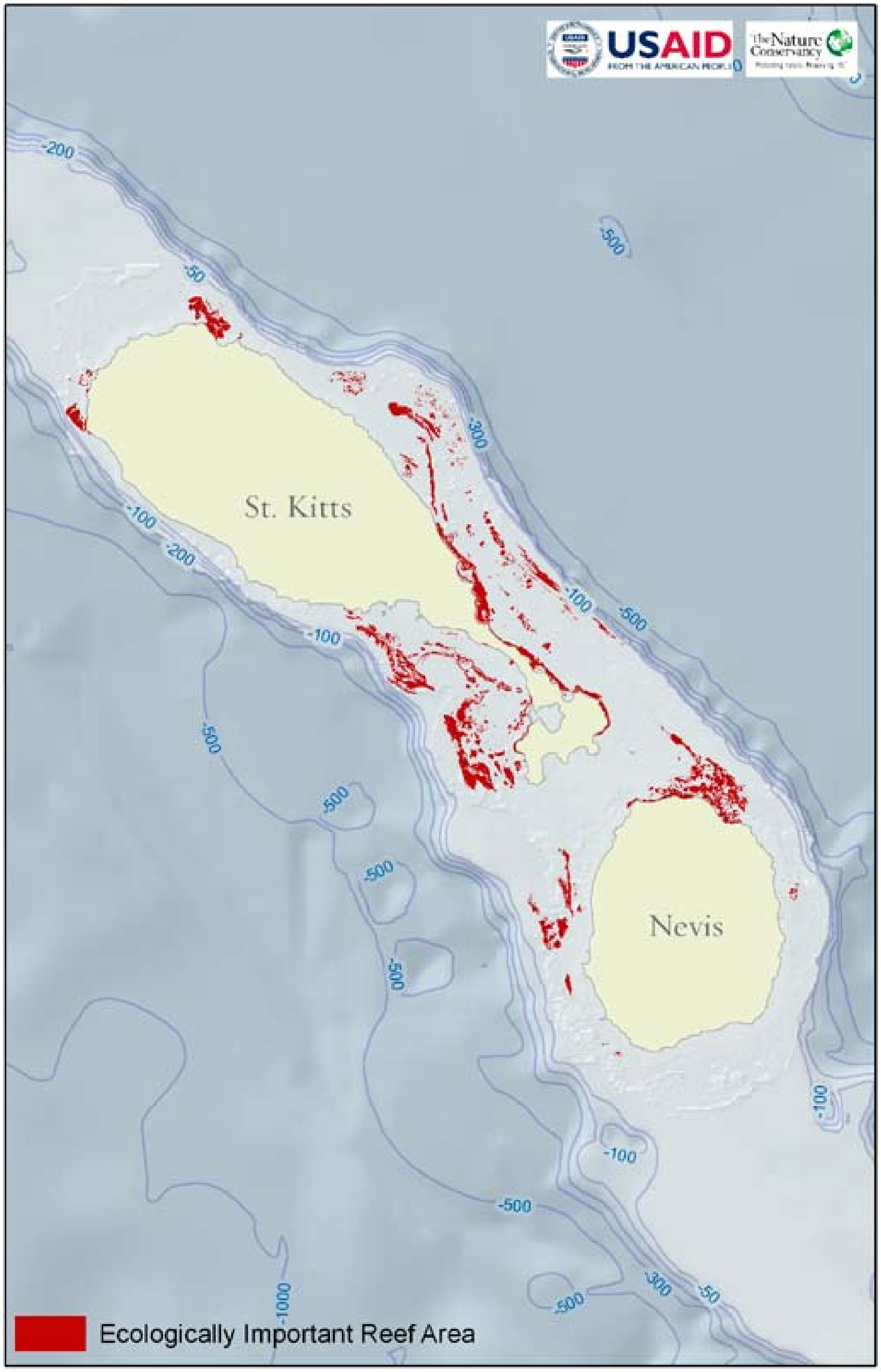
(g) Conservation Feature – Coastal Lagoons: Location of coastal lagoons in St. Kitts and Nevis.



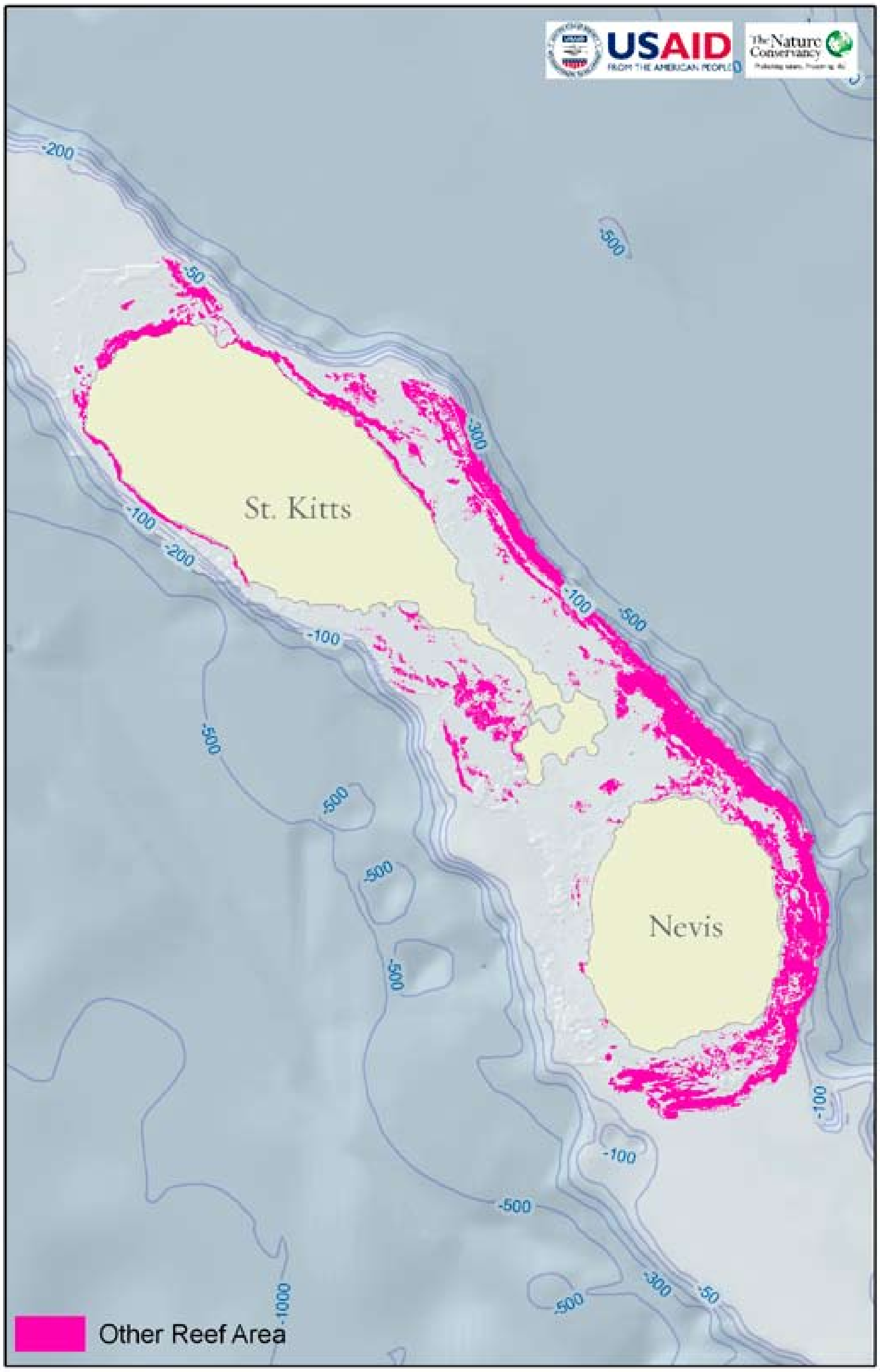
(h) Conservation Feature – Mangroves: Location of mangroves in St. Kitts and Nevis.



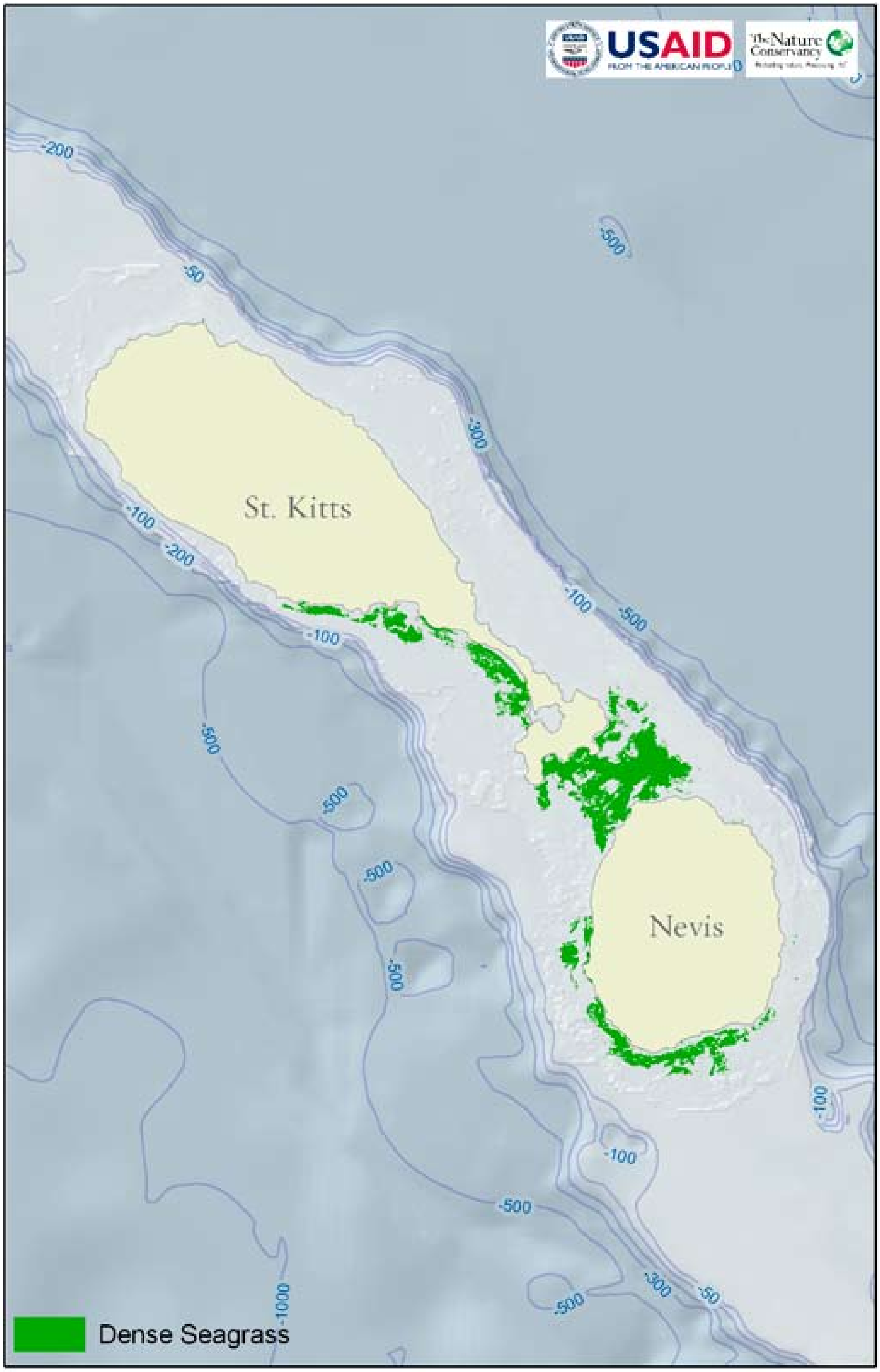
(i) Conservation Feature – Sea Turtle Nesting Sites: Location of important sea turtle nesting sites in St. Kitts and Nevis.



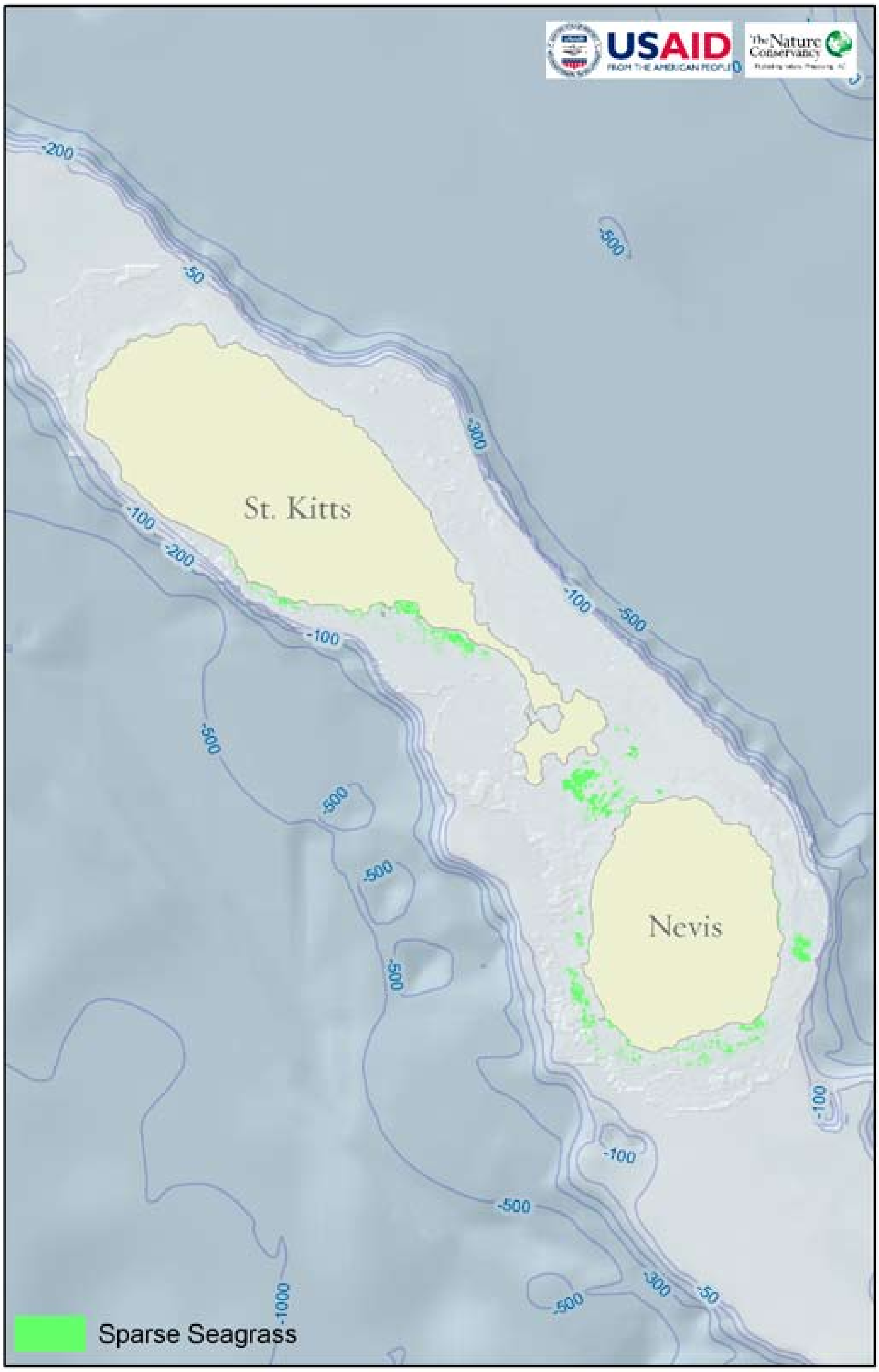
(j) Conservation Feature – Ecologically Important Reefs: Location of ecologically important reefs in St. Kitts and Nevis.



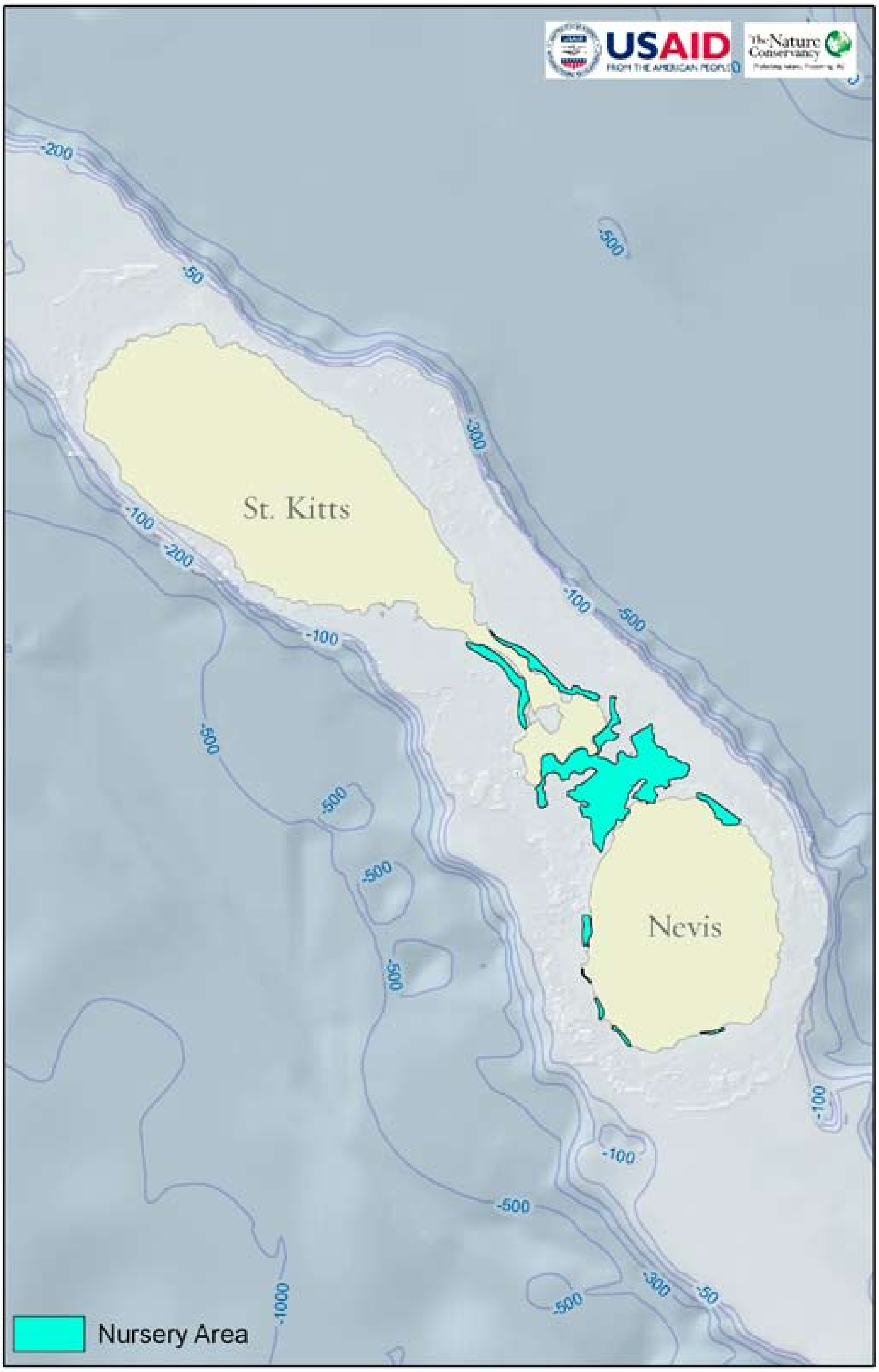
(k) Conservation Feature – Other Reefs: Location of other reef areas in St. Kitts and Nevis.



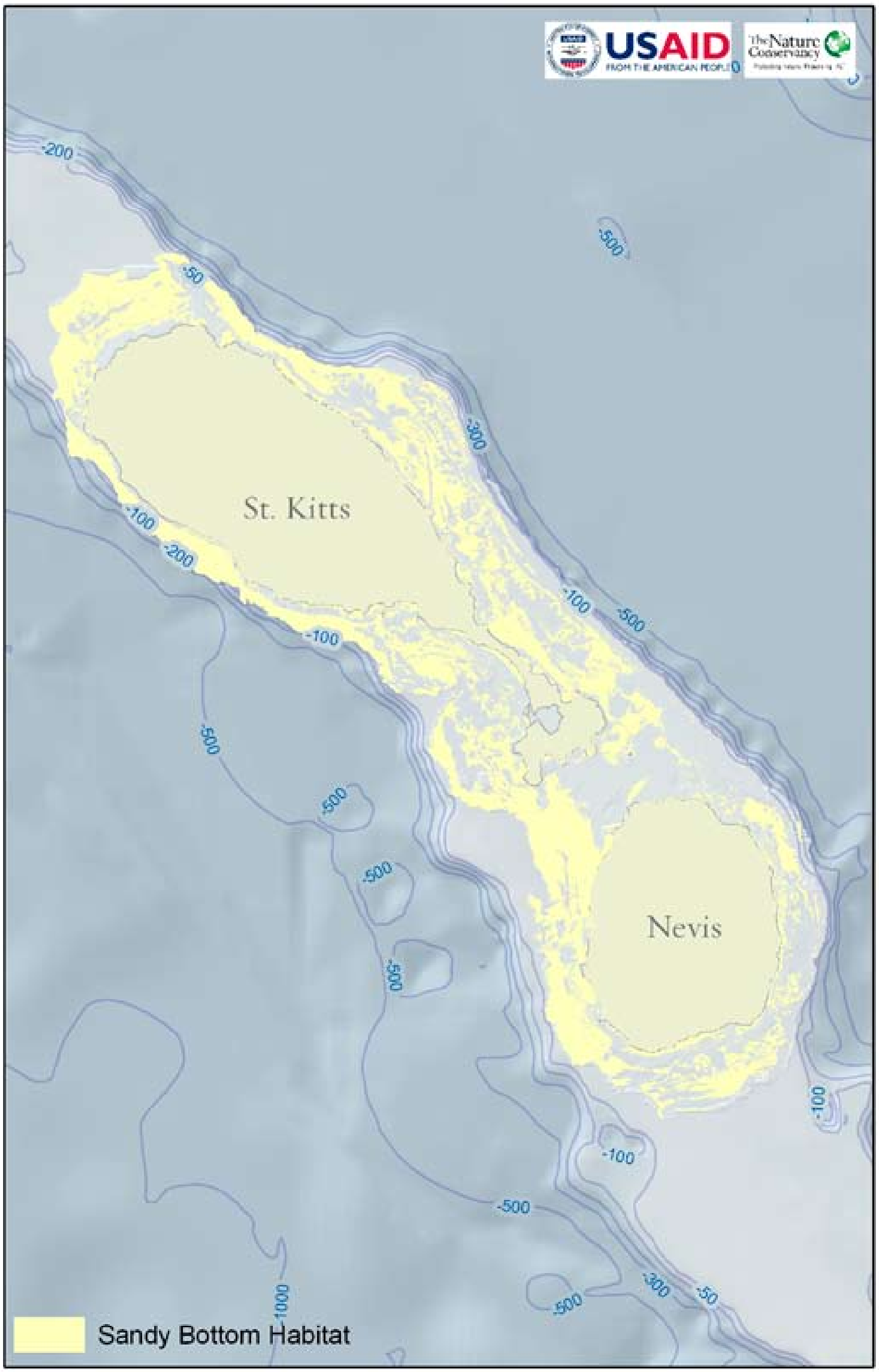
(l) Conservation Feature – Dense Seagrass: Location of dense seagrass in St. Kitts and Nevis.



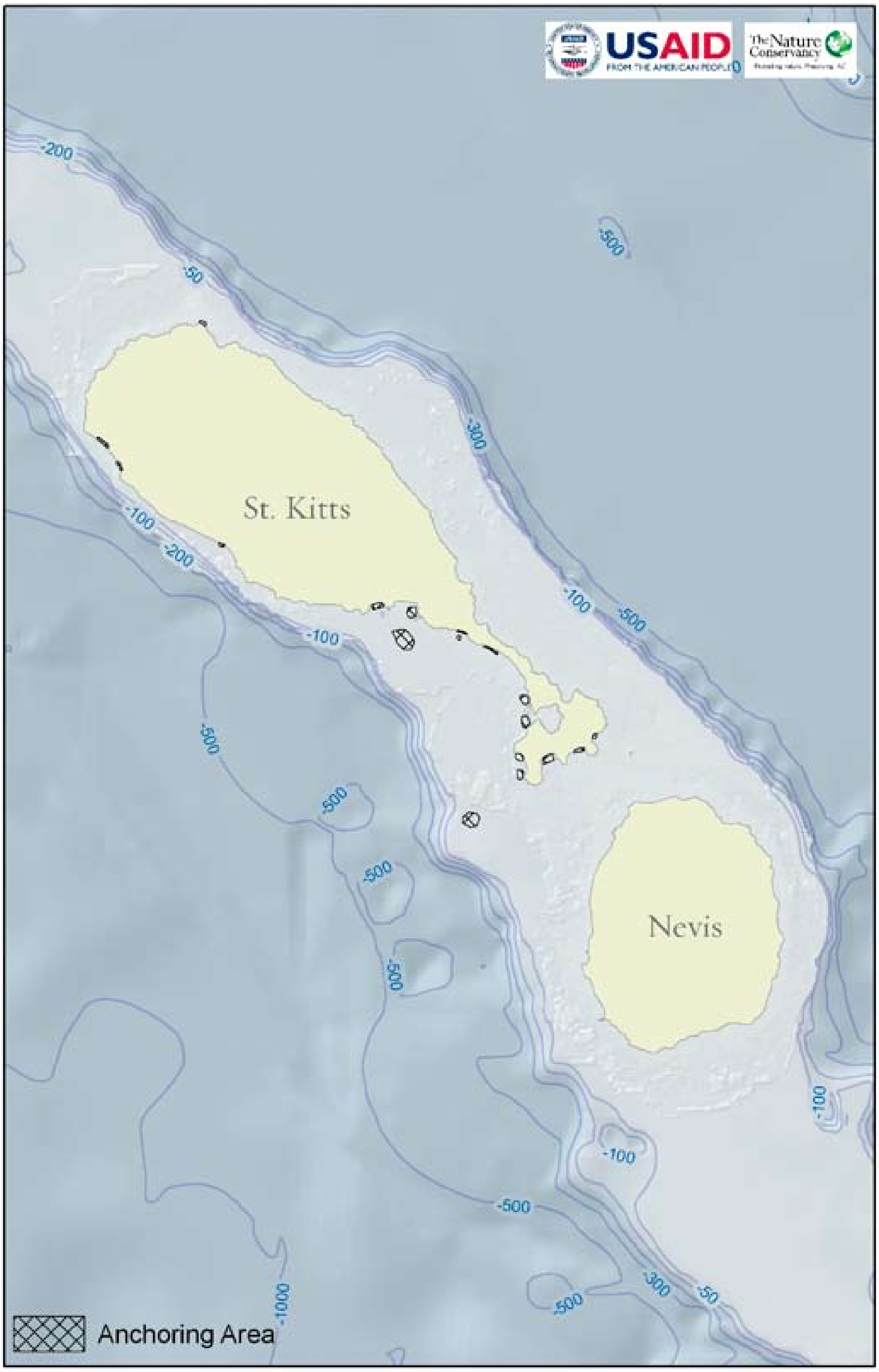
(m) Conservation Feature – Sparse Seagrass: Location of sparse seagrass areas in St. Kitts and Nevis.



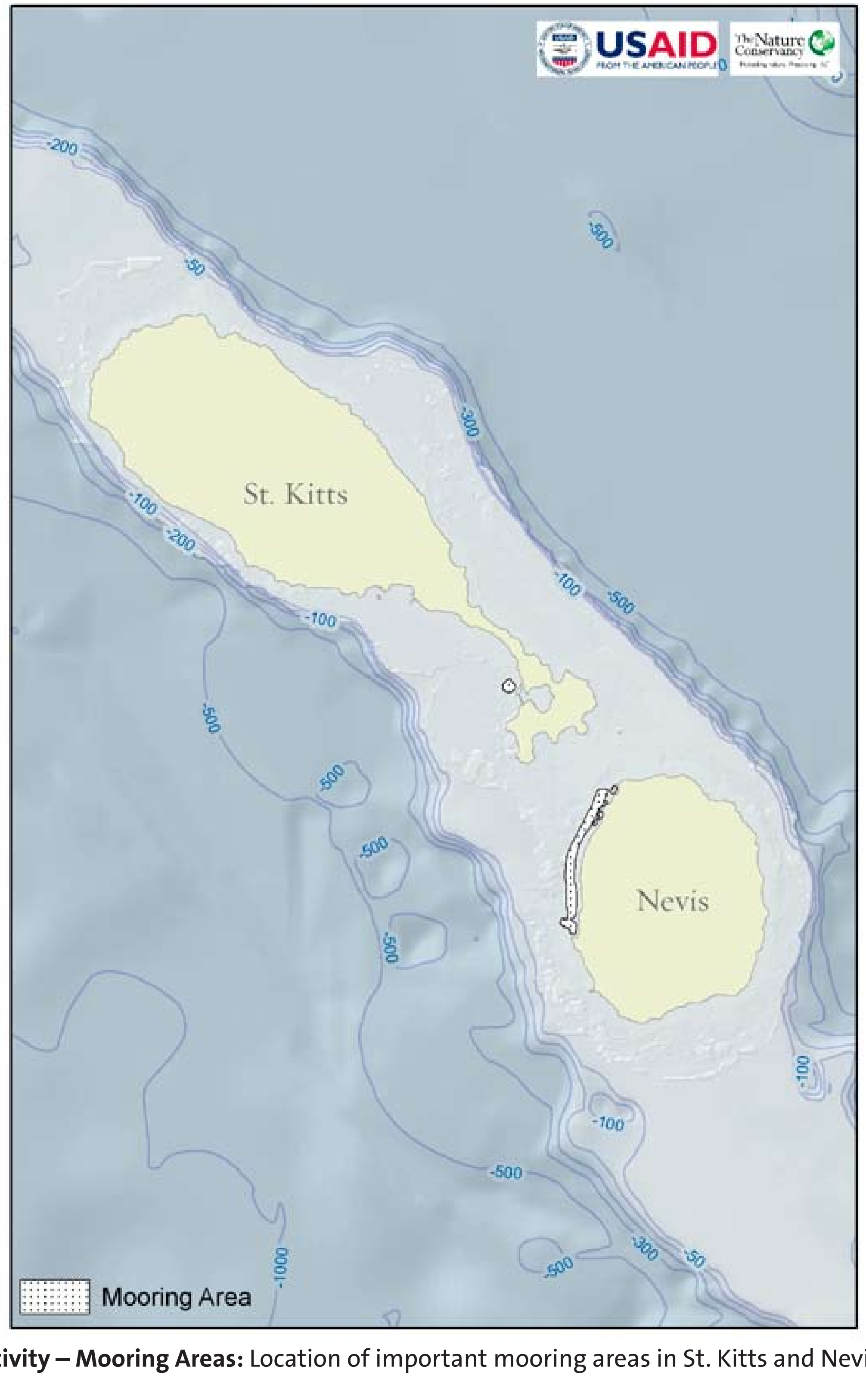
(n) Conservation Feature – Nursery Areas: Location of important fishery nursery areas in St. Kitts and Nevis.



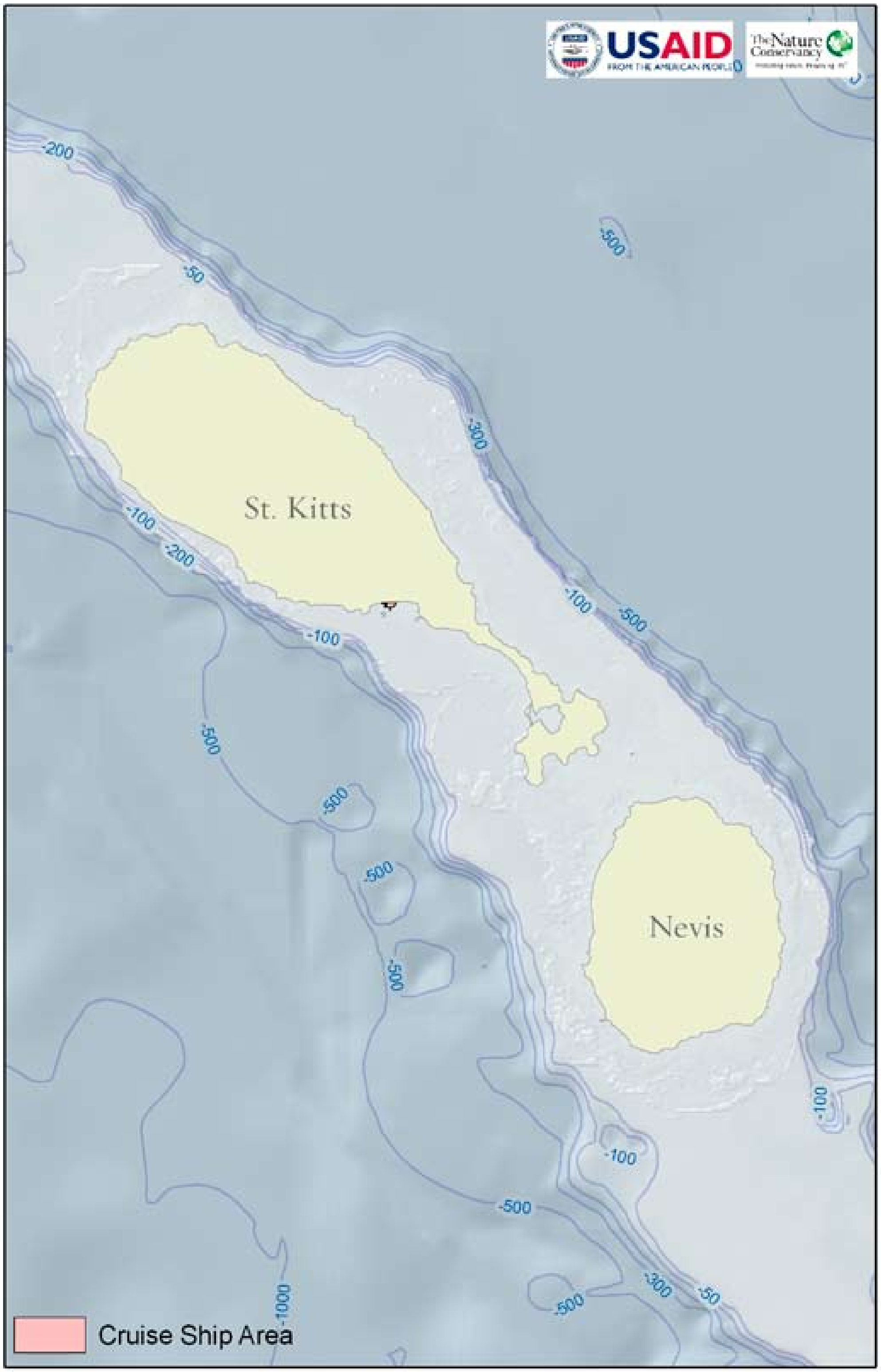
(o) Conservation Feature – Sandy Bottom: Location of sandy bottom areas in St. Kitts and Nevis.



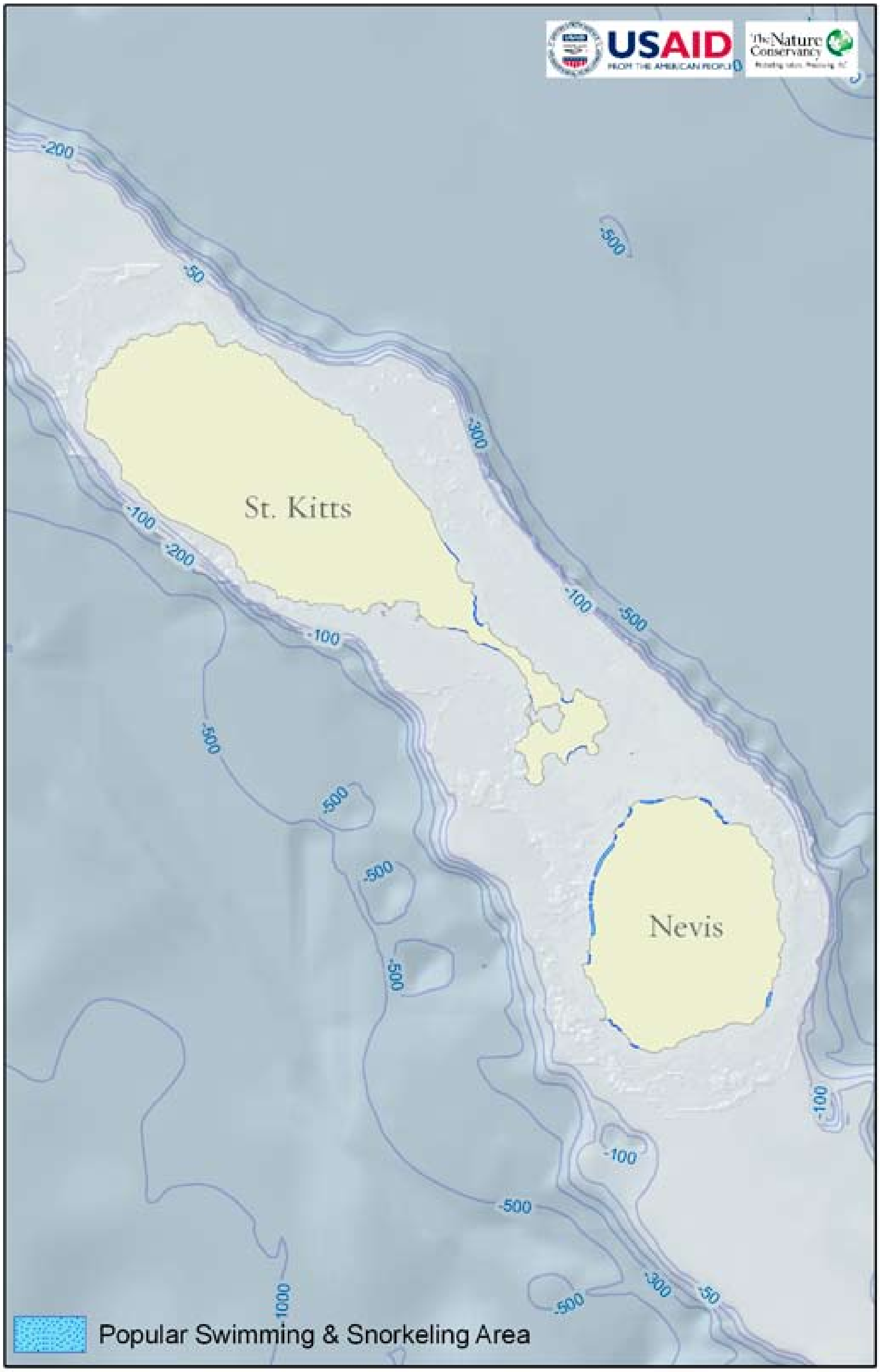
(p) Tourism Activity – Anchoring Areas: Location of popular anchoring areas in St. Kitts and Nevis.



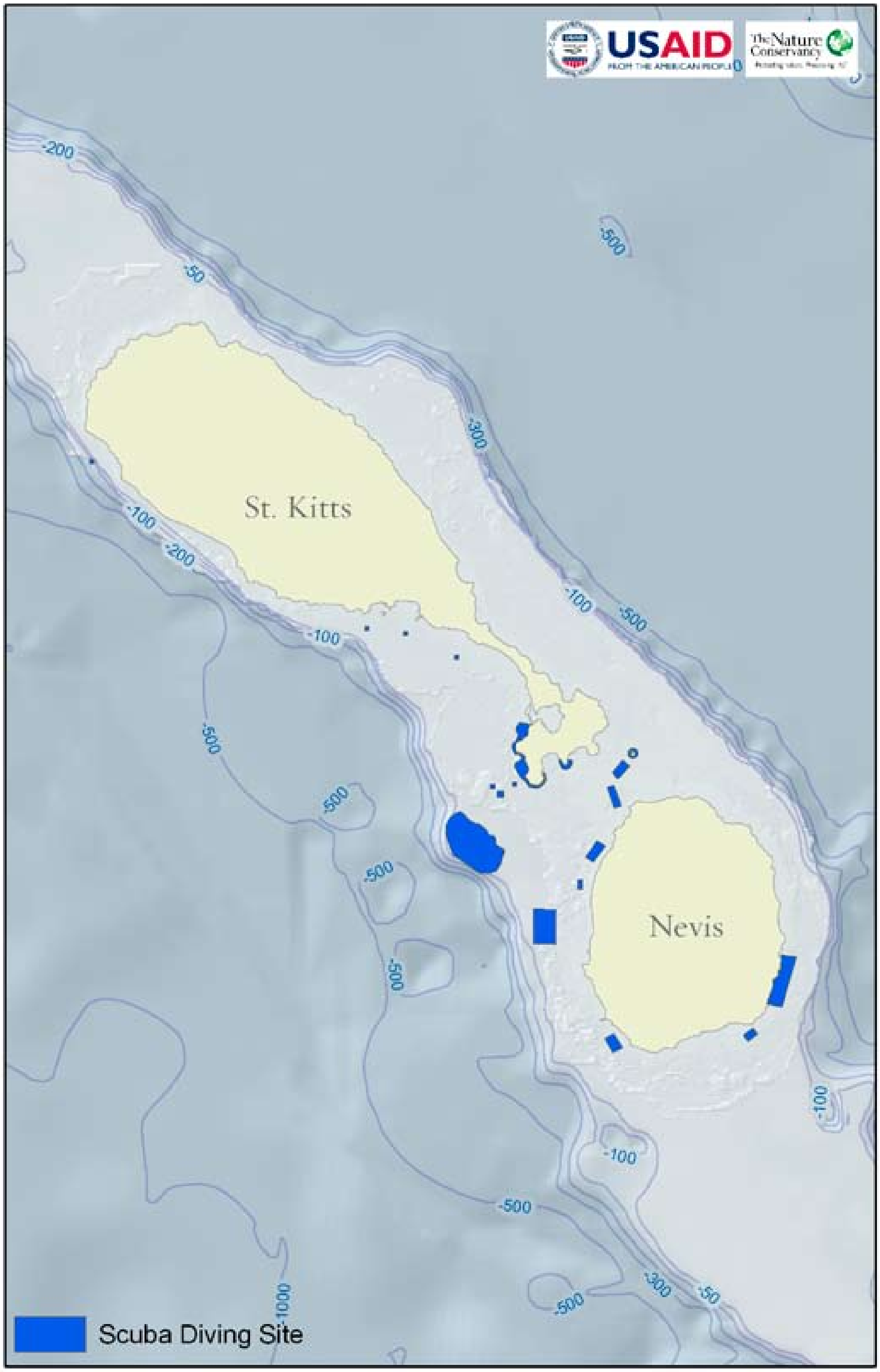
(q) Tourism Activity – Mooring Areas: Location of important mooring areas in St. Kitts and Nevis.



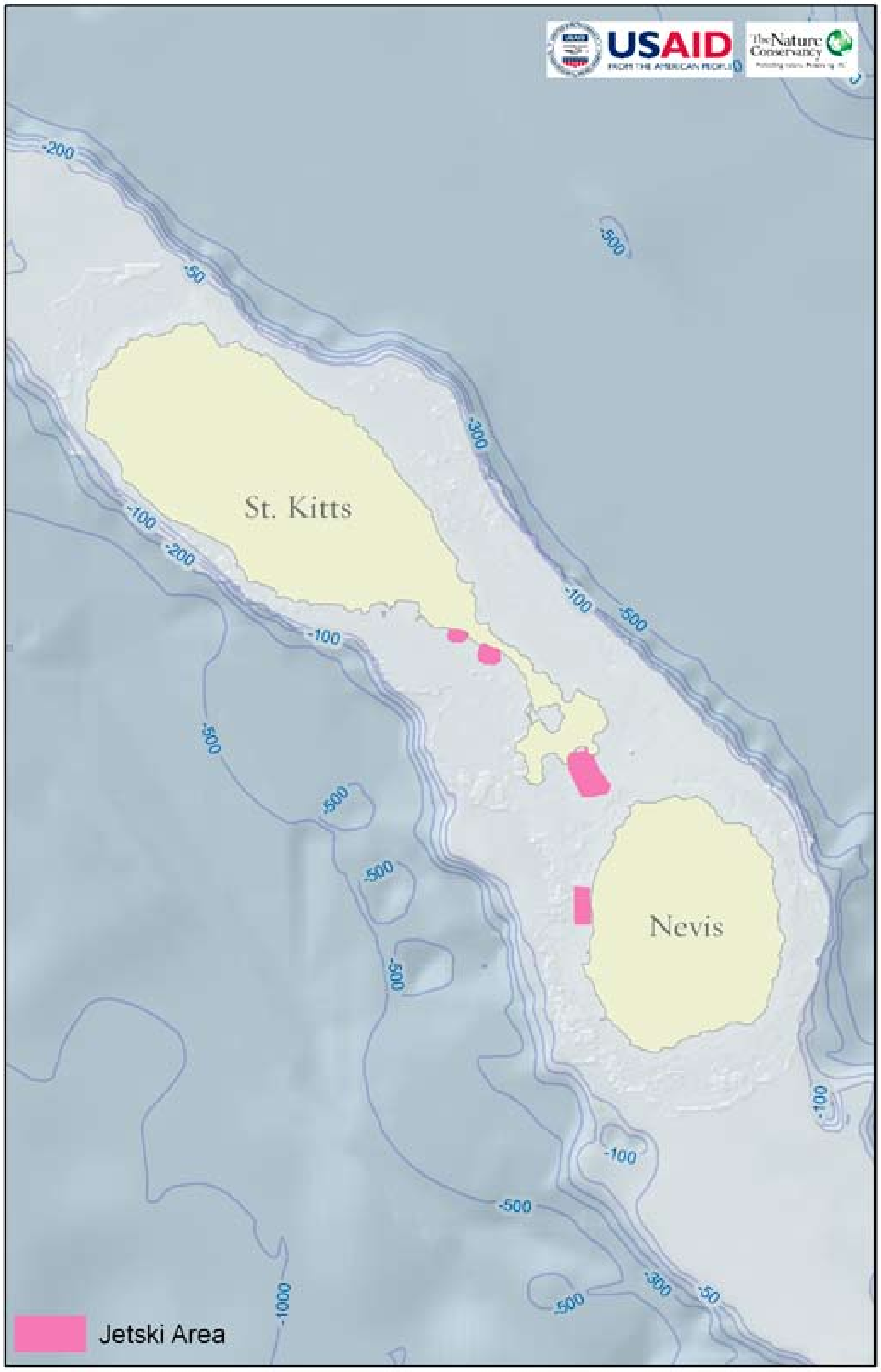
(r) Tourism Activity – Cruise Ship Areas: Location of important cruise ship areas in St. Kitts and Nevis.



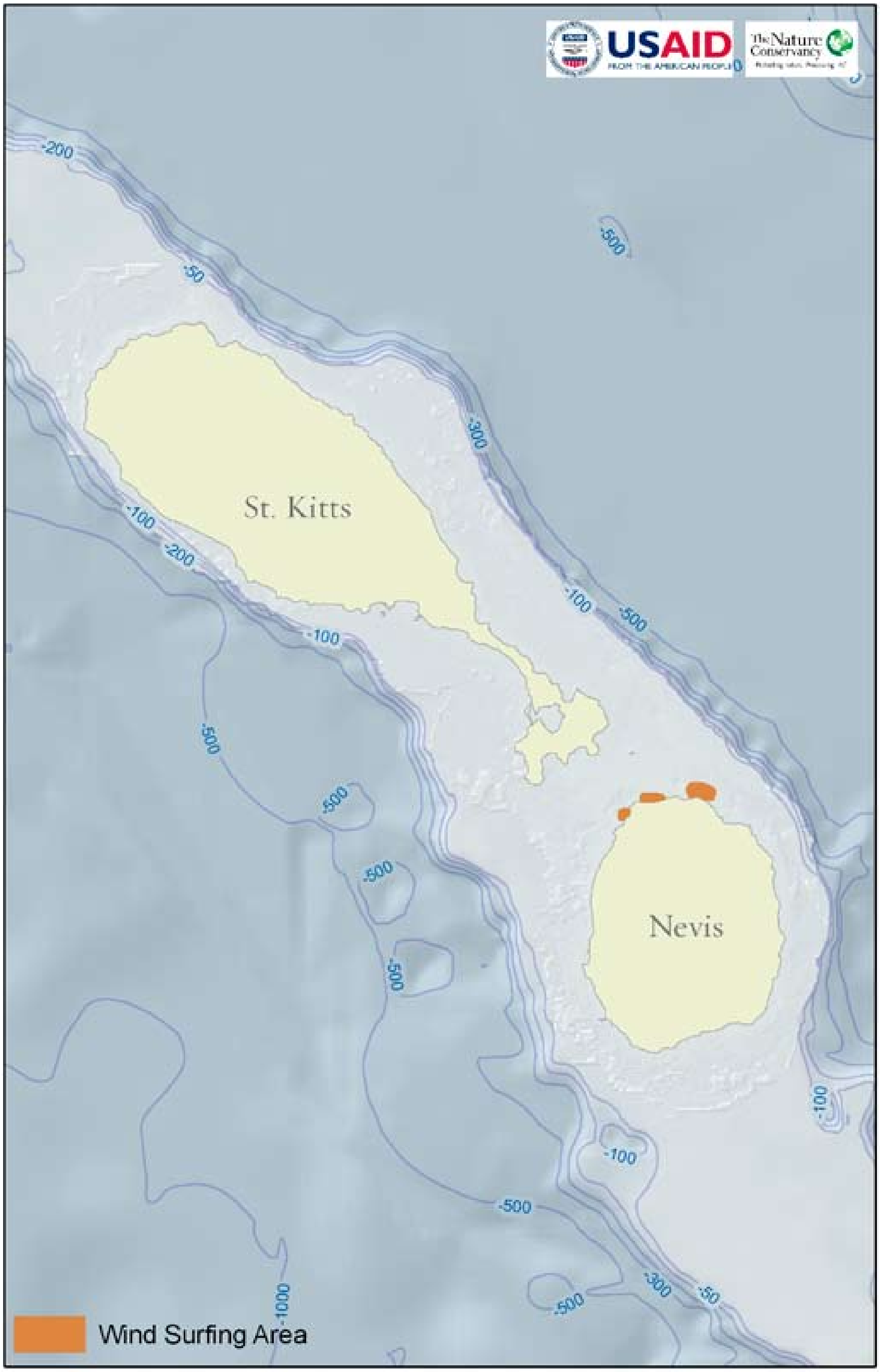
(s) Tourism Activity – Swimming & Snorkeling: Location of popular swimming and snorkeling areas in St. Kitts and Nevis.



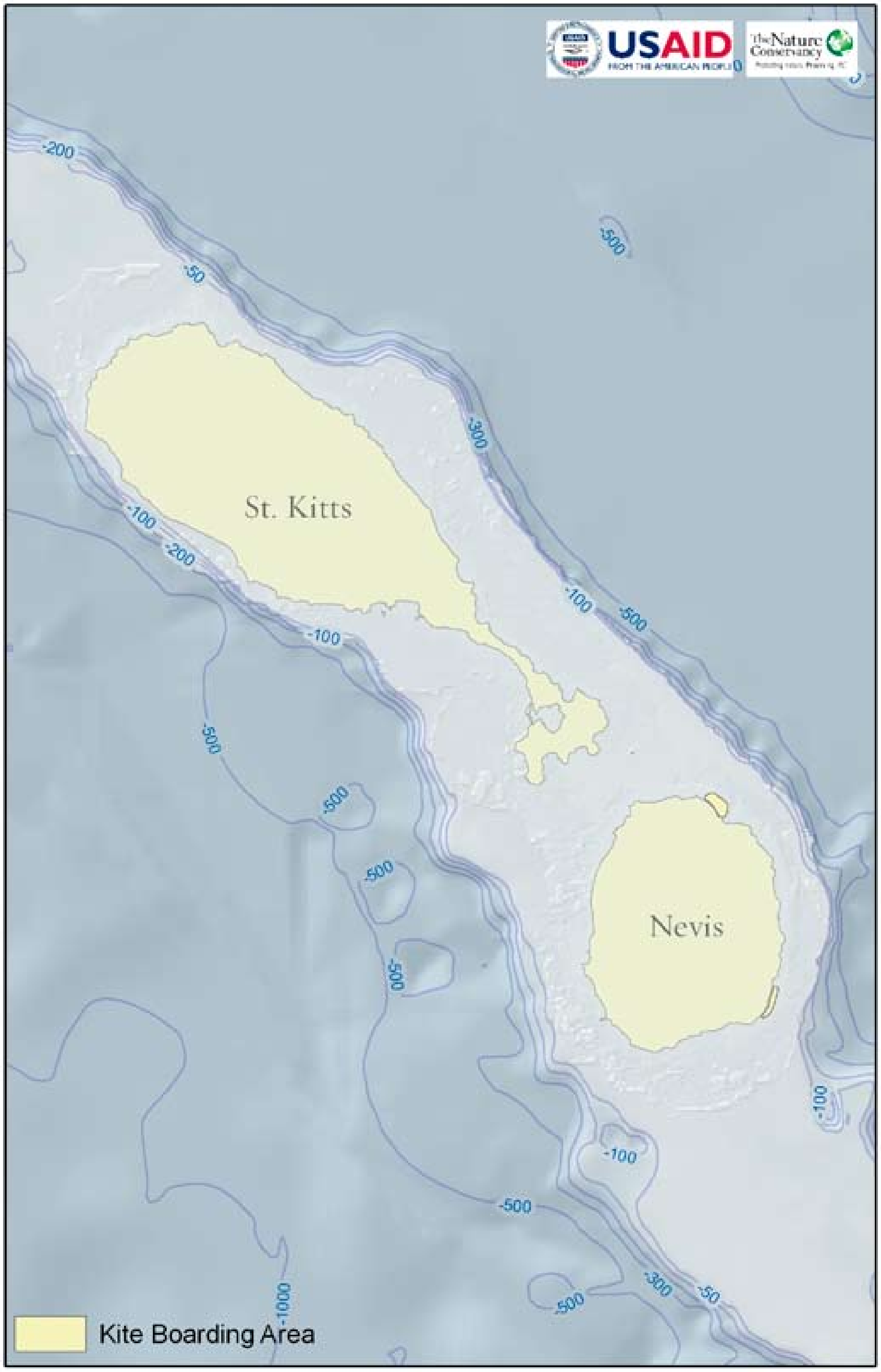
(t) Tourism Activity – Scuba Diving Sites: Location of popular scuba diving sites in St. Kitts and Nevis.



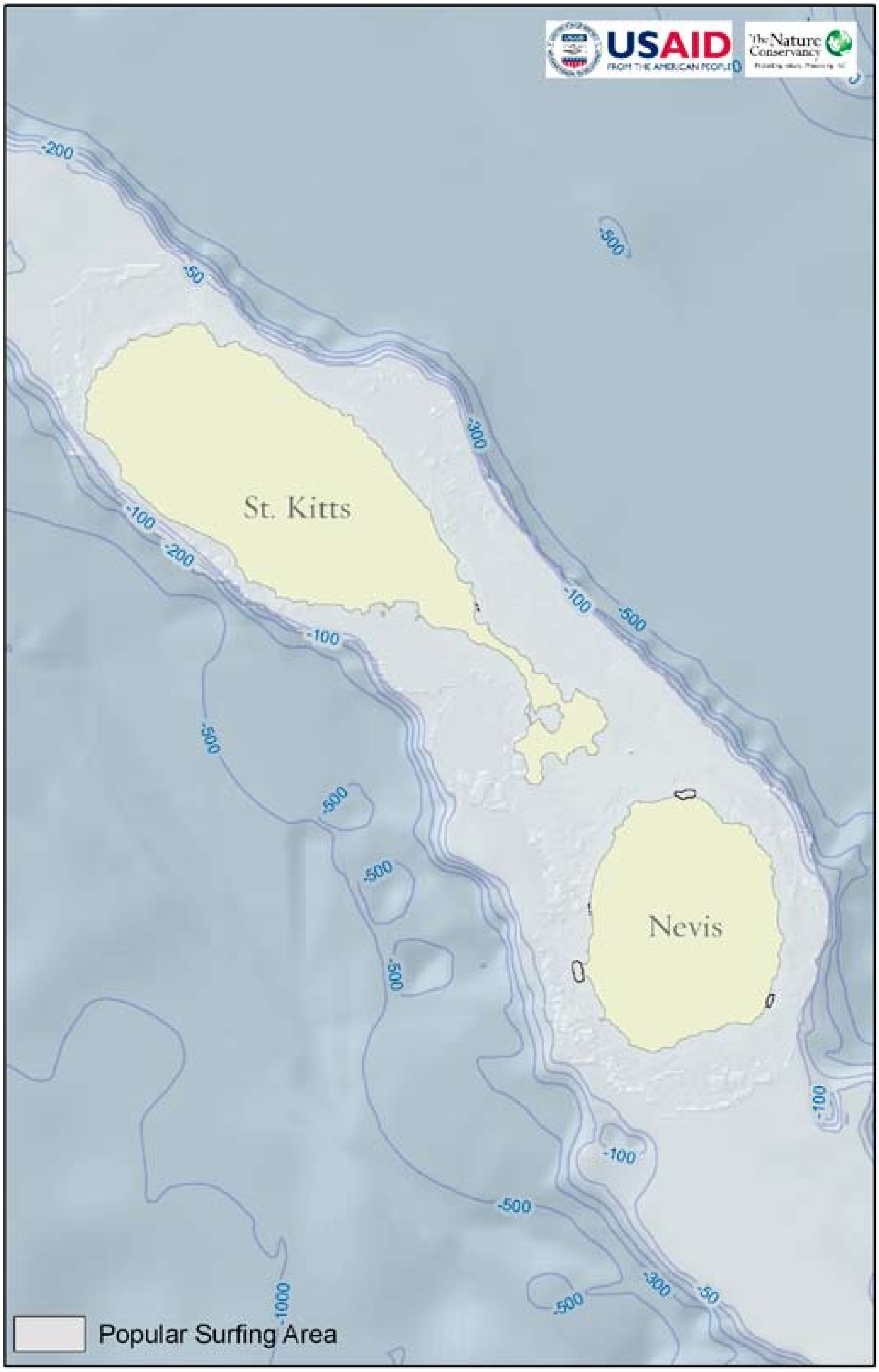
(u) Tourism Activity – Jet Ski Areas: Location of popular jet skiing areas in St. Kitts and Nevis.



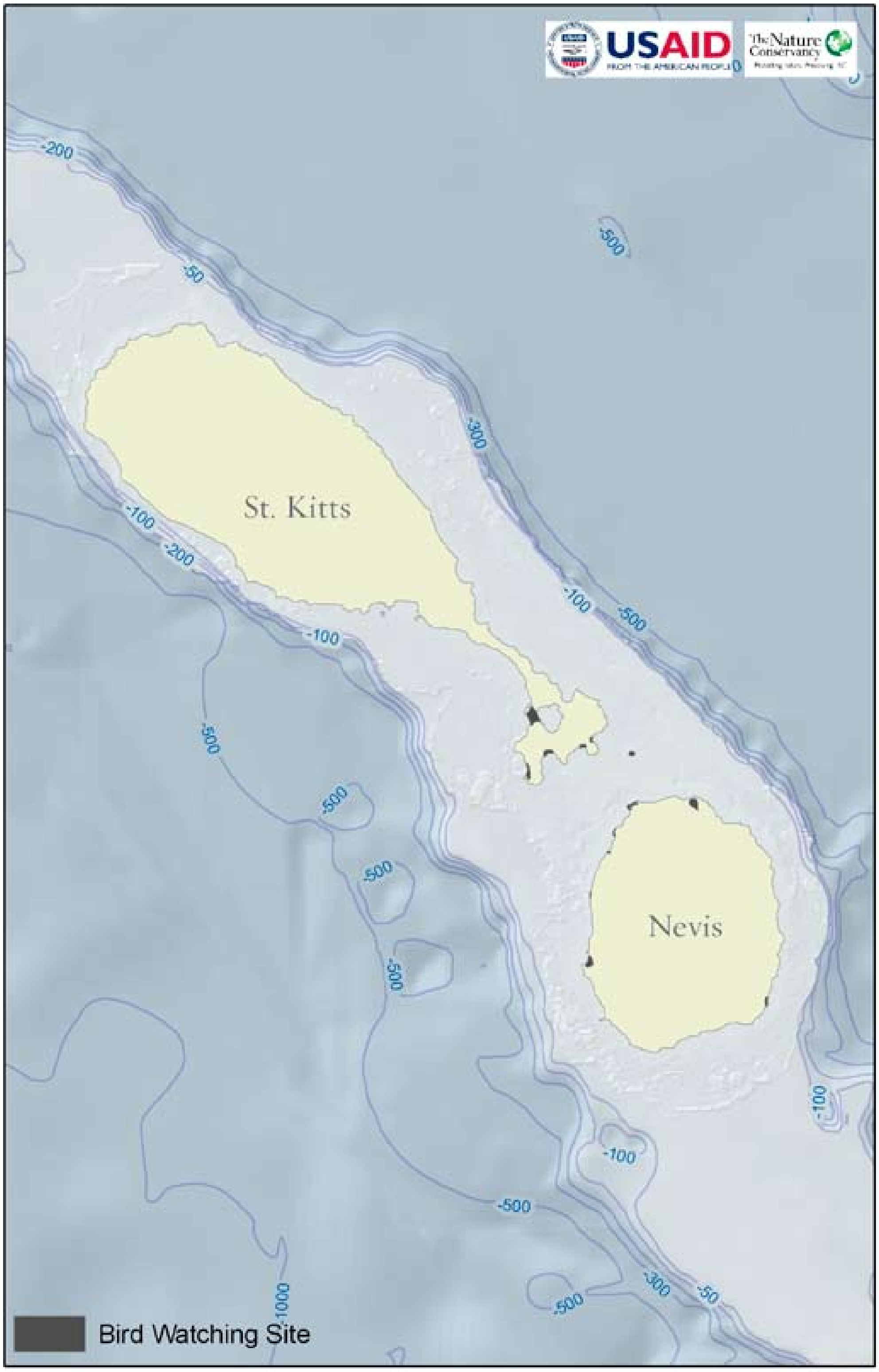
(v) Tourism Activity – Wind Surfing: Location of popular wind surfing areas in St. Kitts and Nevis.



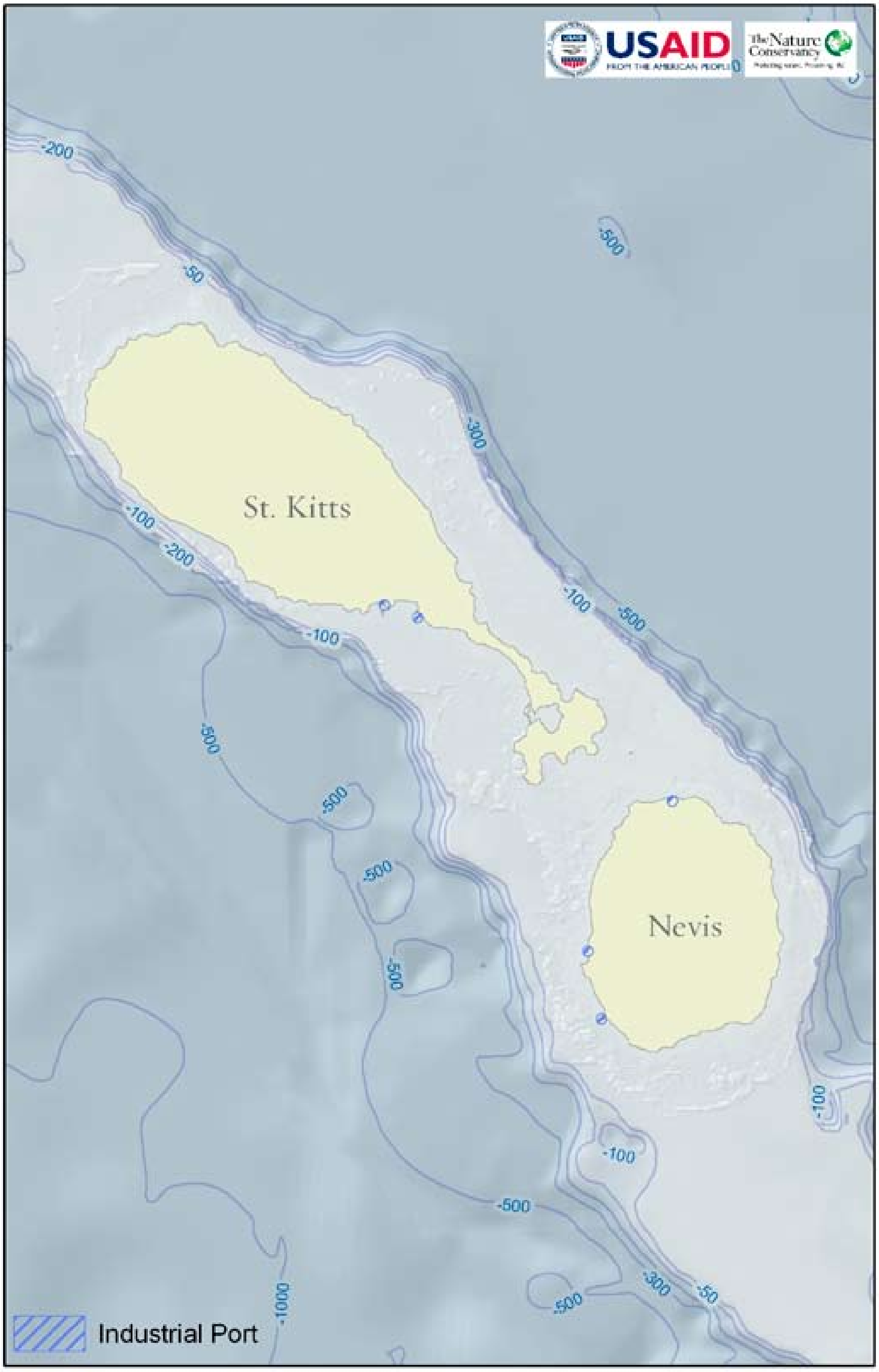
(w) Tourism Activity – Kite Boarding Areas: Location of popular kite boarding areas in St. Kitts and Nevis.



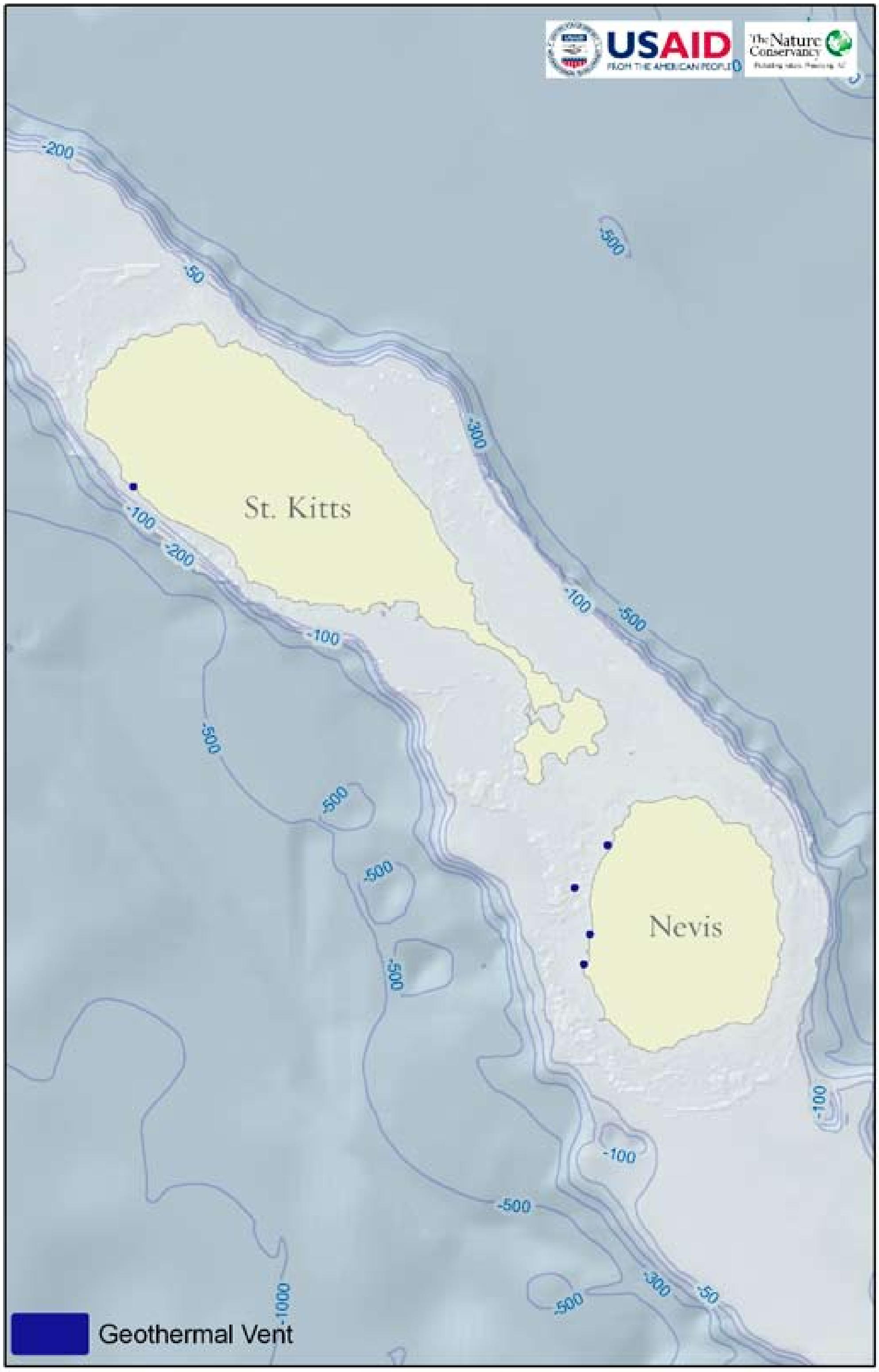
(x) Tourism Activity – Surfing: Location of popular surfing areas in St. Kitts and Nevis.



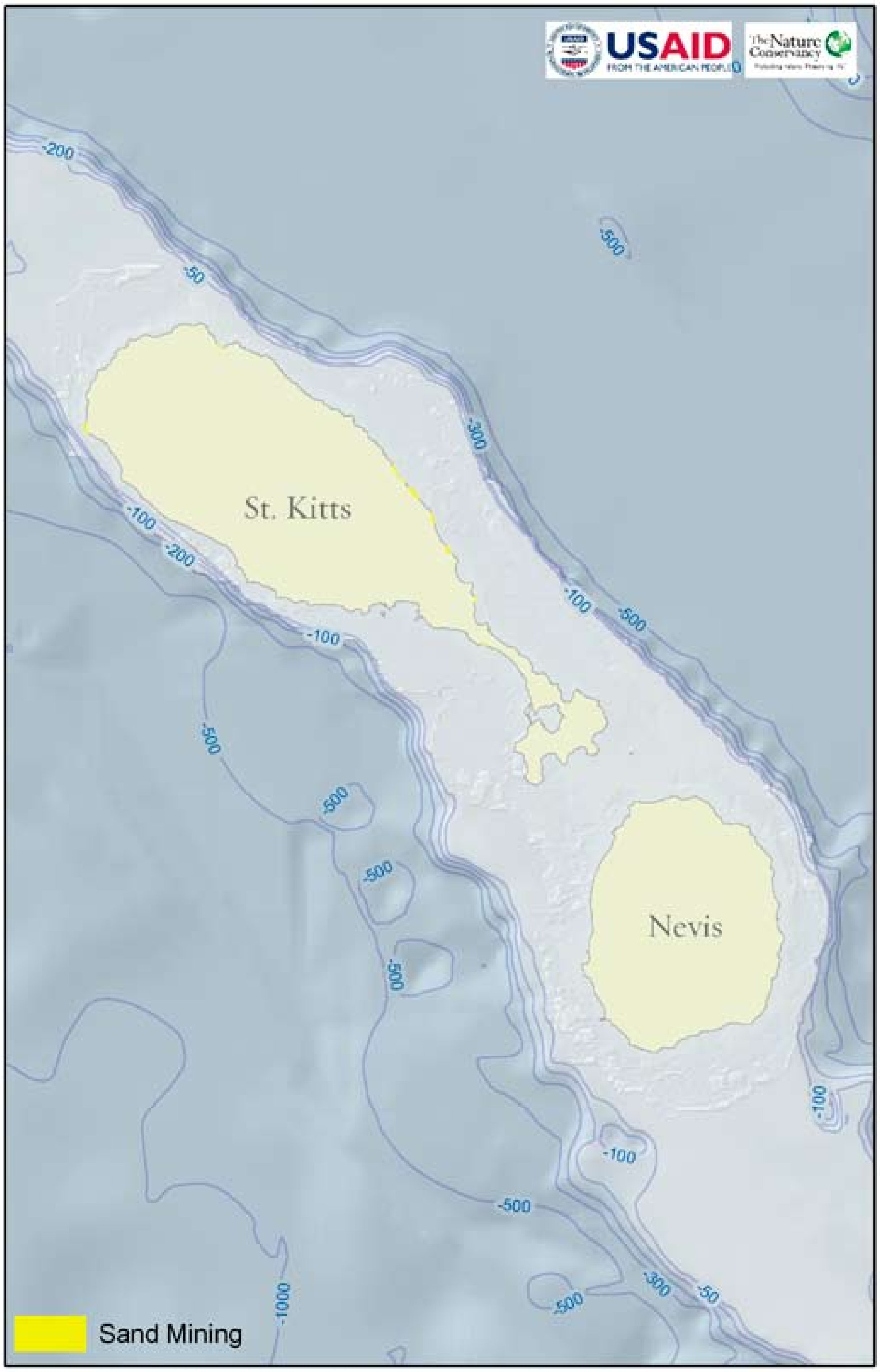
(y) Tourism Activity – Bird Watching: Location of popular bird watching areas in St. Kitts and Nevis.



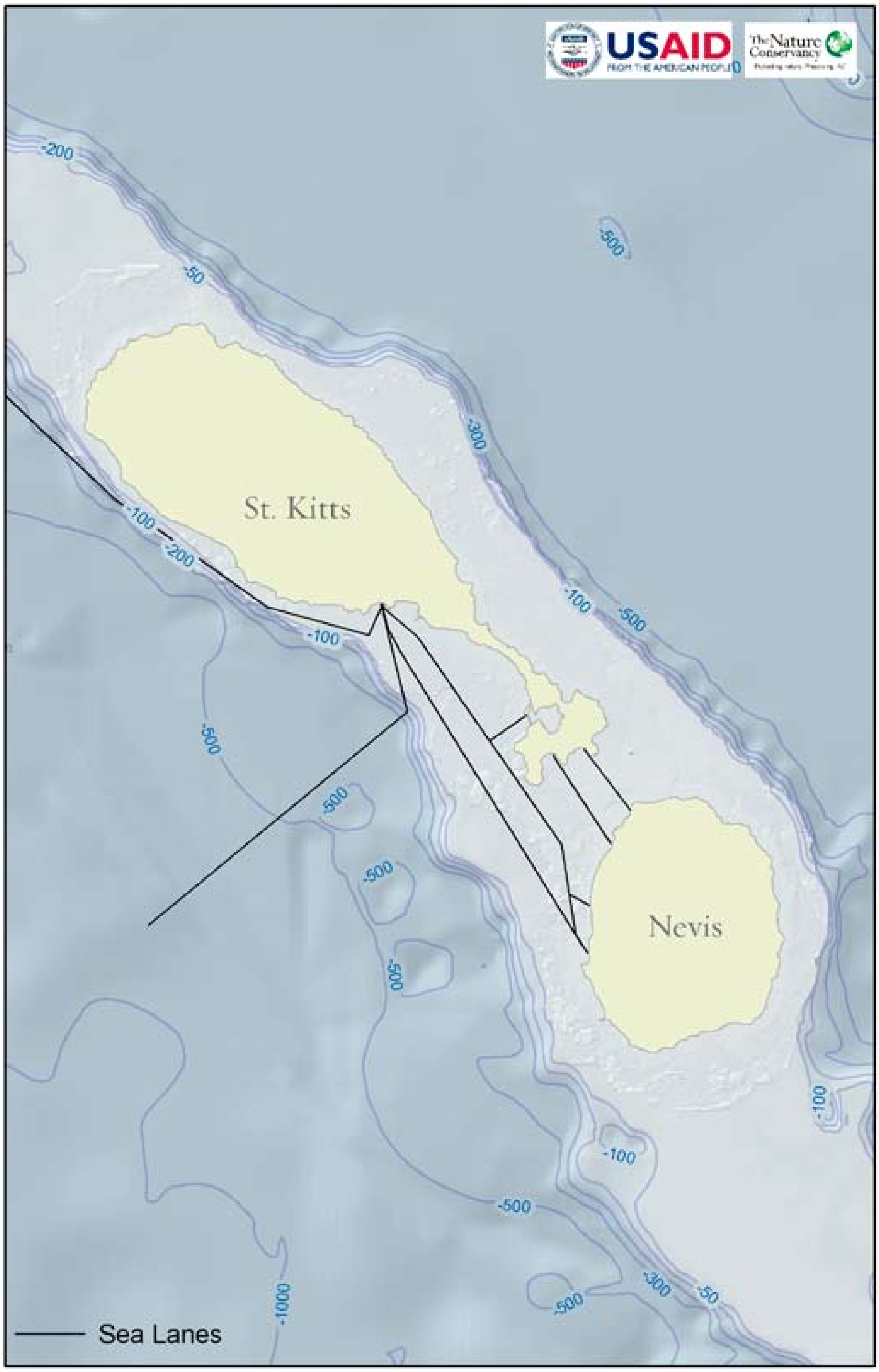
(z) Industrial Activity – Industrial Ports: Location of important industrial ports in St. Kitts and Nevis.



(aa) Industrial Activity – Geothermal Vents: Location of important geothermal vents in St. Kitts and Nevis.

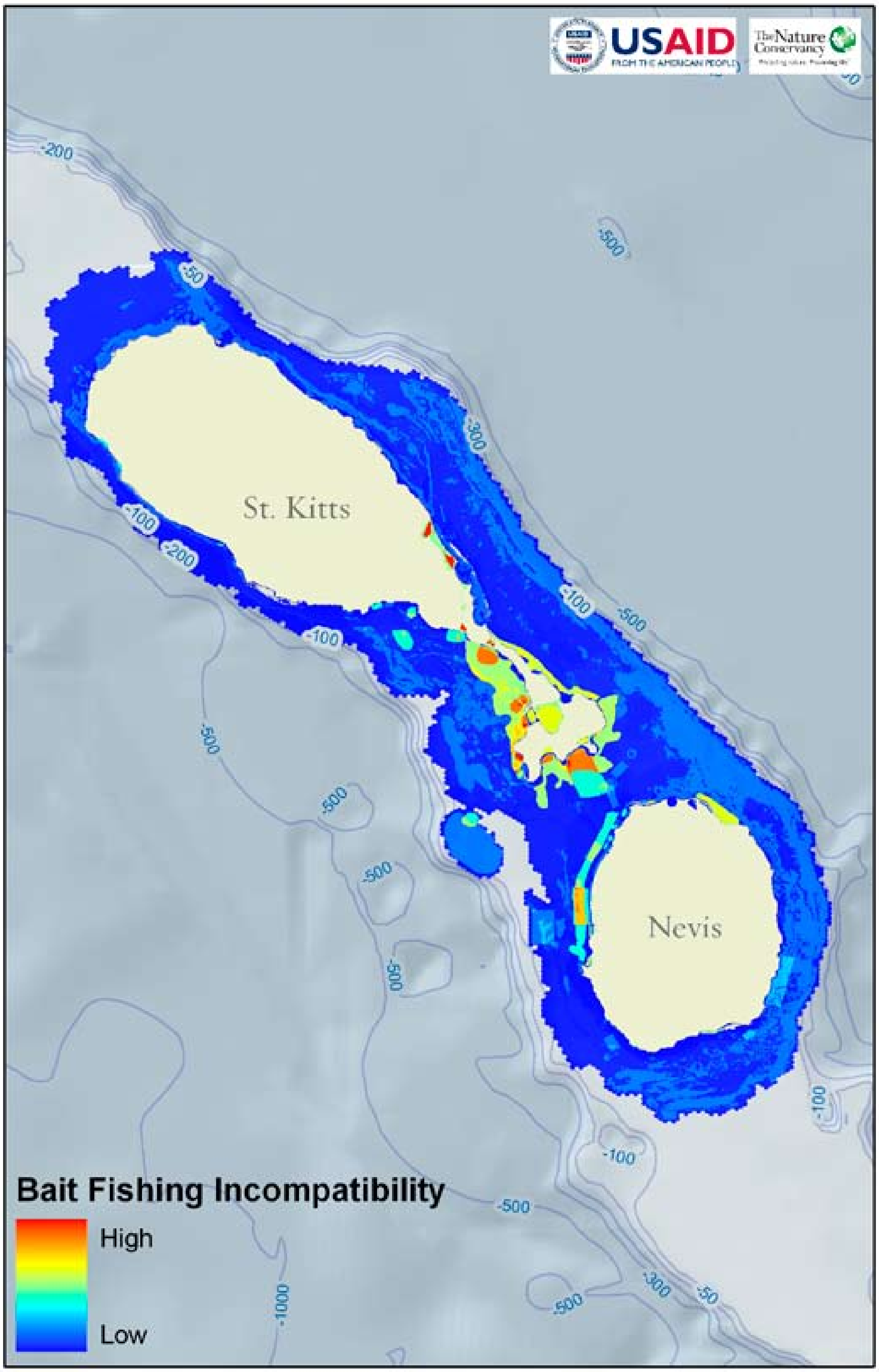


(bb) Industrial Activity – Sand Mining: Location of important sand mining areas in St. Kitts and Nevis.

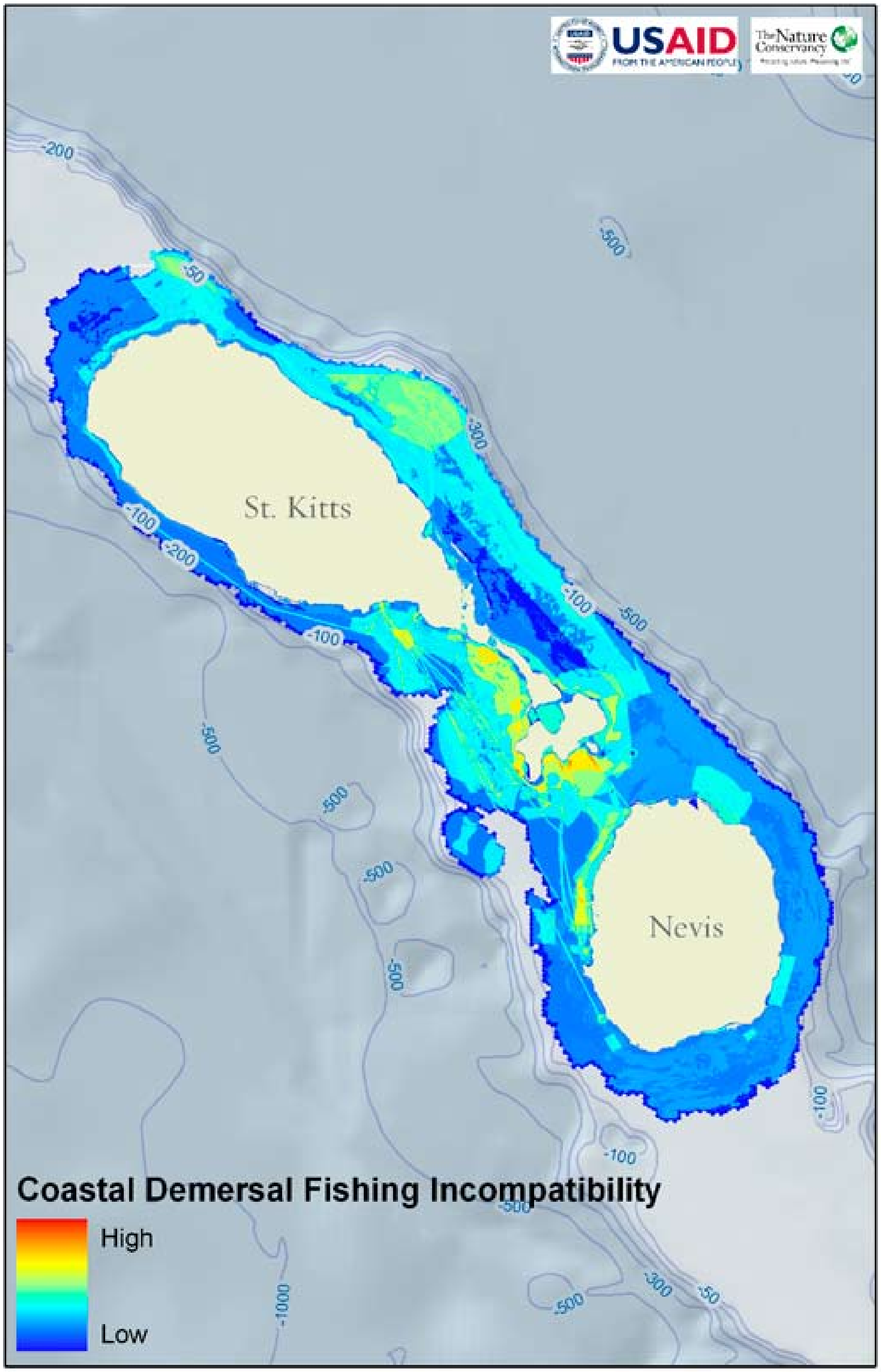


(cc) Transportation Activity – Sea Lanes: Location of important sea lanes in St. Kitts and Nevis.

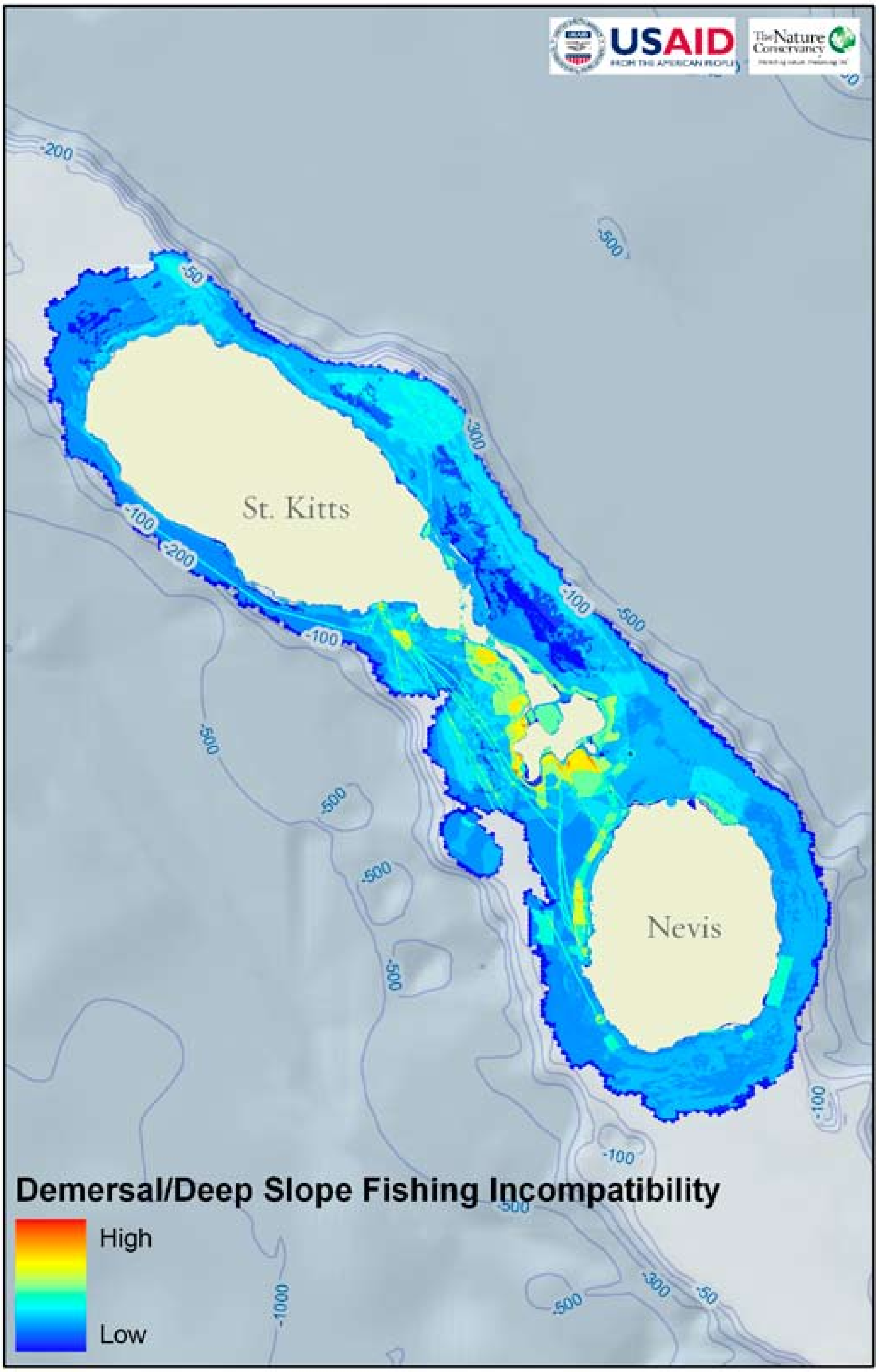
FIGURE E4. **Compatibility:** These maps are created from a compatibility matrix generated with stakeholder input during the second workshop. For each feature and activity, each map depicts the level of compatibility between that specific feature and all other features and activities. (Note that compatibility maps are described further in the main report.)



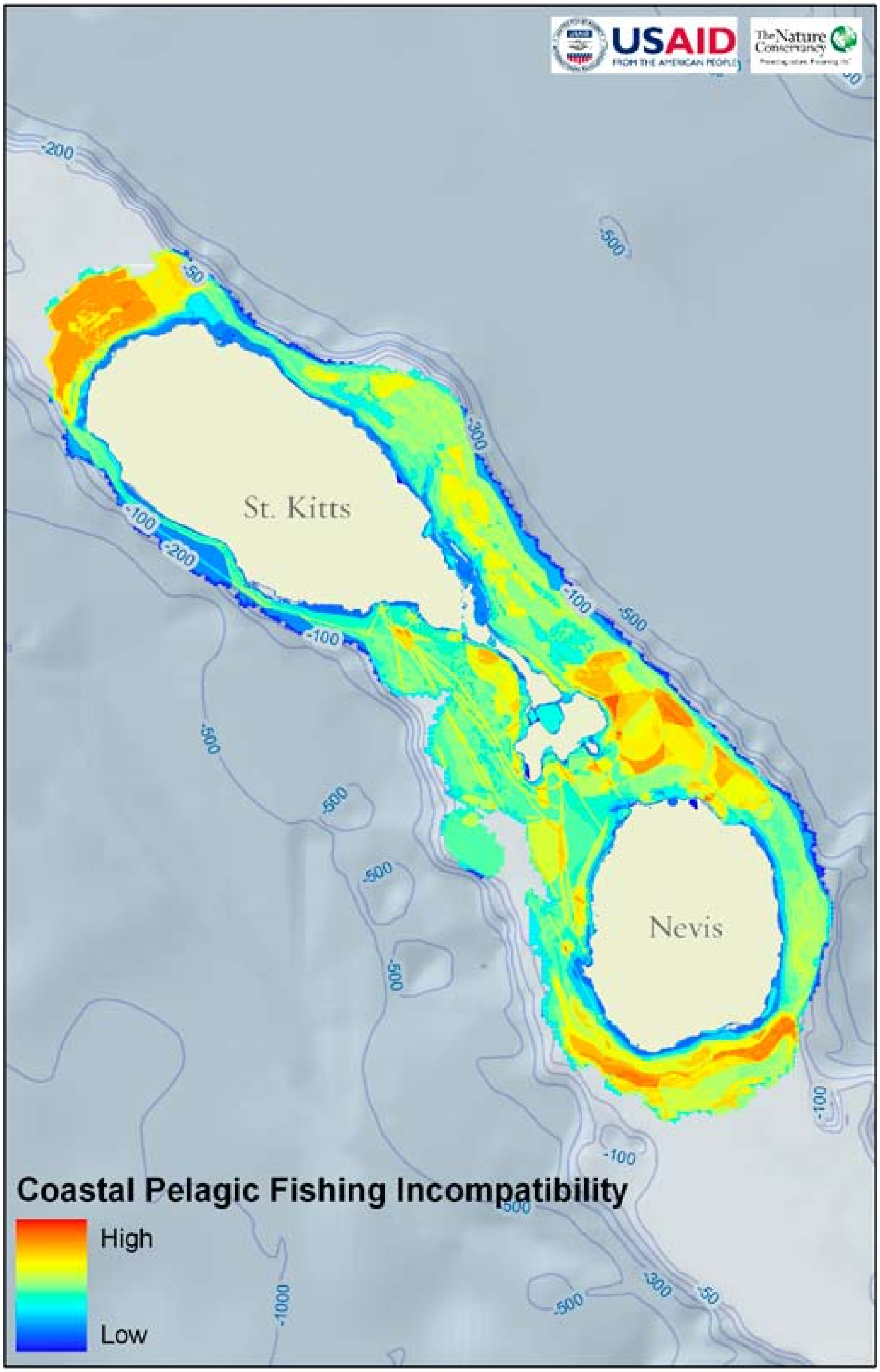
(a) Fishing Activity – Bait Fishing: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for bait fishing.



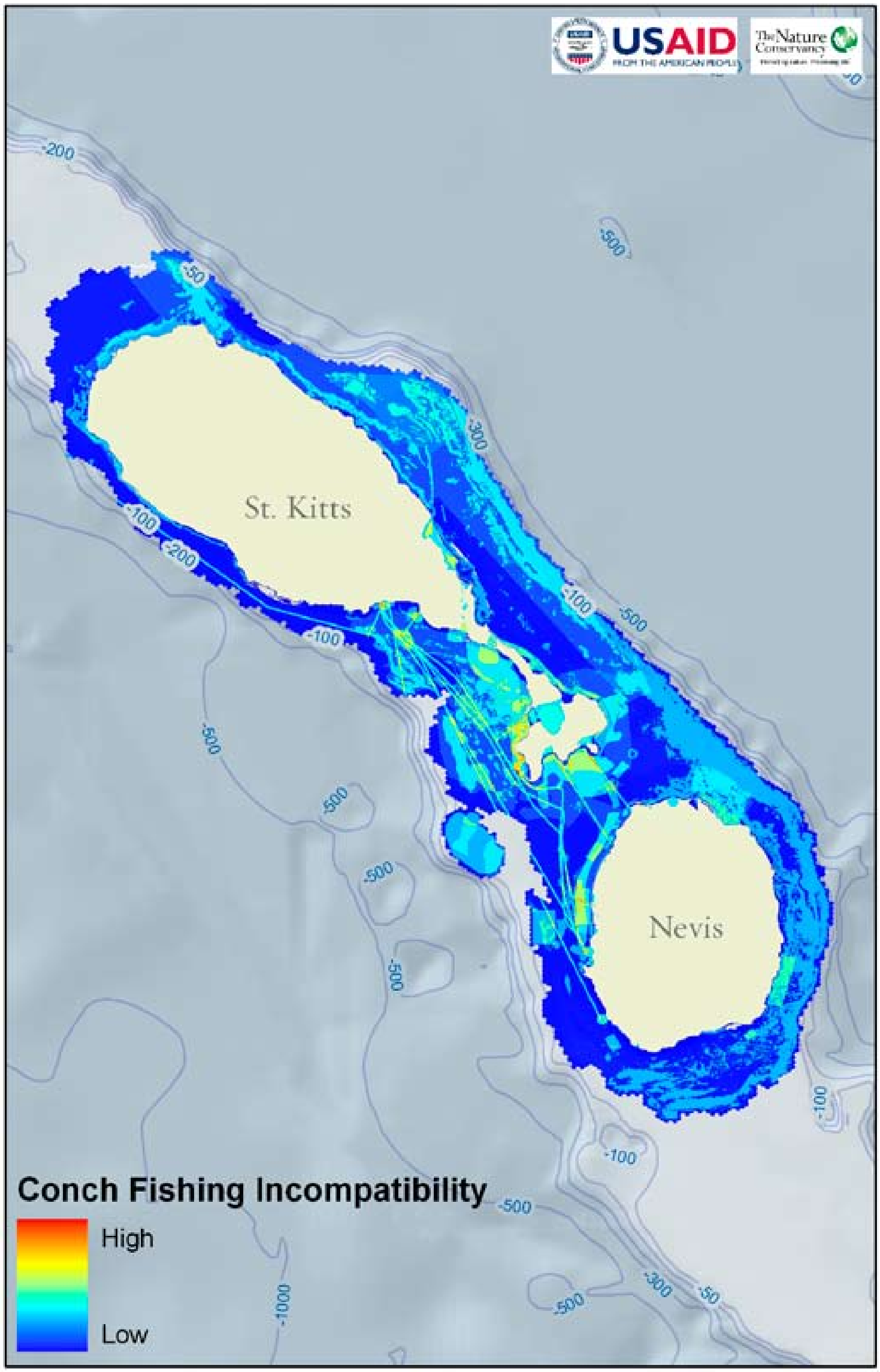
(b) Fishing Activity – Coastal Demersal Fishing: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for coastal demersal fishing.



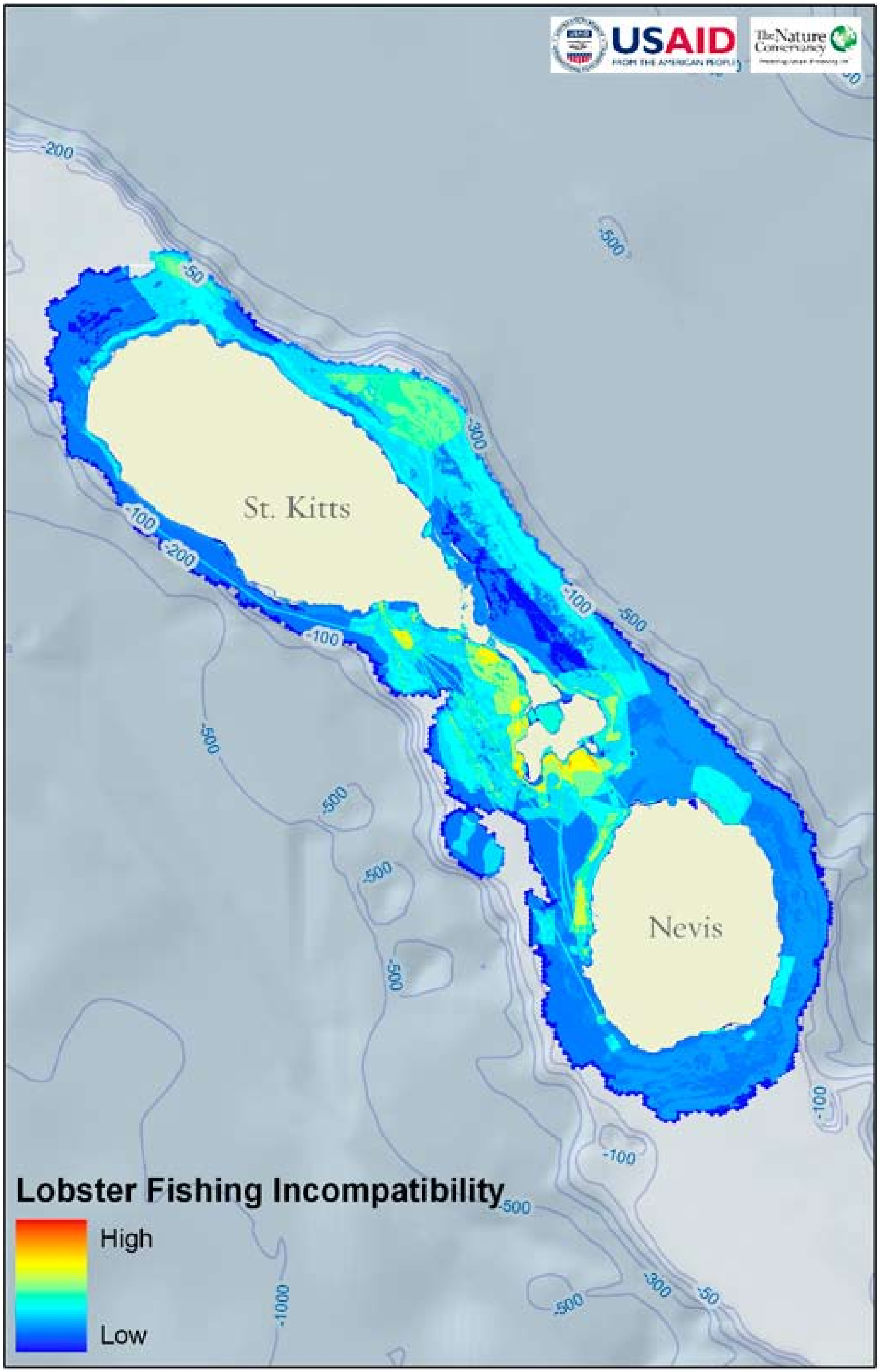
(c) Fishing Activity – Demersal/Deep Slope Fishing: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for demersal/deep-slope fishing.



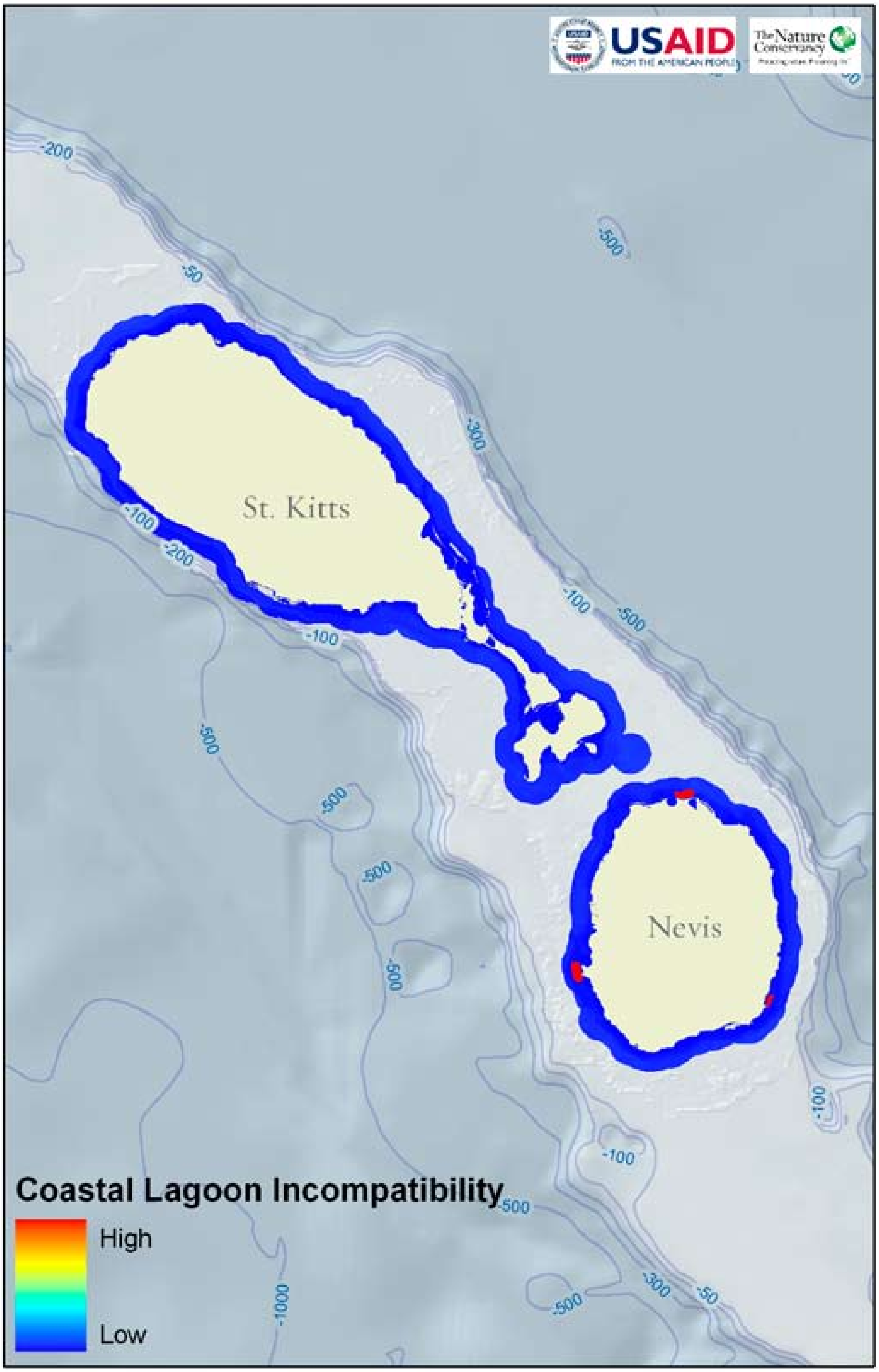
(d) Fishing Activity – Pelagic Fishing: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for pelagic fishing.



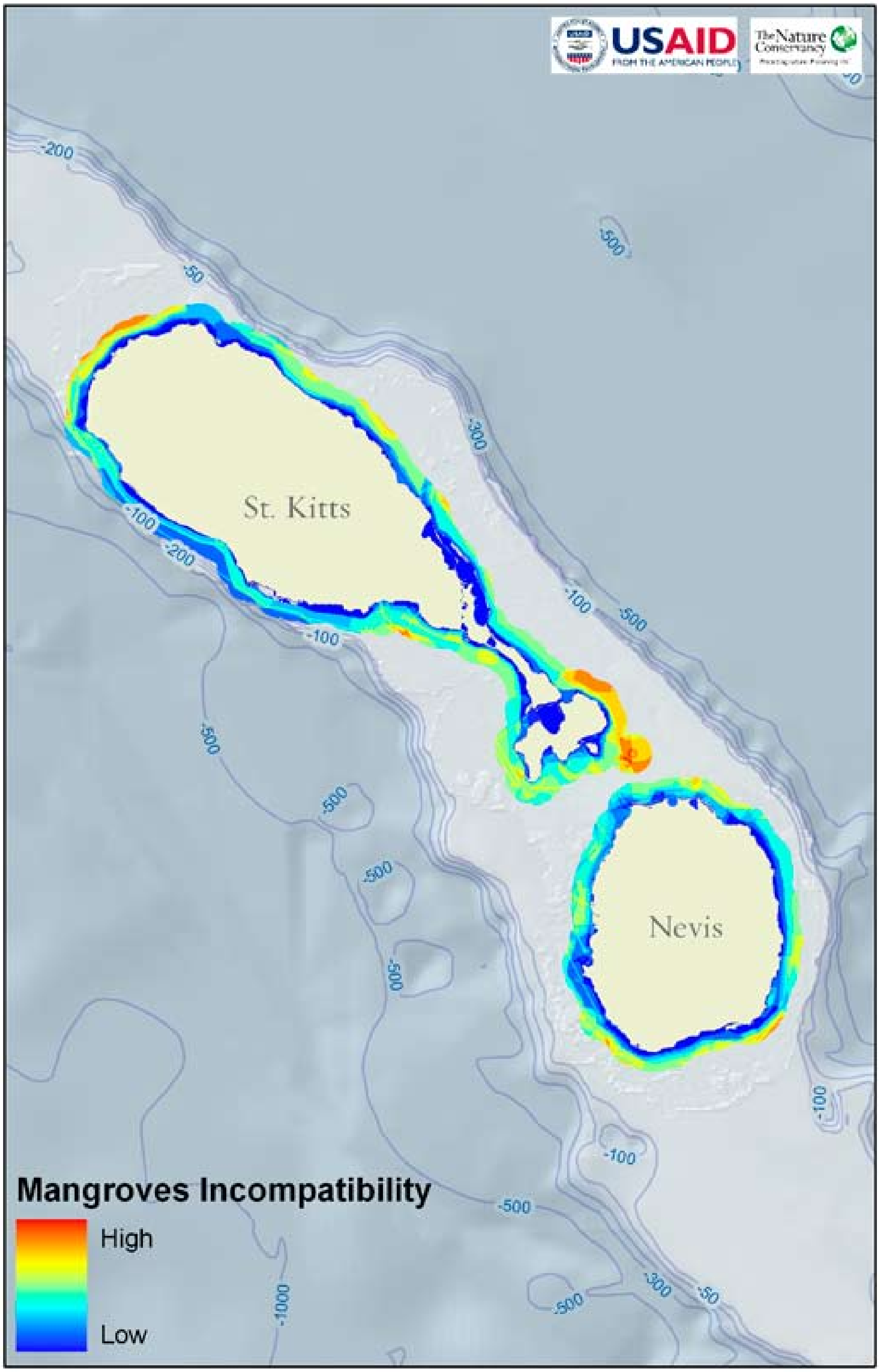
(e) Fishing Activity – Conch Fishing: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for conch fishing.



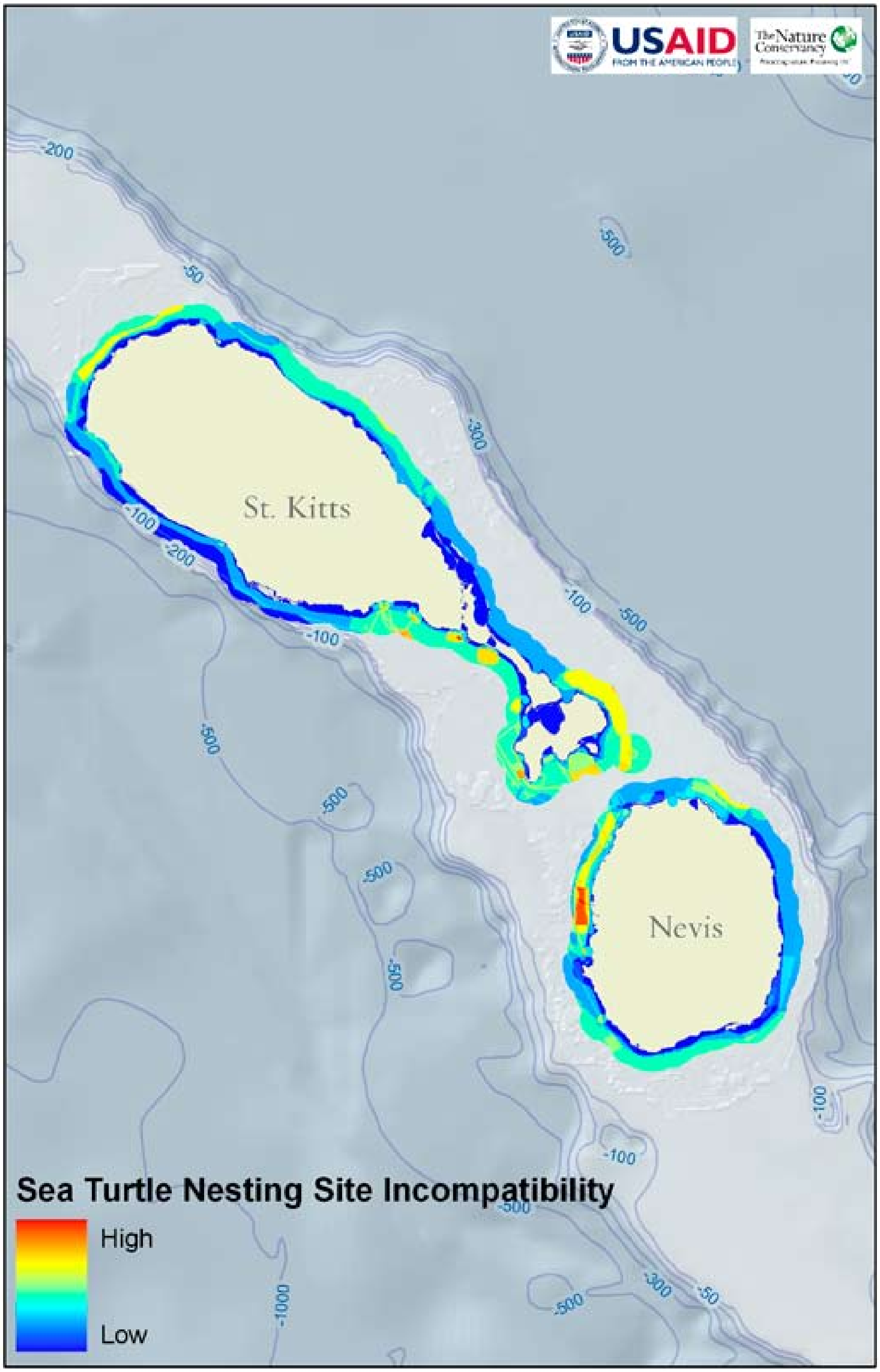
(f) Fishing Activity – Lobster Fishing: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for lobster fishing.



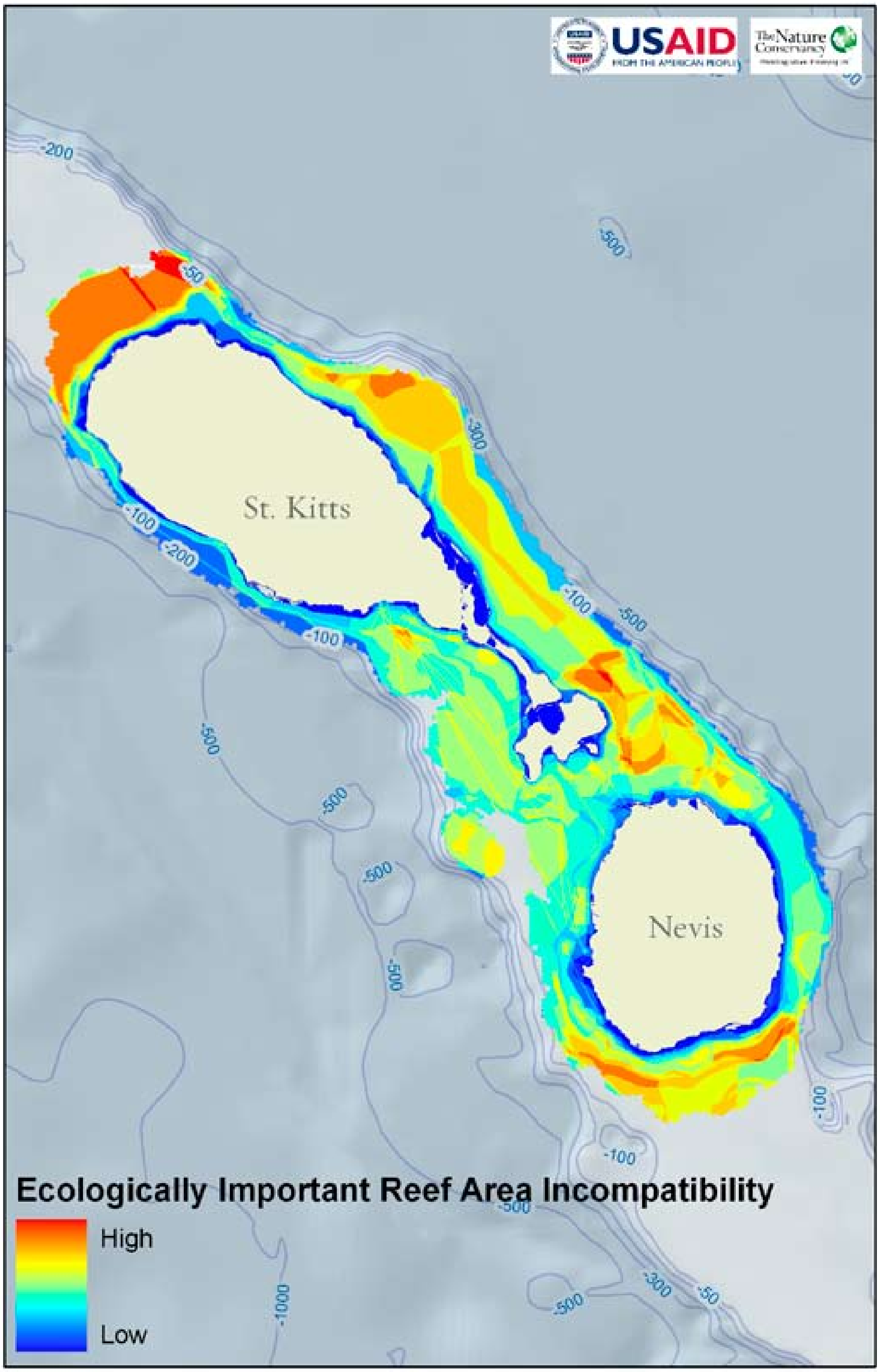
(g) Conservation Feature – Coastal Lagoons: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for conserving coastal lagoons.



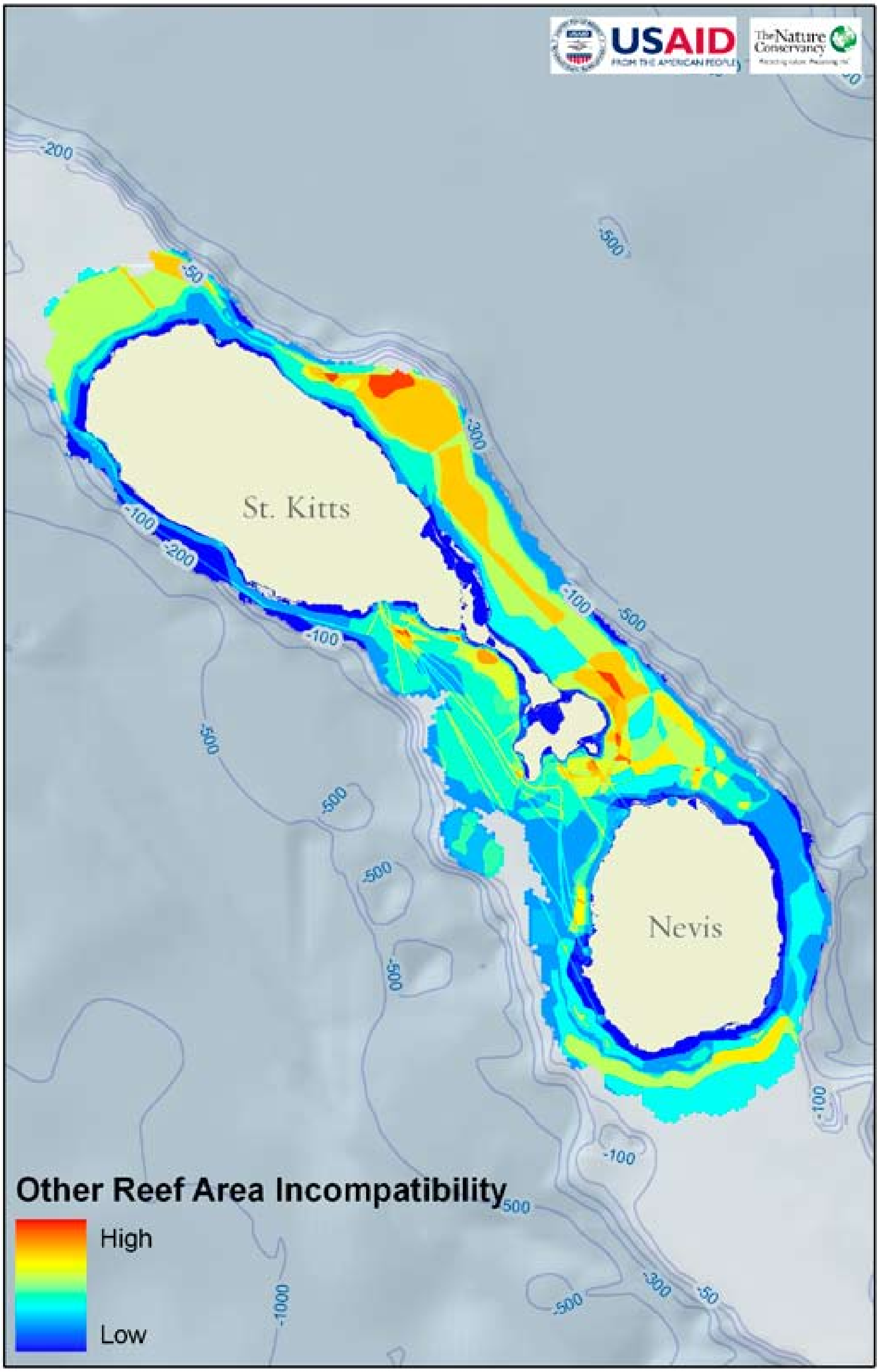
(h) Conservation Feature – Mangroves: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for conserving mangroves.



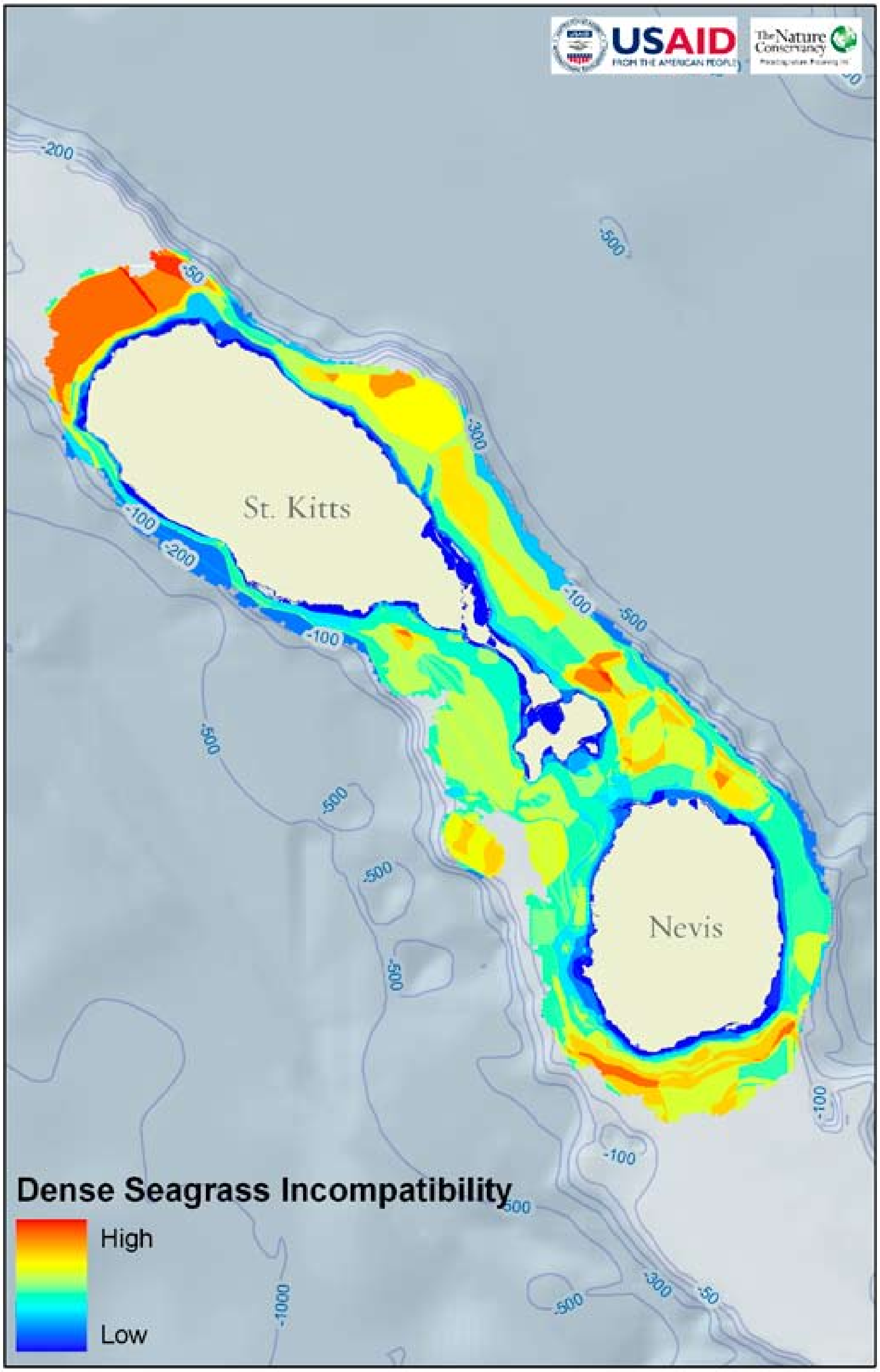
(i) Conservation Feature – Sea Turtle Nesting Sites: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for conserving sea turtle nesting sites.



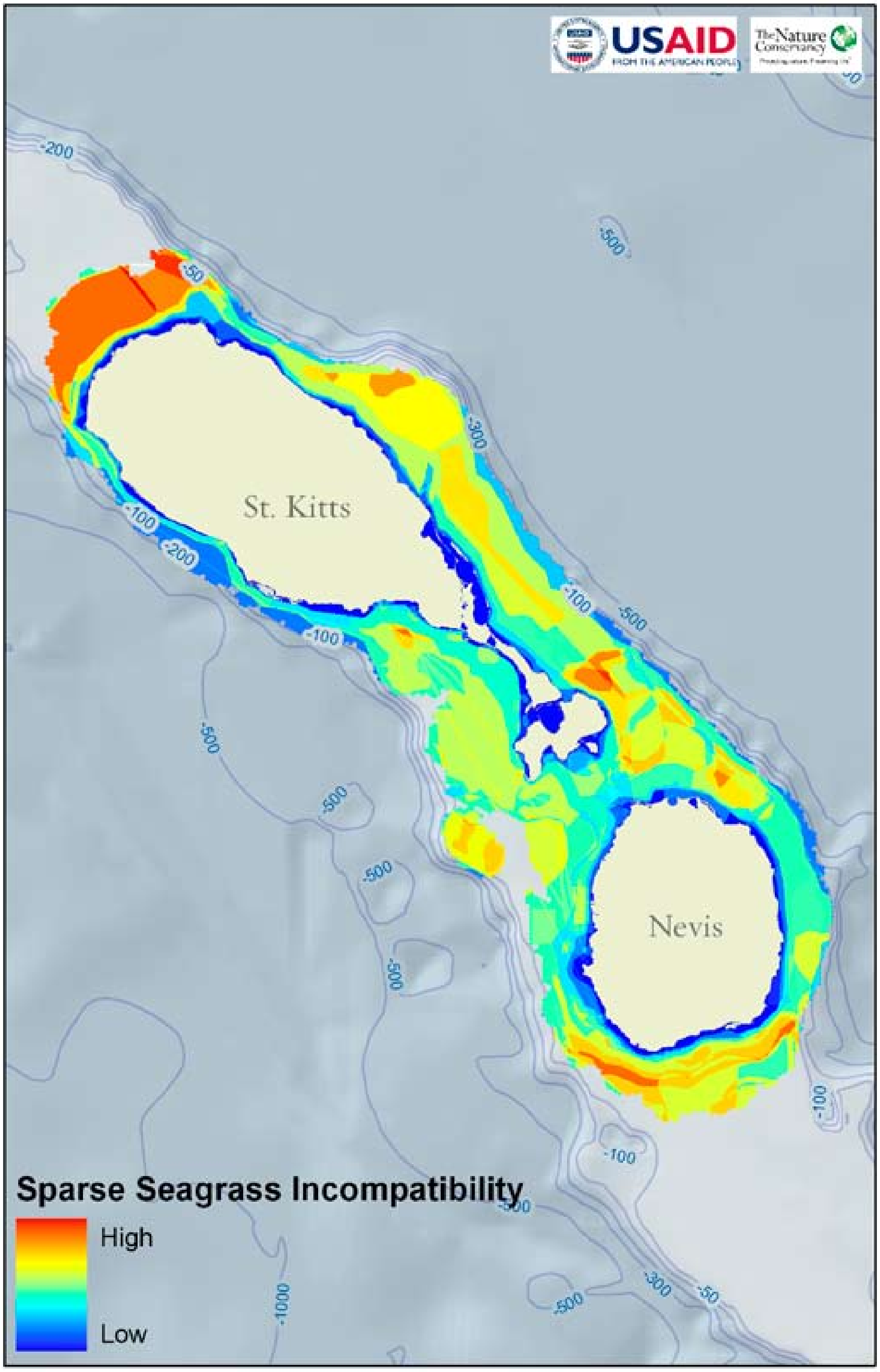
(j) Conservation Feature – Ecologically Important Reefs: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for conserving ecologically important reefs.



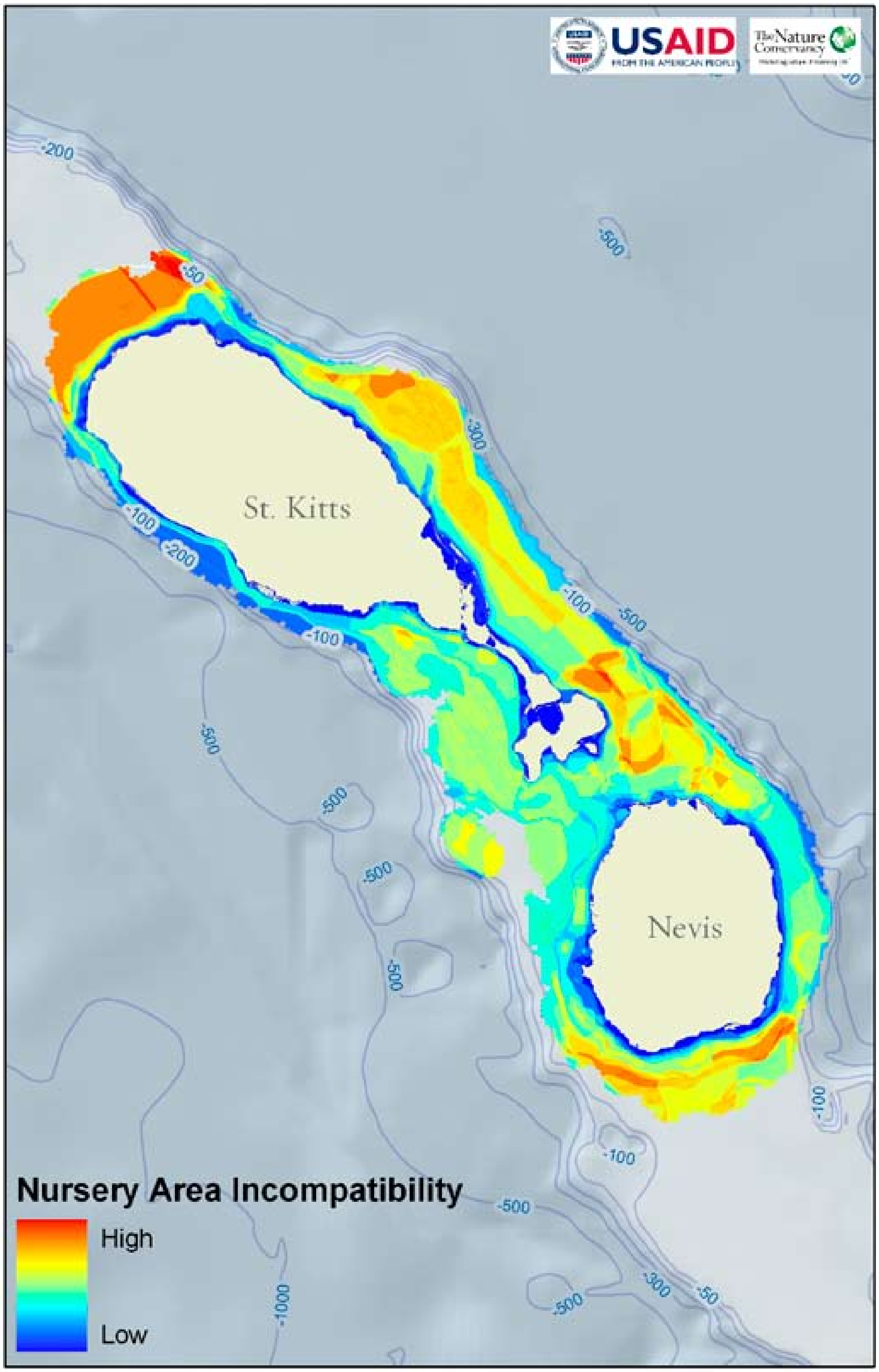
(k) Conservation Feature – Other Reefs: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for conserving other reef areas.



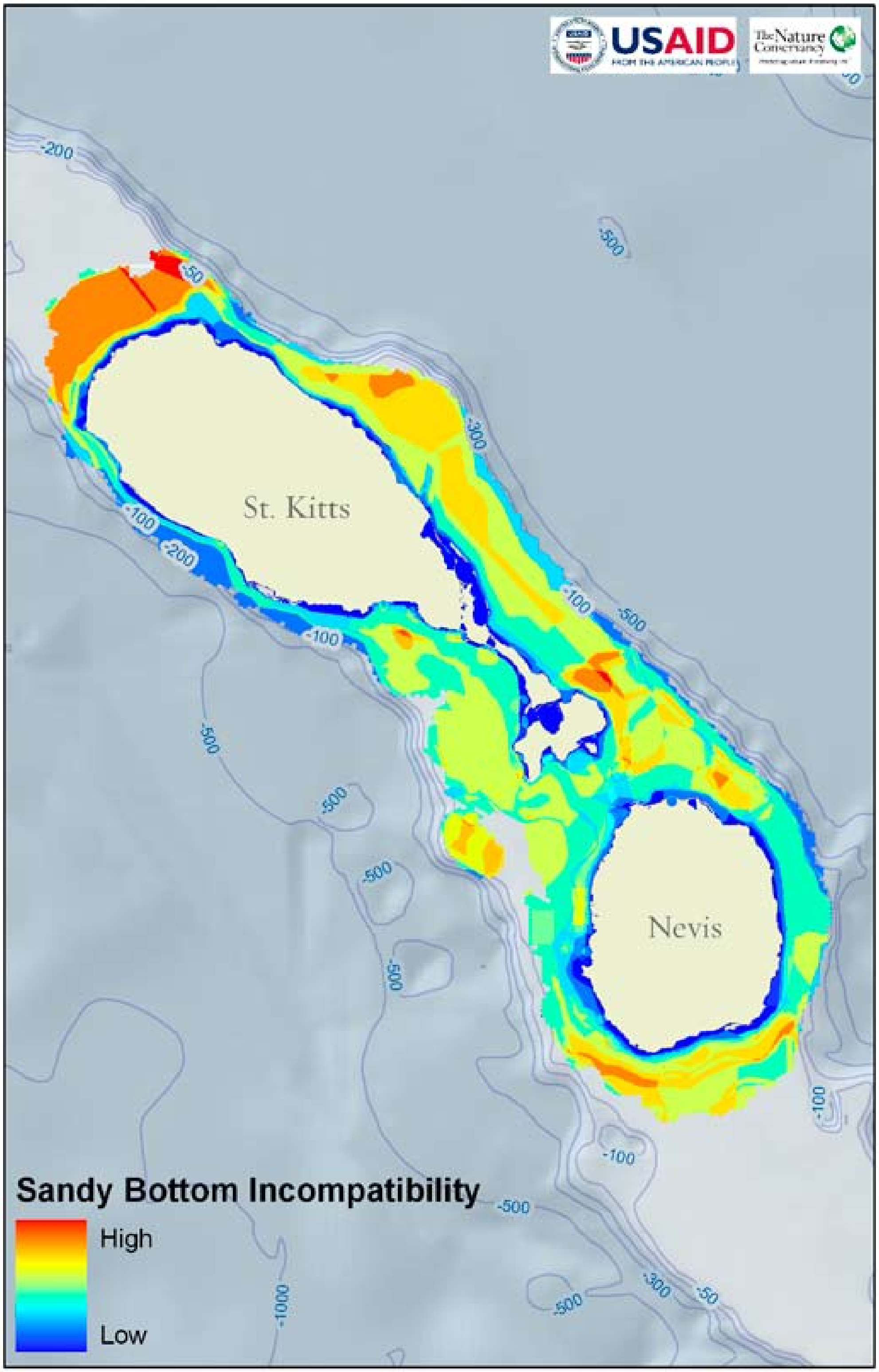
(l) Conservation Feature – Dense Seagrass: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for conserving dense seagrass.



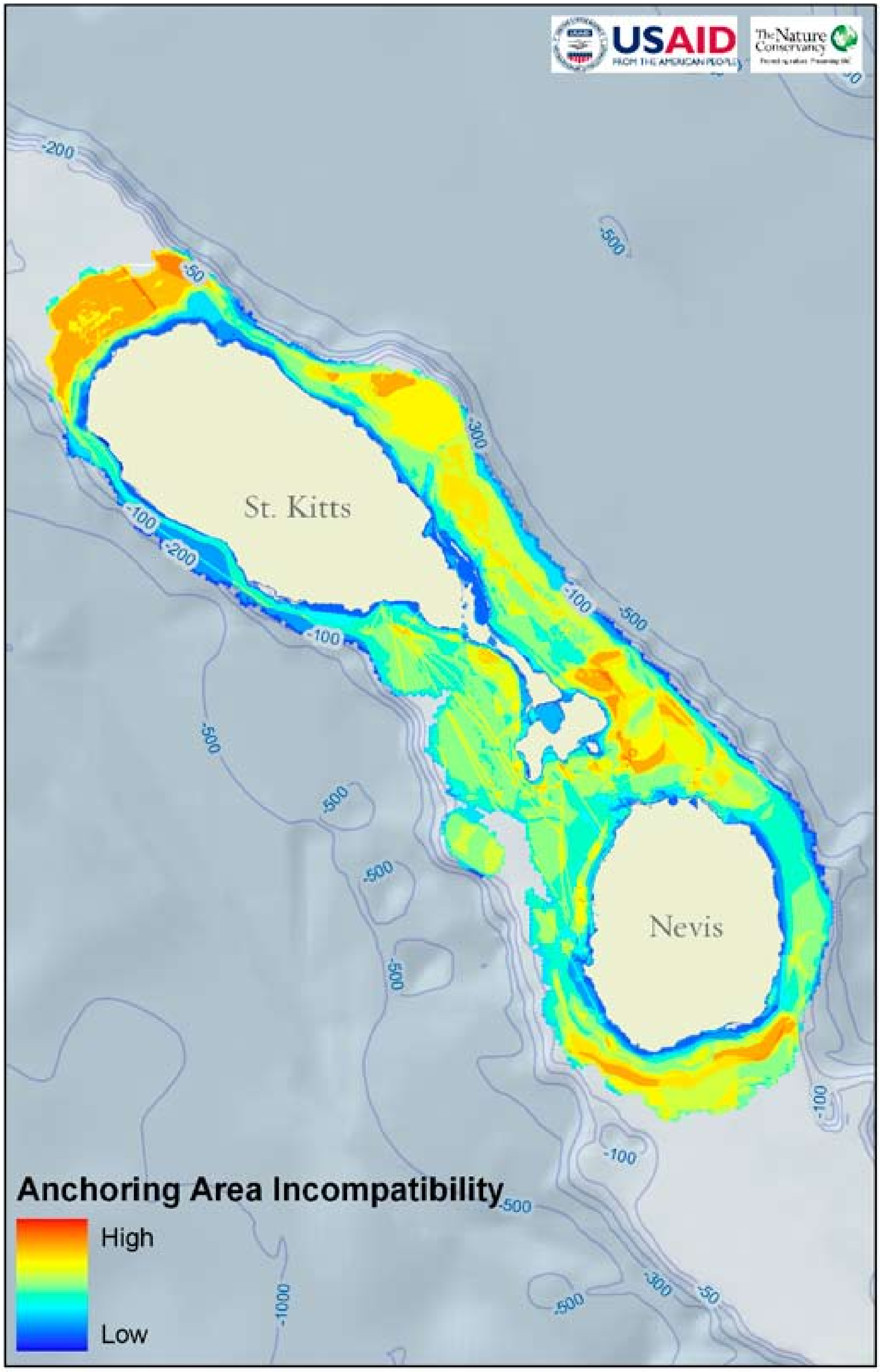
(m) Conservation Feature – Sparse Seagrass: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for conserving sparse seagrass.



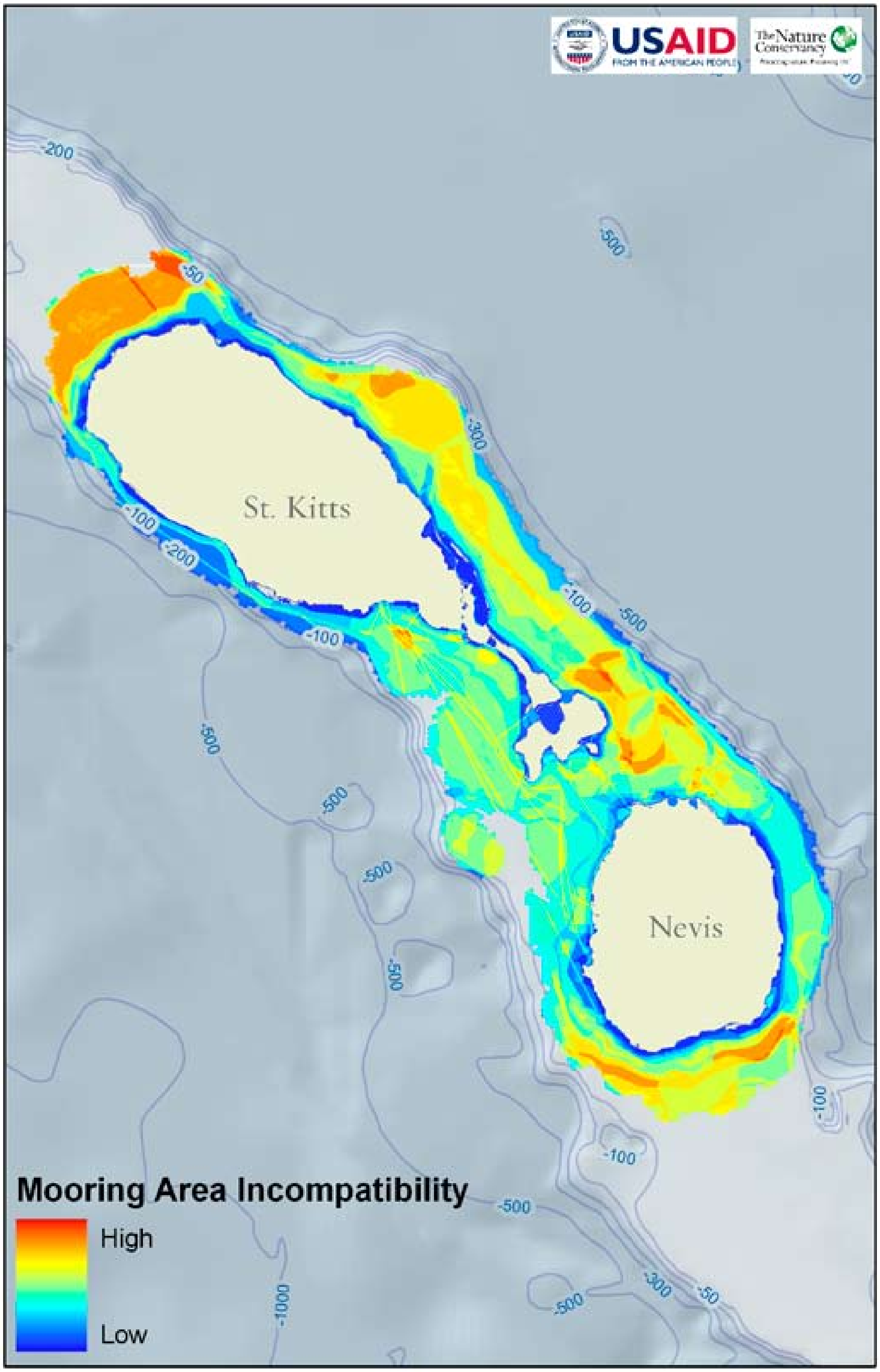
(n) Conservation Feature – Nursery Areas: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for conserving fishery nursery areas.



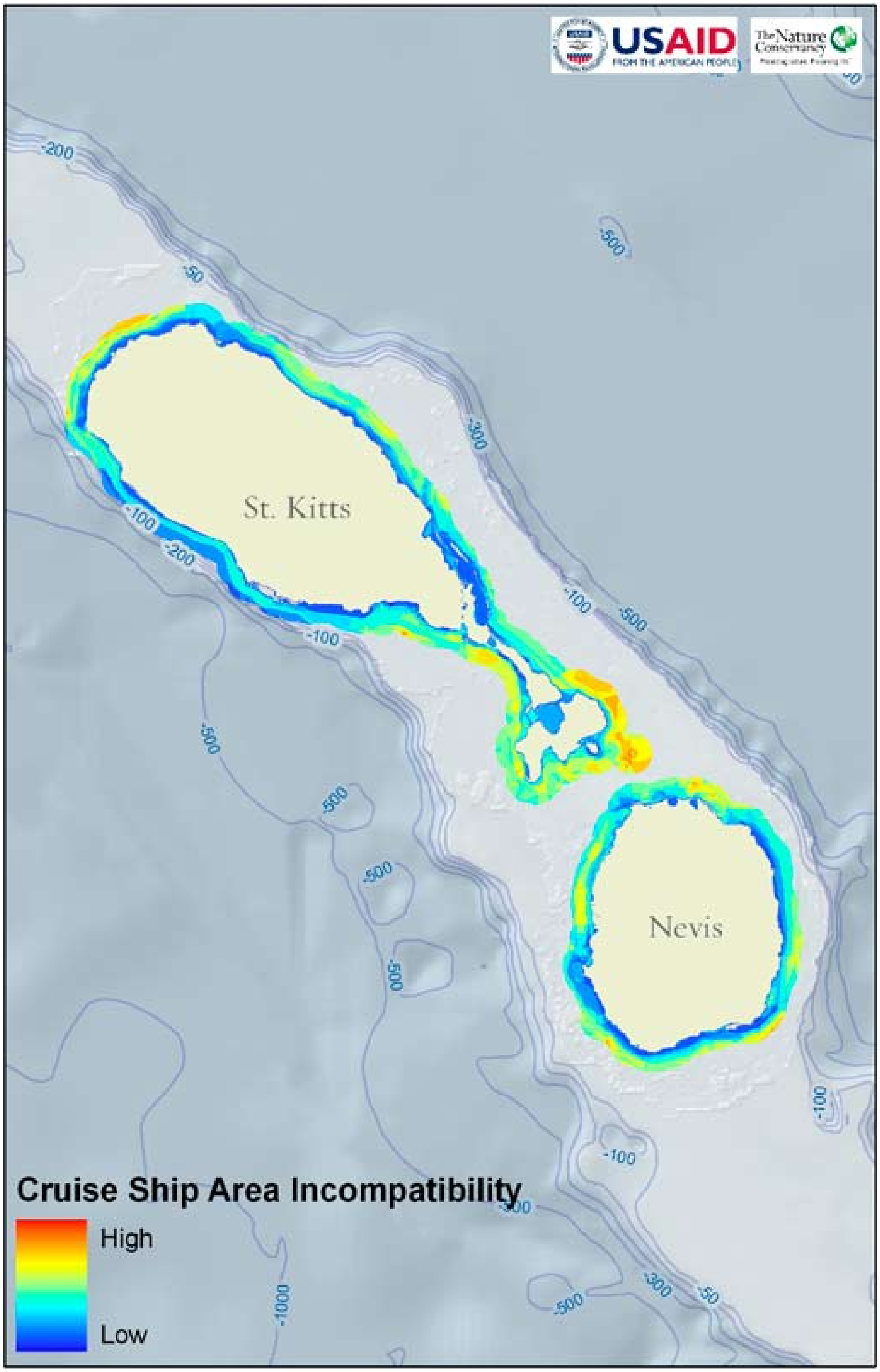
(o) Conservation Feature – Sandy Bottom: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for conserving sandy bottom areas.



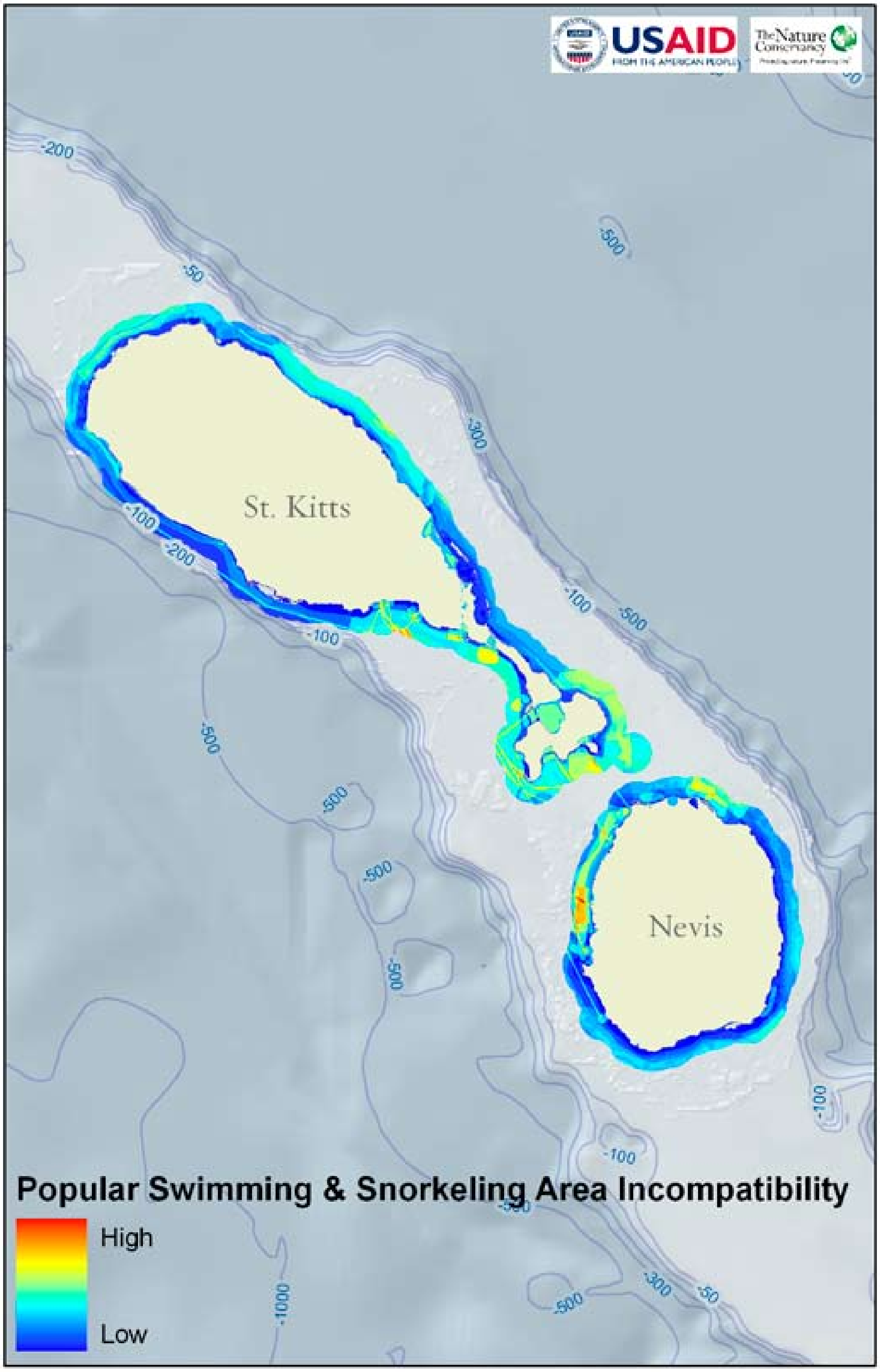
(p) Tourism Activity – Anchoring Areas: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for anchoring.



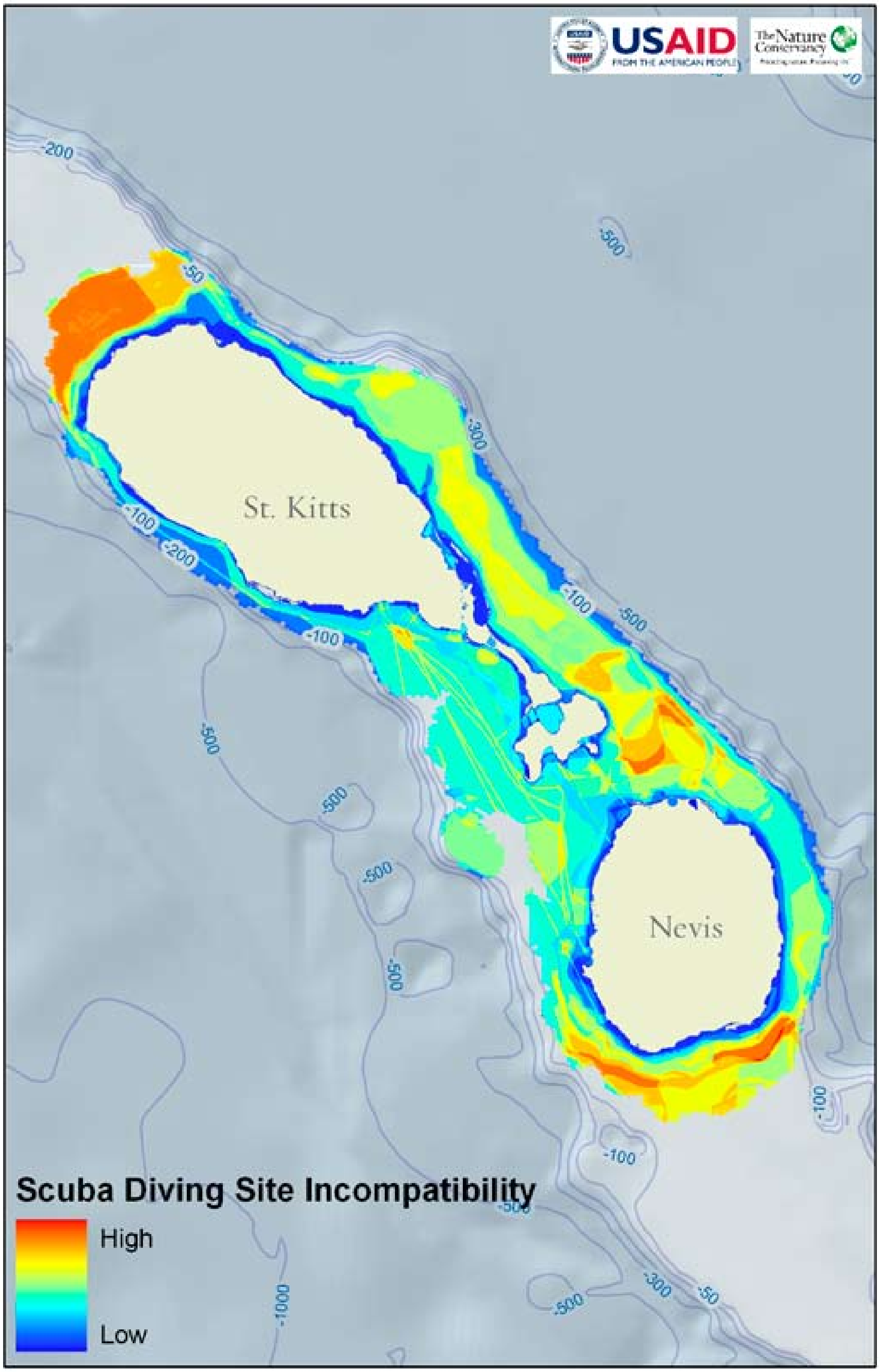
(q) Tourism Activity – Mooring Areas: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for mooring.



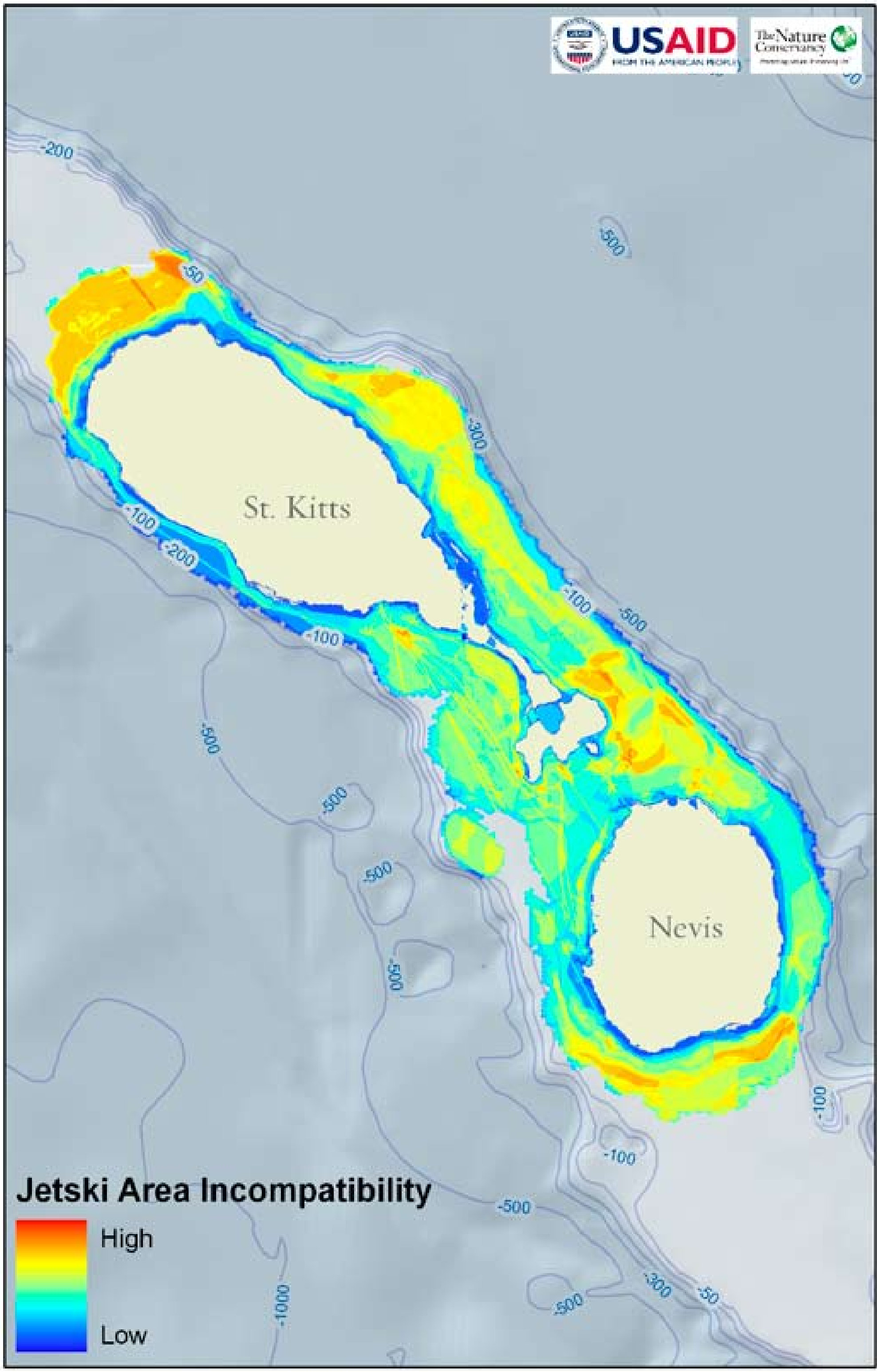
(r) Tourism Activity – Cruise Ship Areas: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for cruise ships.



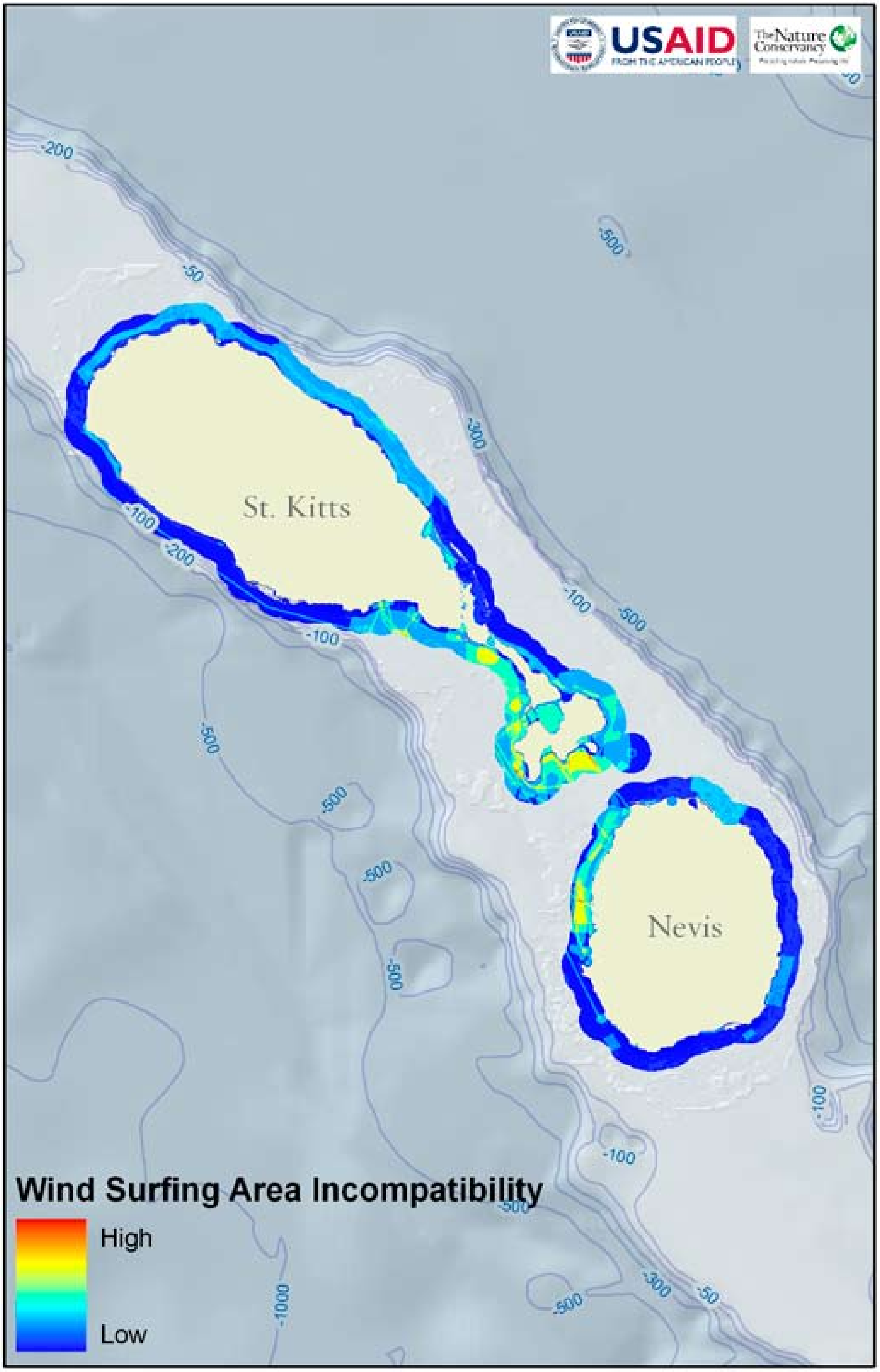
(s) Tourism Activity – Swimming & Snorkeling: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for swimming and snorkeling.



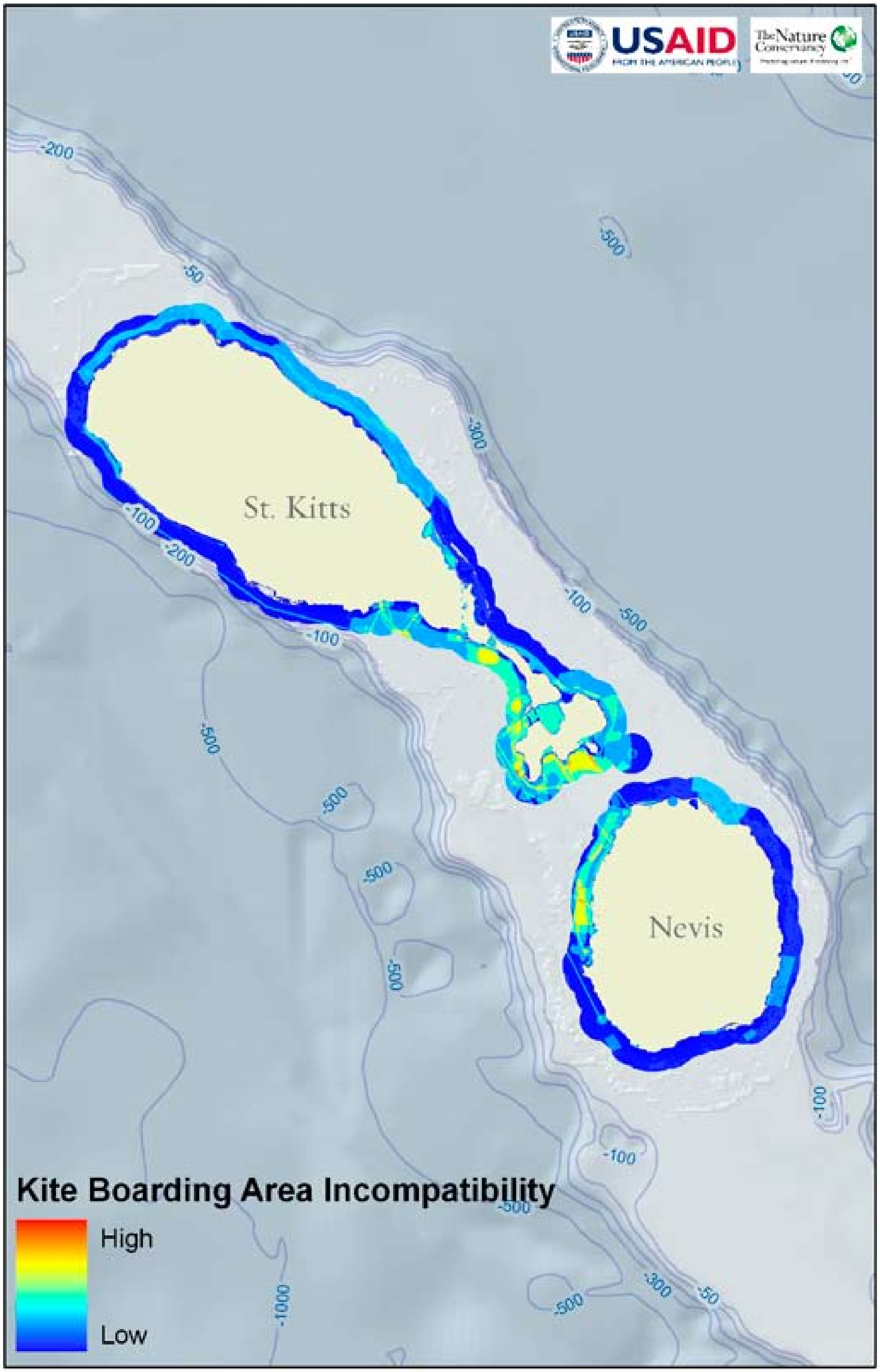
(t) Tourism Activity – Scuba Diving Sites: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for scuba diving.



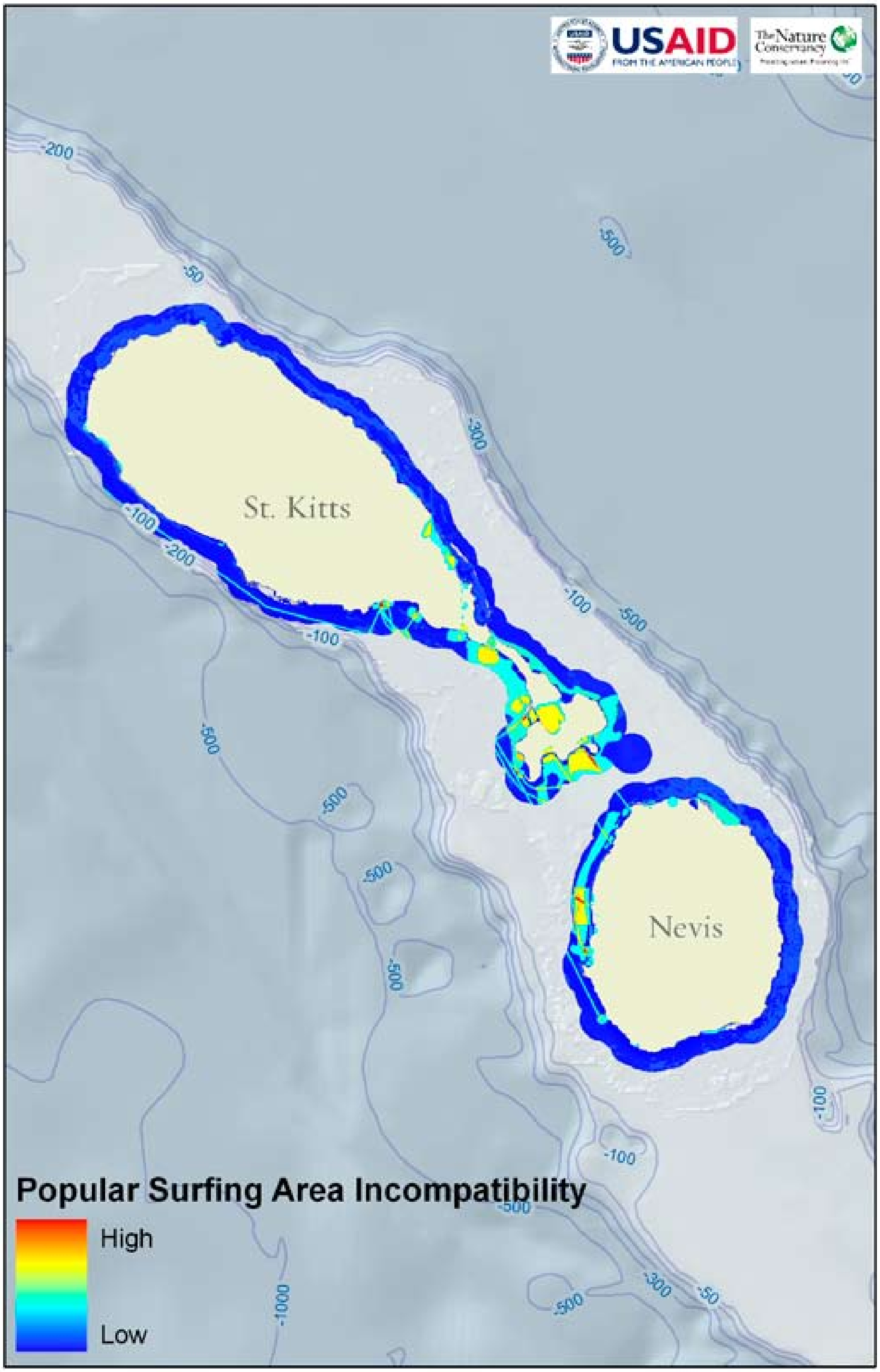
(u) Tourism Activity – Jet Ski Areas: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for jet skiing.



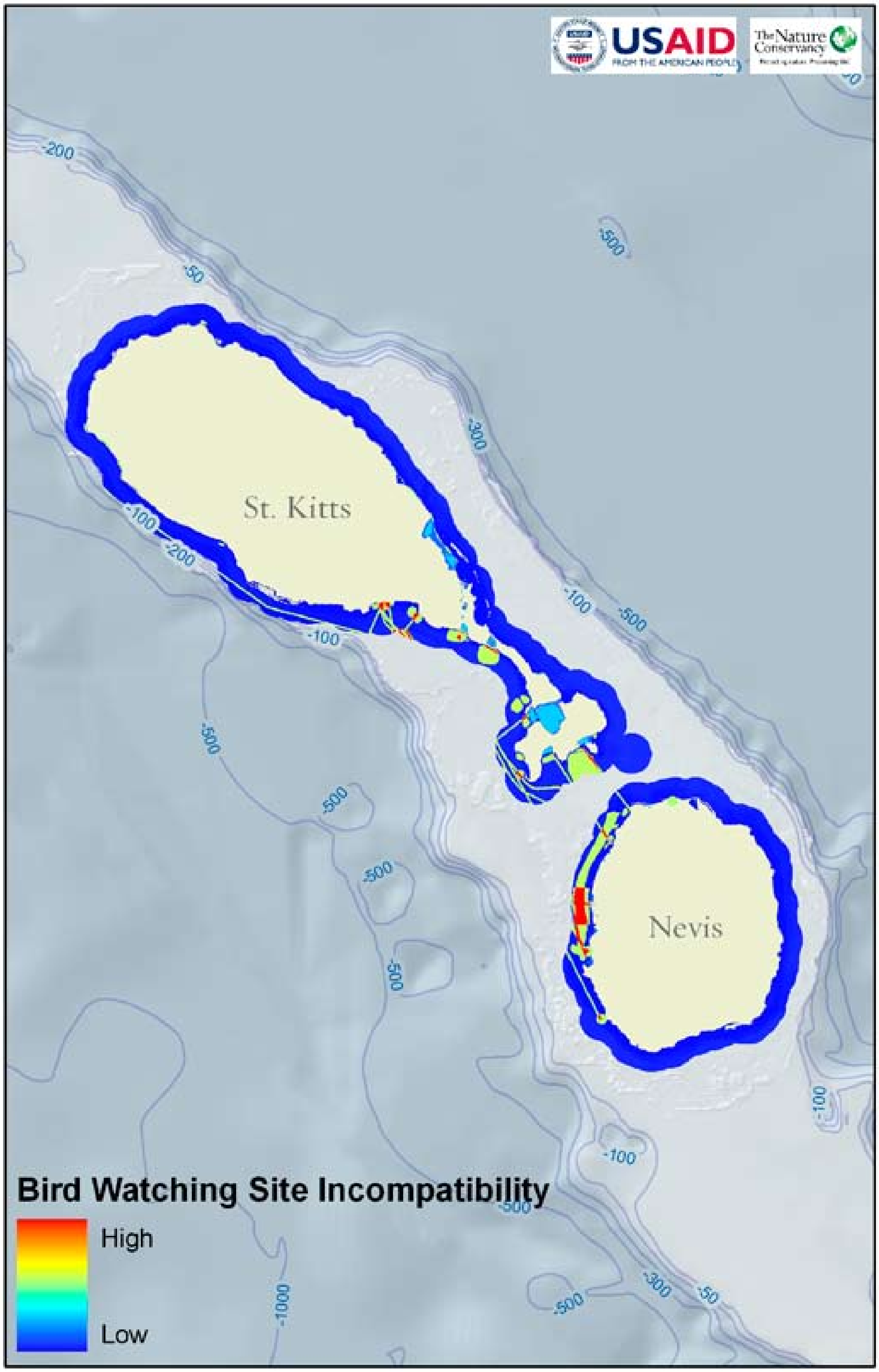
(v) Tourism Activity – Wind Surfing: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for wind surfing.



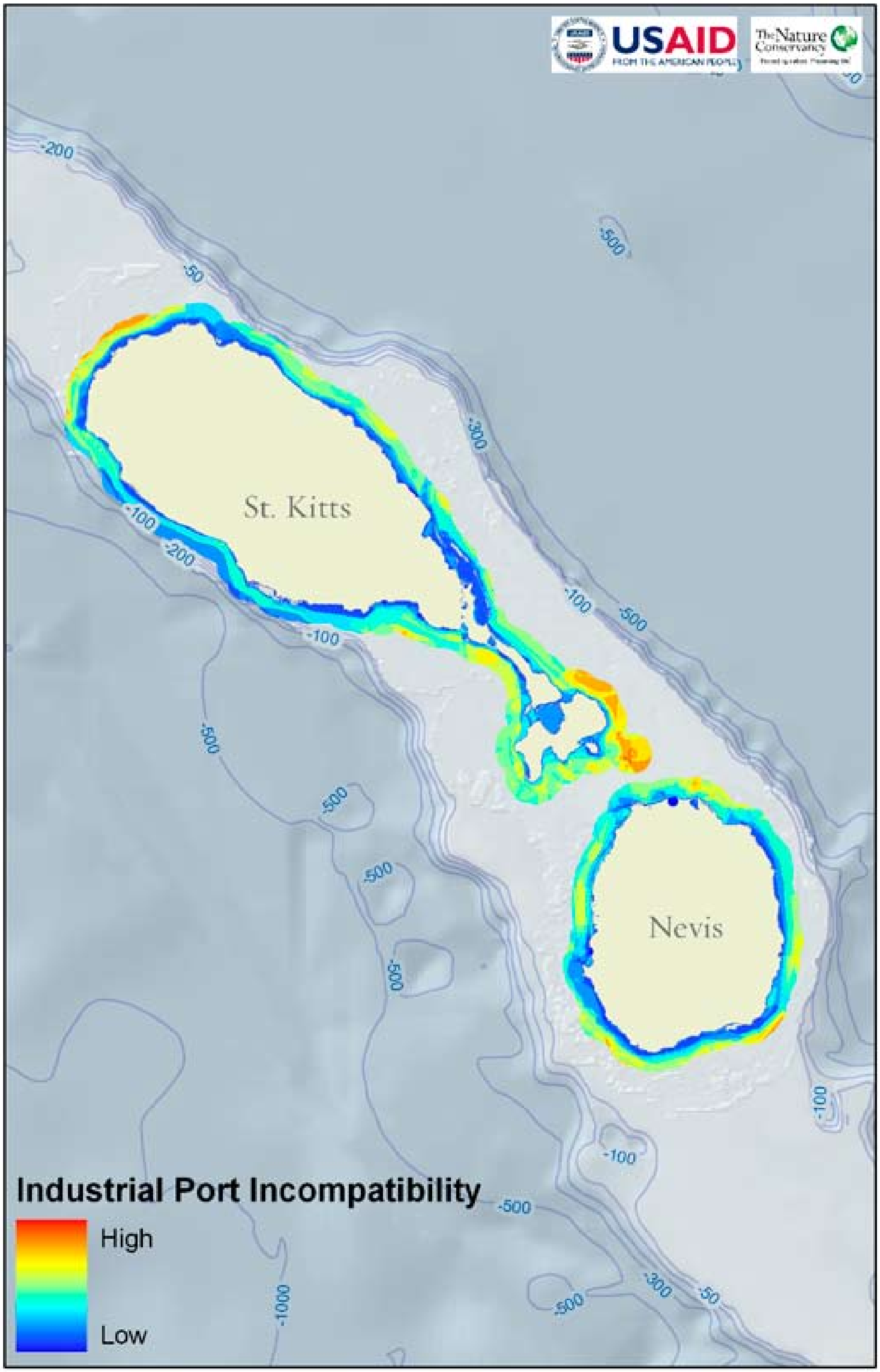
(w) Tourism Activity – Kite Boarding Areas: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for kite boarding.



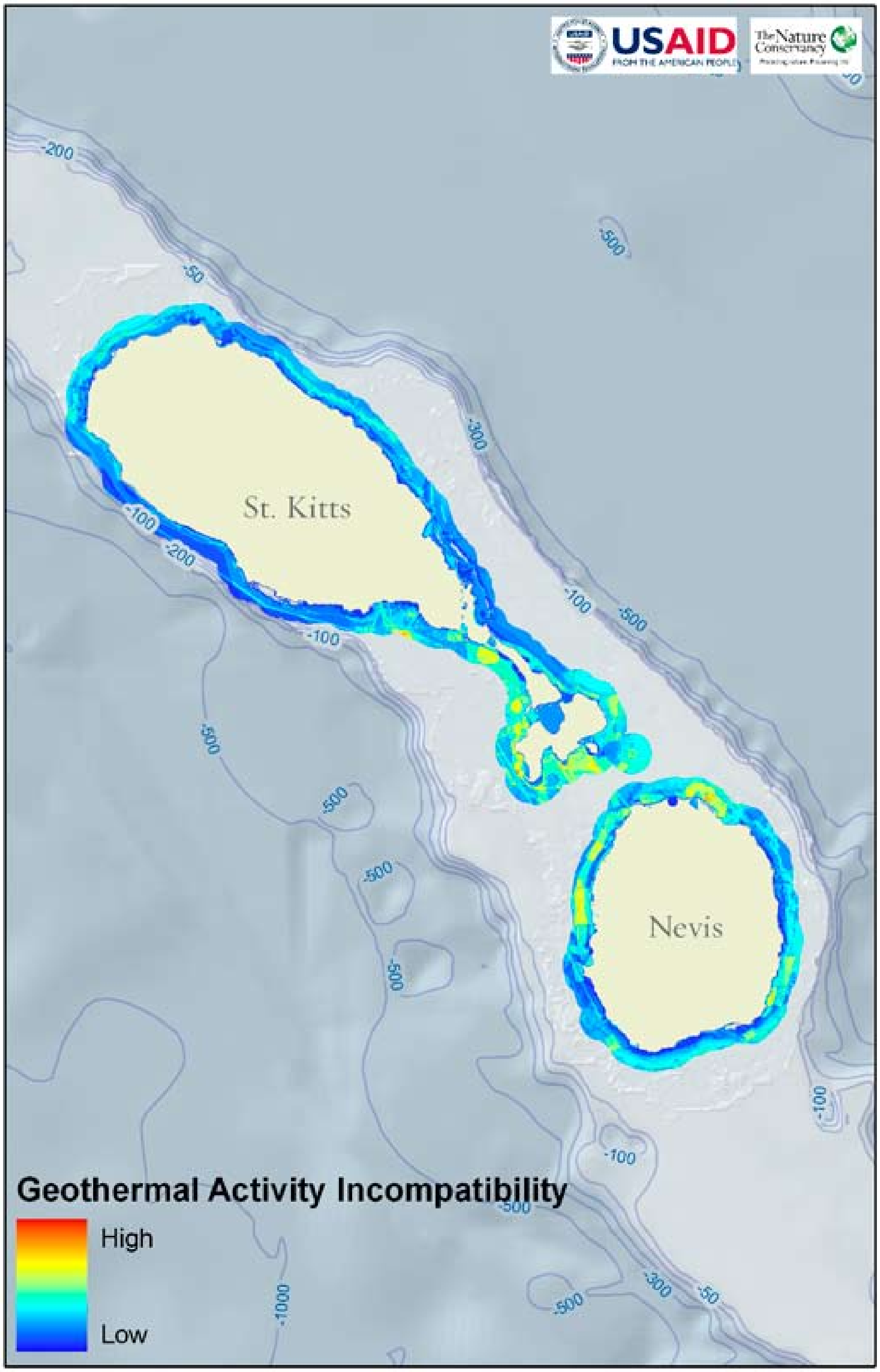
(x) Tourism Activity – Surfing: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for surfing.



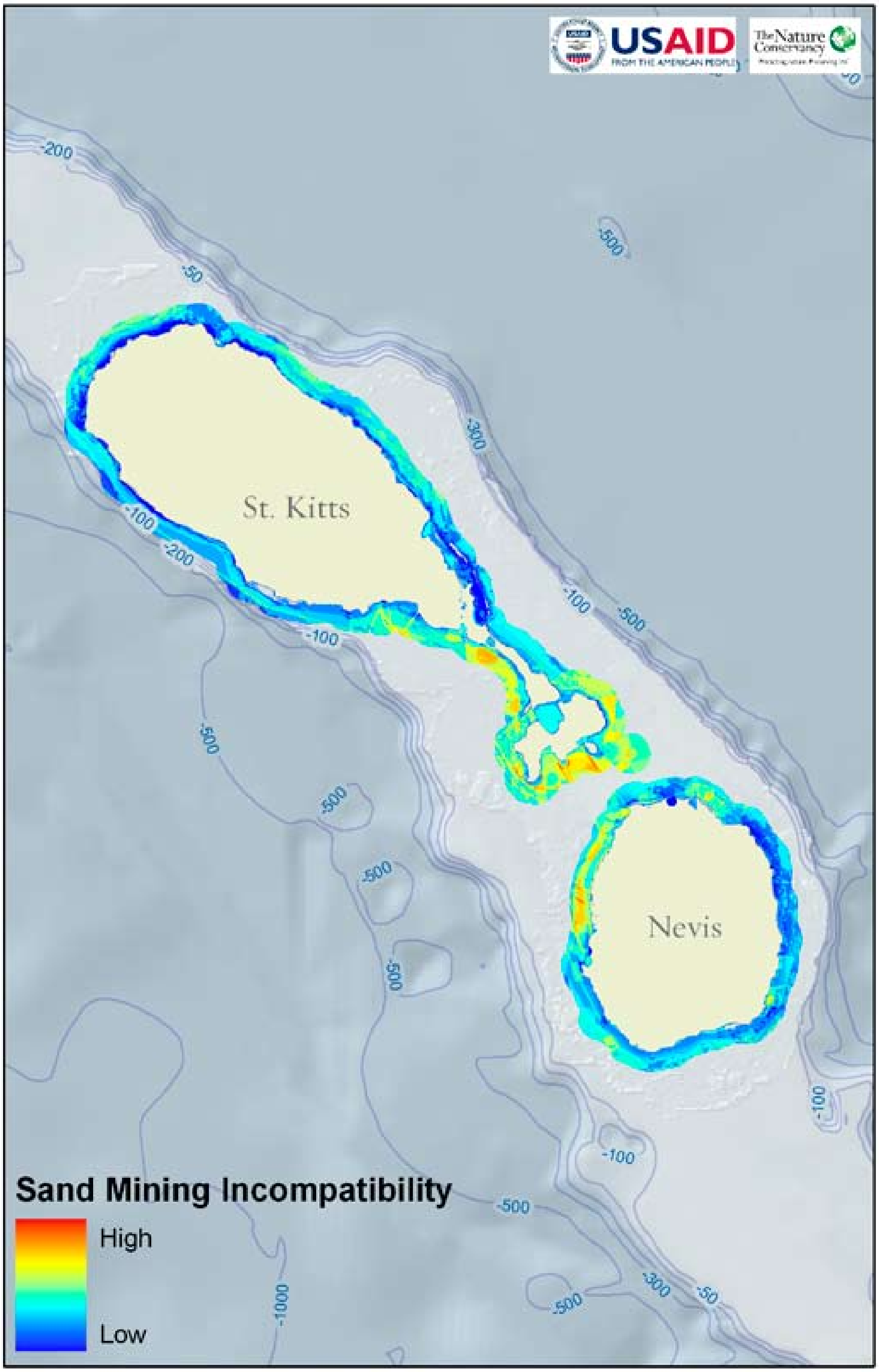
(y) Tourism Activity – Bird Watching: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for bird watching.



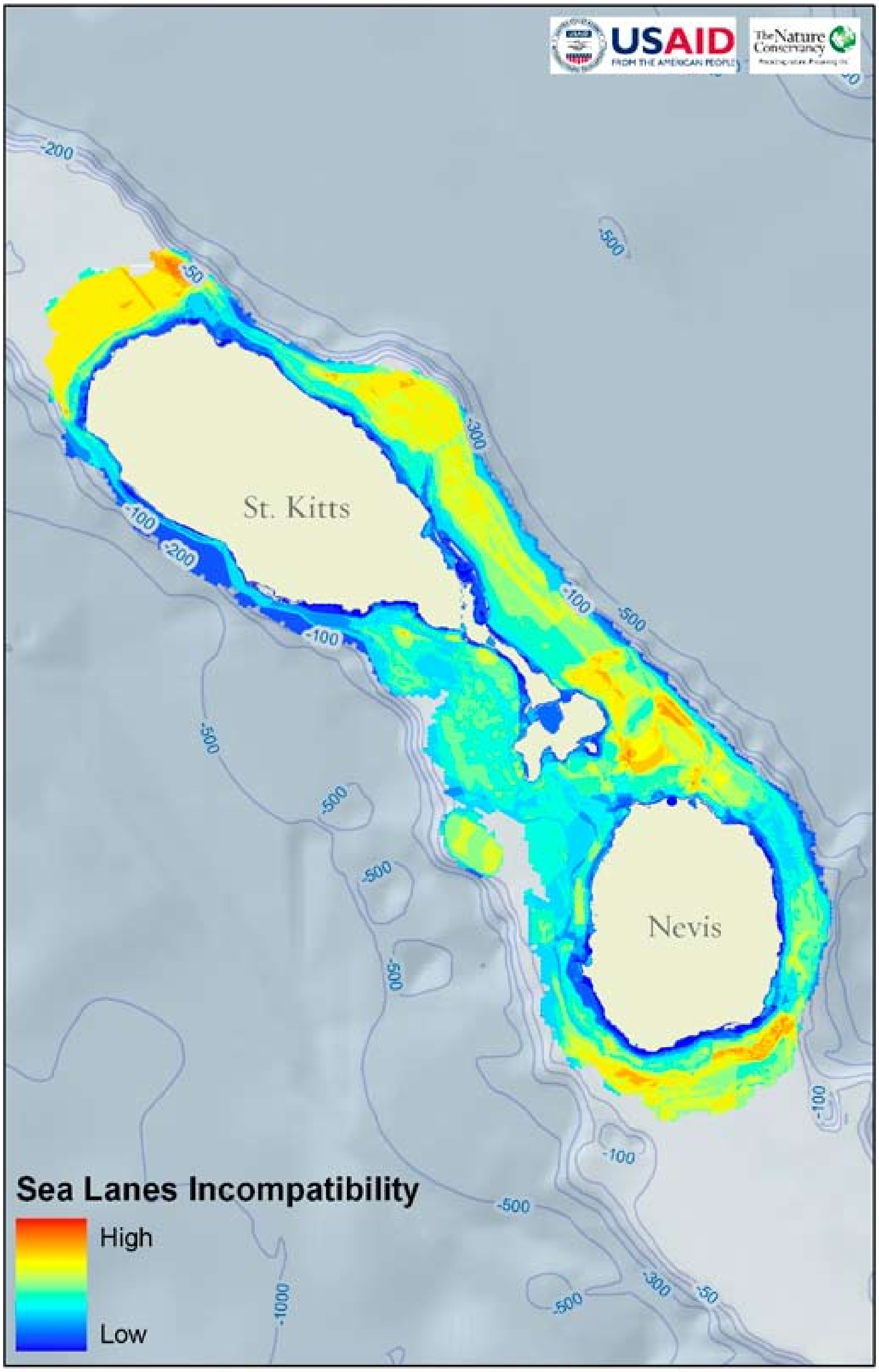
(z) Industrial Activity – Industrial Ports: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for industrial uses of industrial ports.



(aa) Industrial Activity – Geothermal Vents: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for industrial uses of geothermal vents.

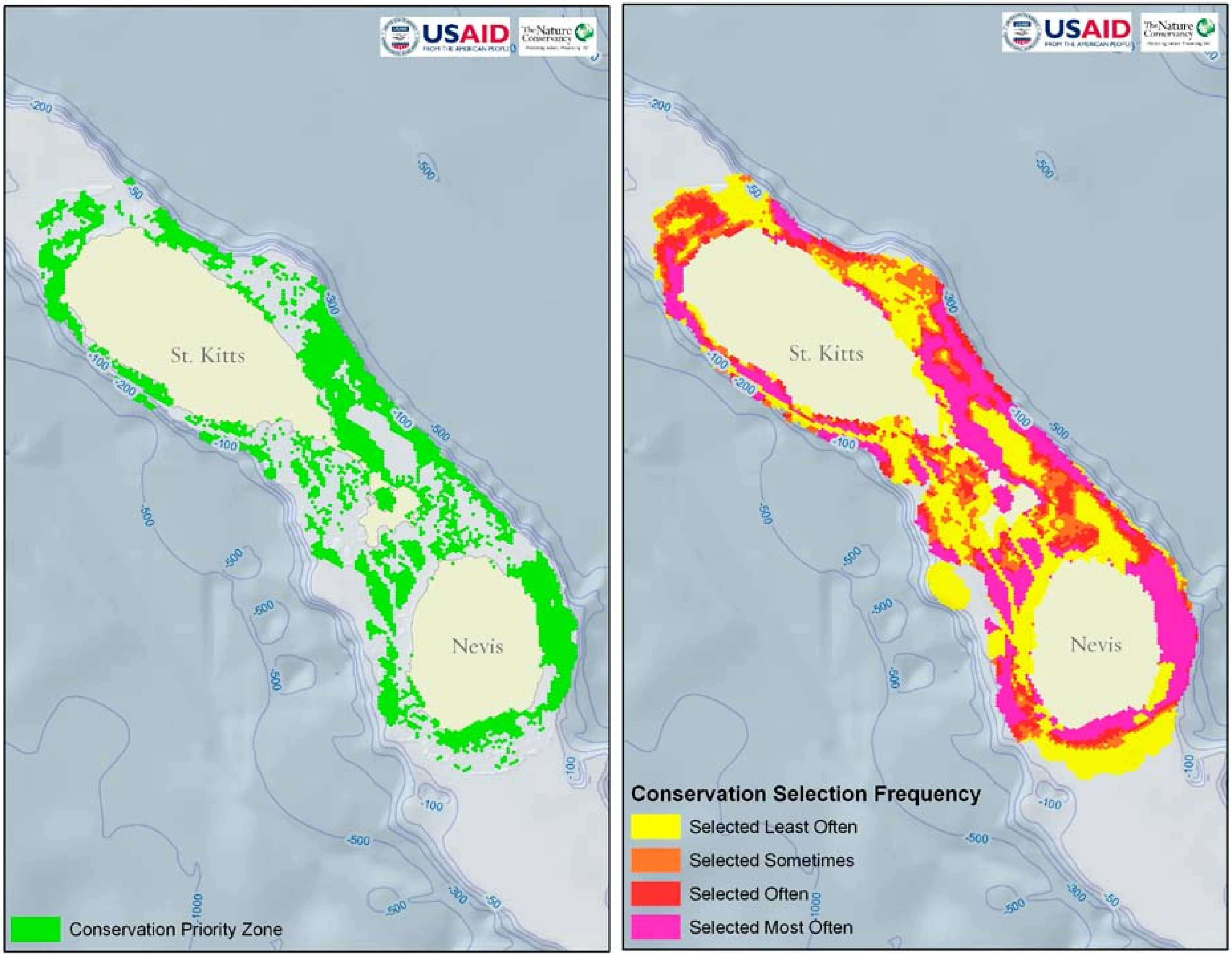


(bb) Industrial Activity – Sand Mining: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for sand mining.

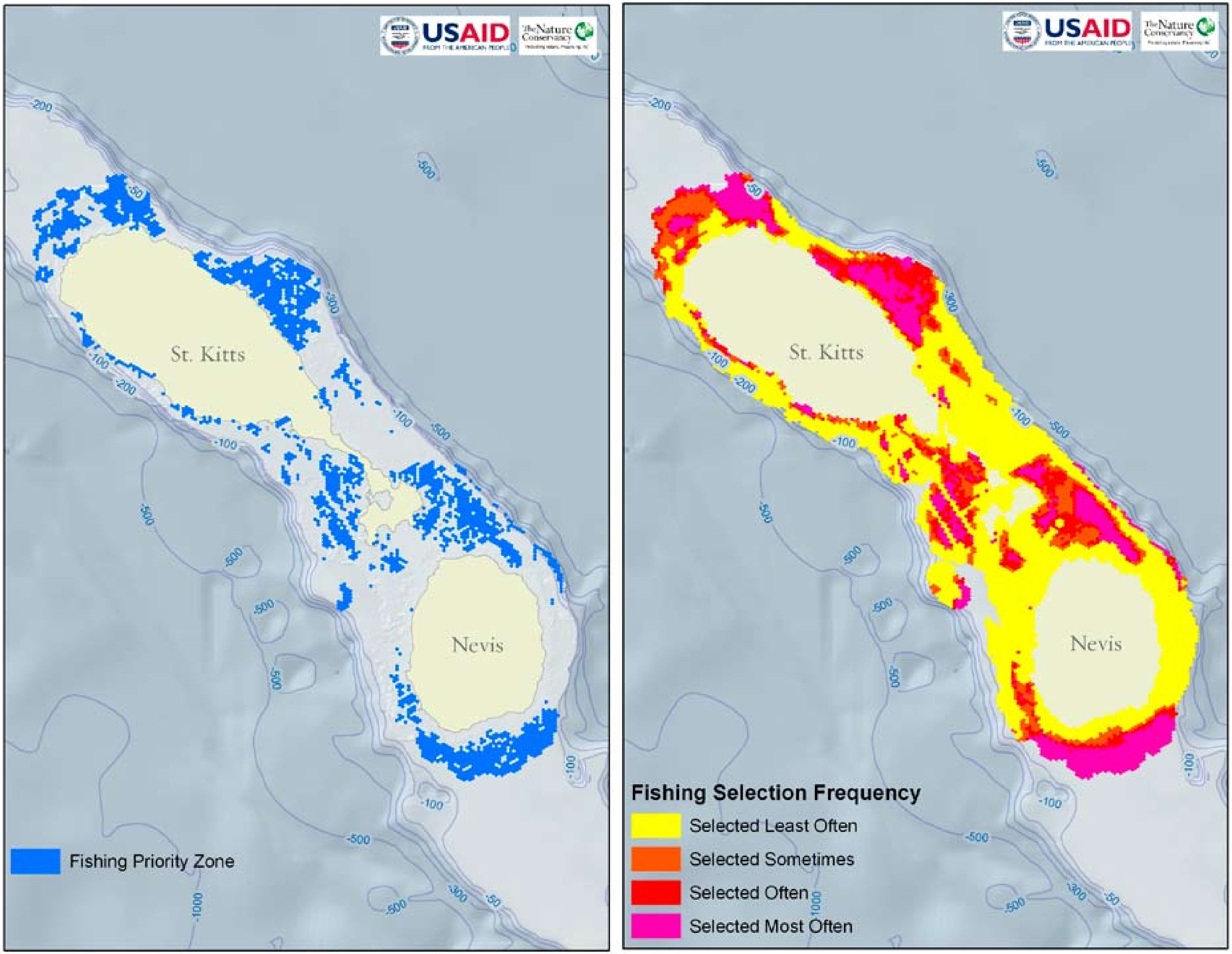


(cc) Transportation Activity – Sea Lanes: Areas in red and yellow indicate higher levels of incompatibility (or potential conflict) for sea lane traffic.

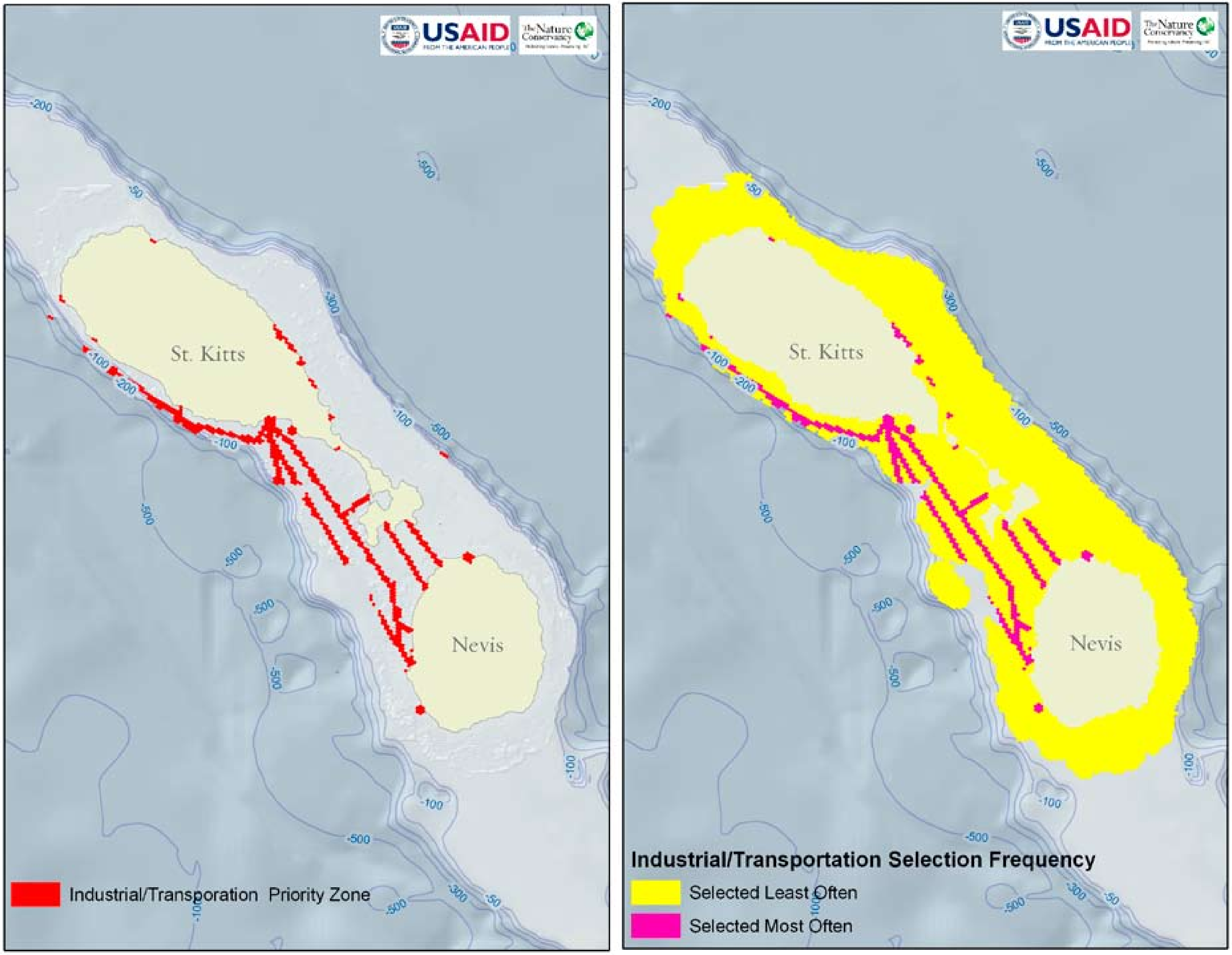
FIGURE E5. **Selection Frequency:** These maps represent information on how often each planning unit was assigned a specific zone based on 100 repetitions of the model. Higher numbers indicate higher value of that planning unit towards contributing to an optimal zoning configuration. These maps are useful to compare between runs in order to identify areas that are consistently assigned to specific zones. Areas that continually are assigned to the same zone, regardless of the run parameters, are important to meeting objectives of that zone.



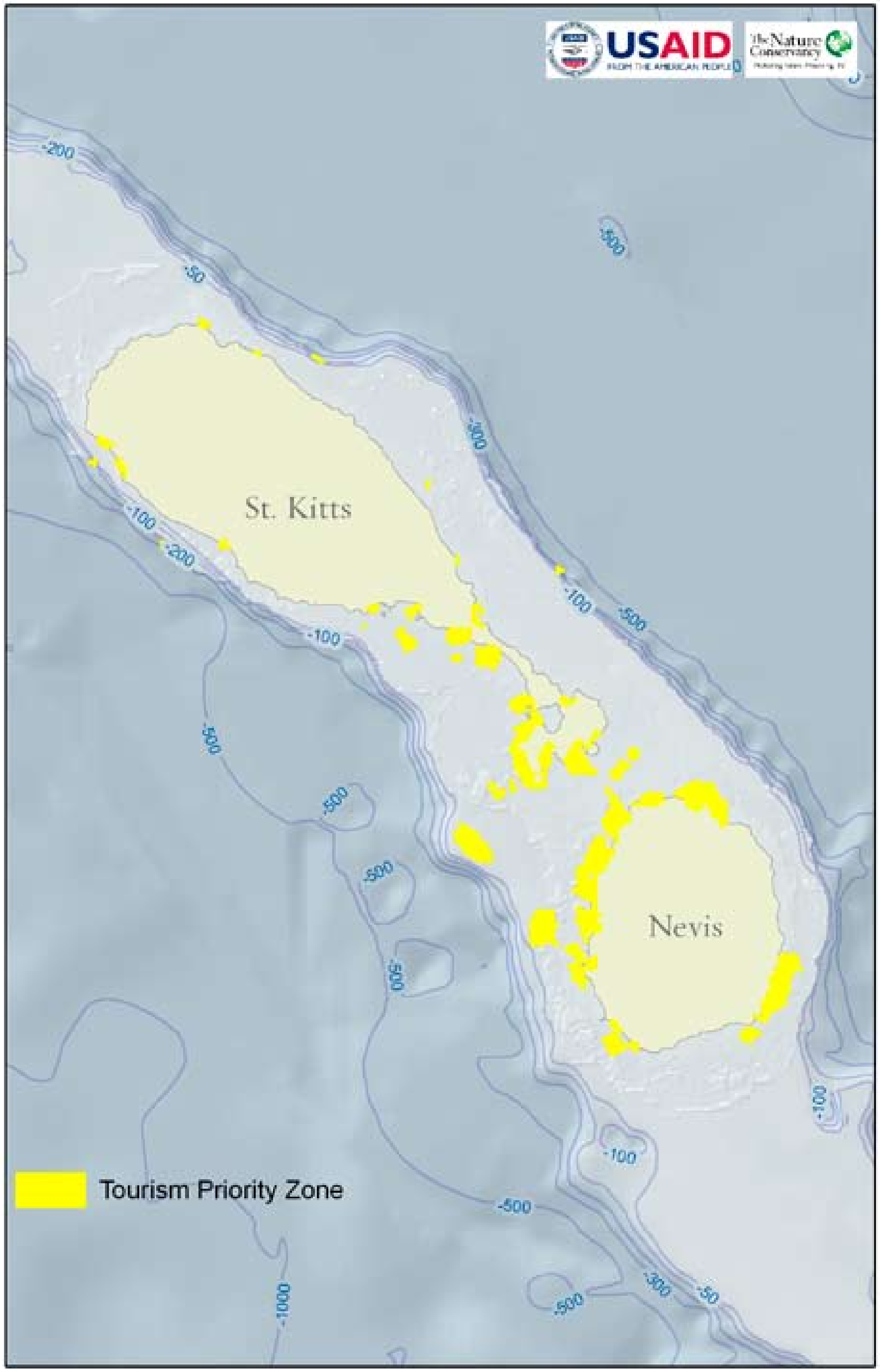
(a) Conservation: On the left are the high-priority conservation zone areas as modeled by Marxan with Zones, indicating an optimized solution for meeting conservation goals. On the right is the modeled selection frequency of the same solution showing the results in four classes of priority based on how often the areas were selected for inclusion in the solution.

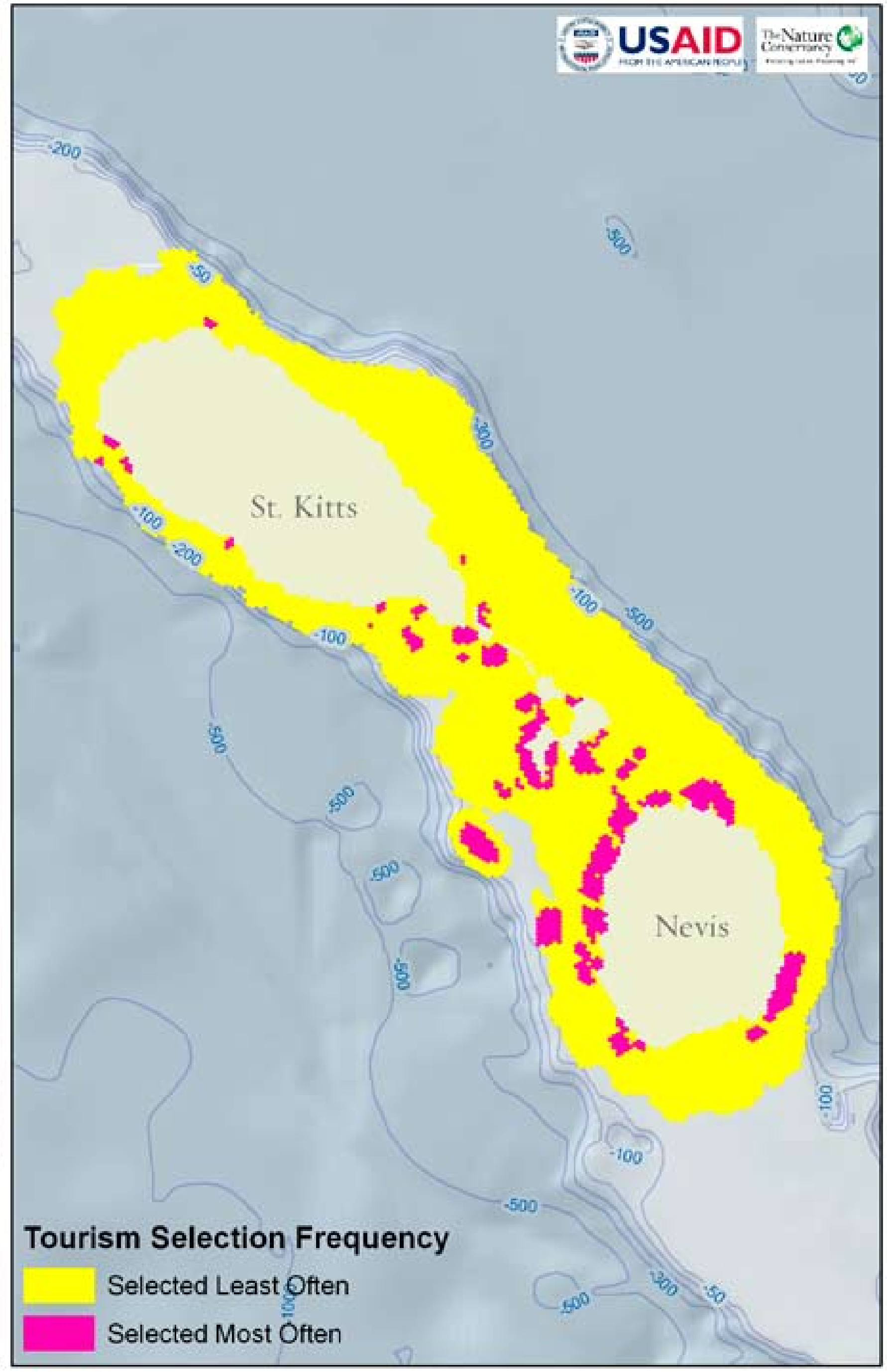


(b) Fishing: On the left are the high-priority fishing zone areas as modeled by Marxan with Zones, indicating an optimized solution for meeting fishing goals. On the right is the modeled selection frequency of the same solution showing the results in four classes of priority based on how often the areas were selected for inclusion in the solution.



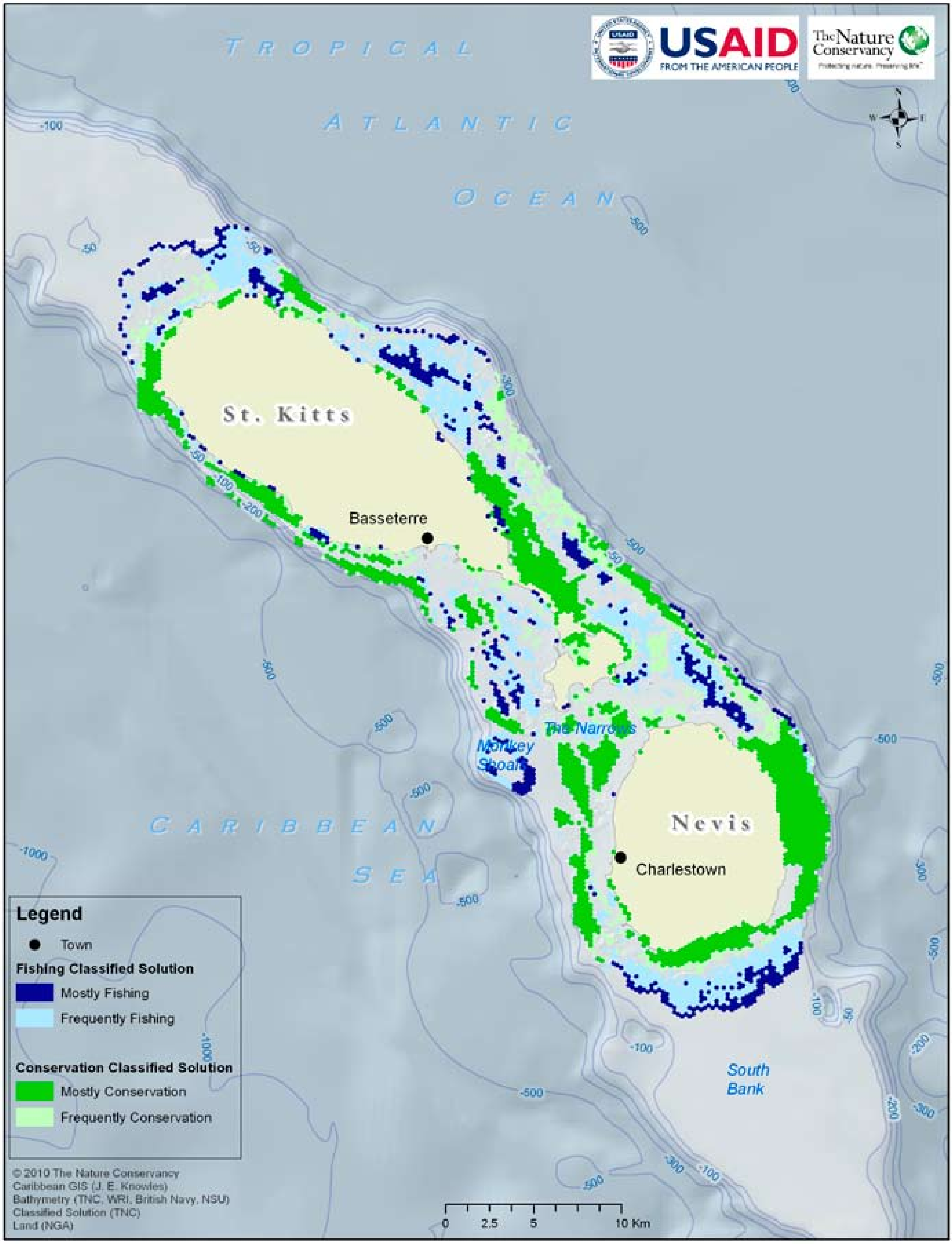
(c) Industrial/Transportation: On the left are the industrial/transportation areas that were locked into the zoning solution for the Flat Goal 30% and Variable Goals Reduced scenarios. On the right is the selection frequency of industrial/transportation areas showing locked (Selected Most Often) versus non-locked (Selected Least Often) locations.



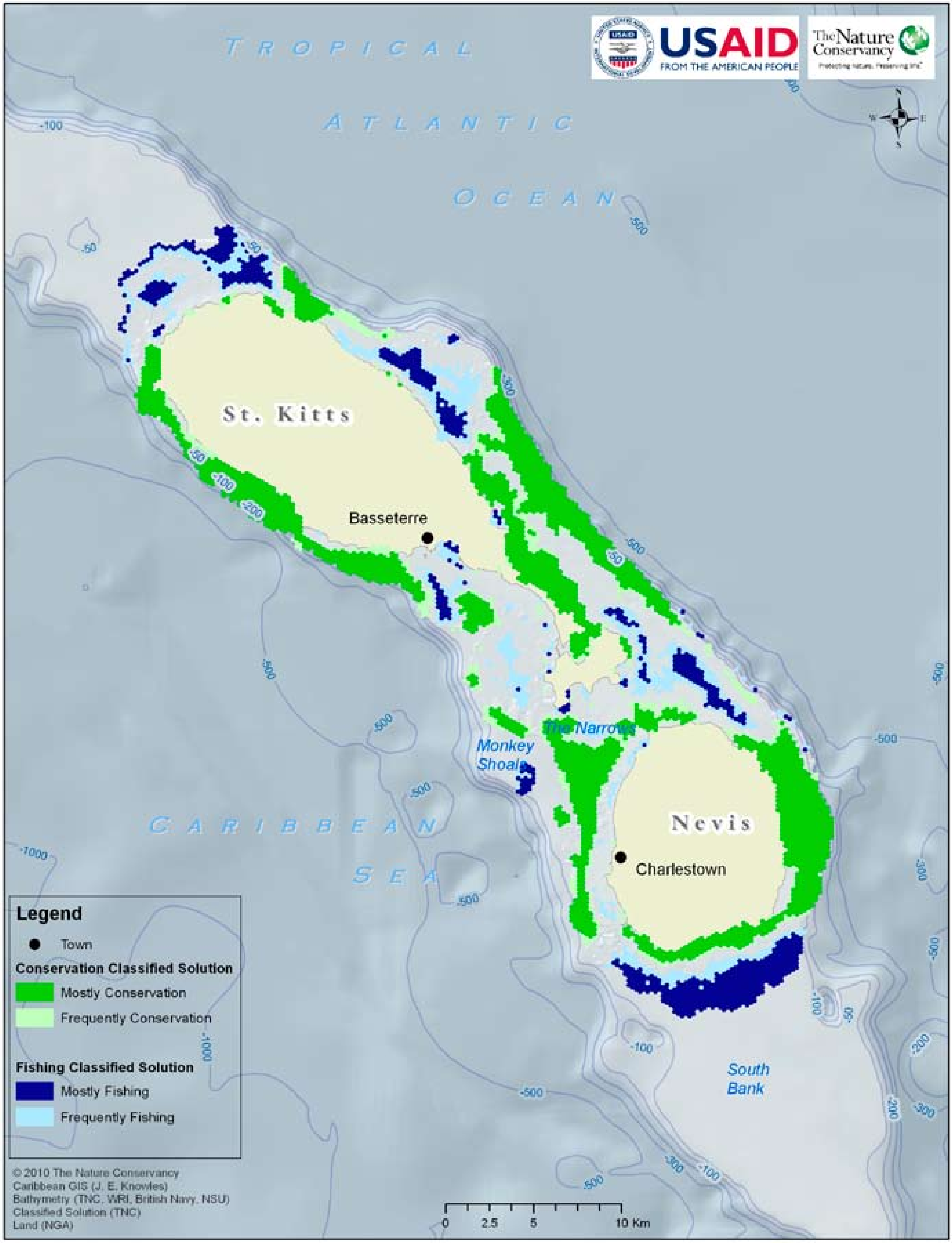


(d) Tourism: On the left are the tourism areas that were locked into the zoning solution for the Flat Goal 30% and Variable Goals Reduced scenarios. On the right is the selection frequency of tourism areas showing locked (Selected Most Often) versus non-locked (Selected Least Often) locations.

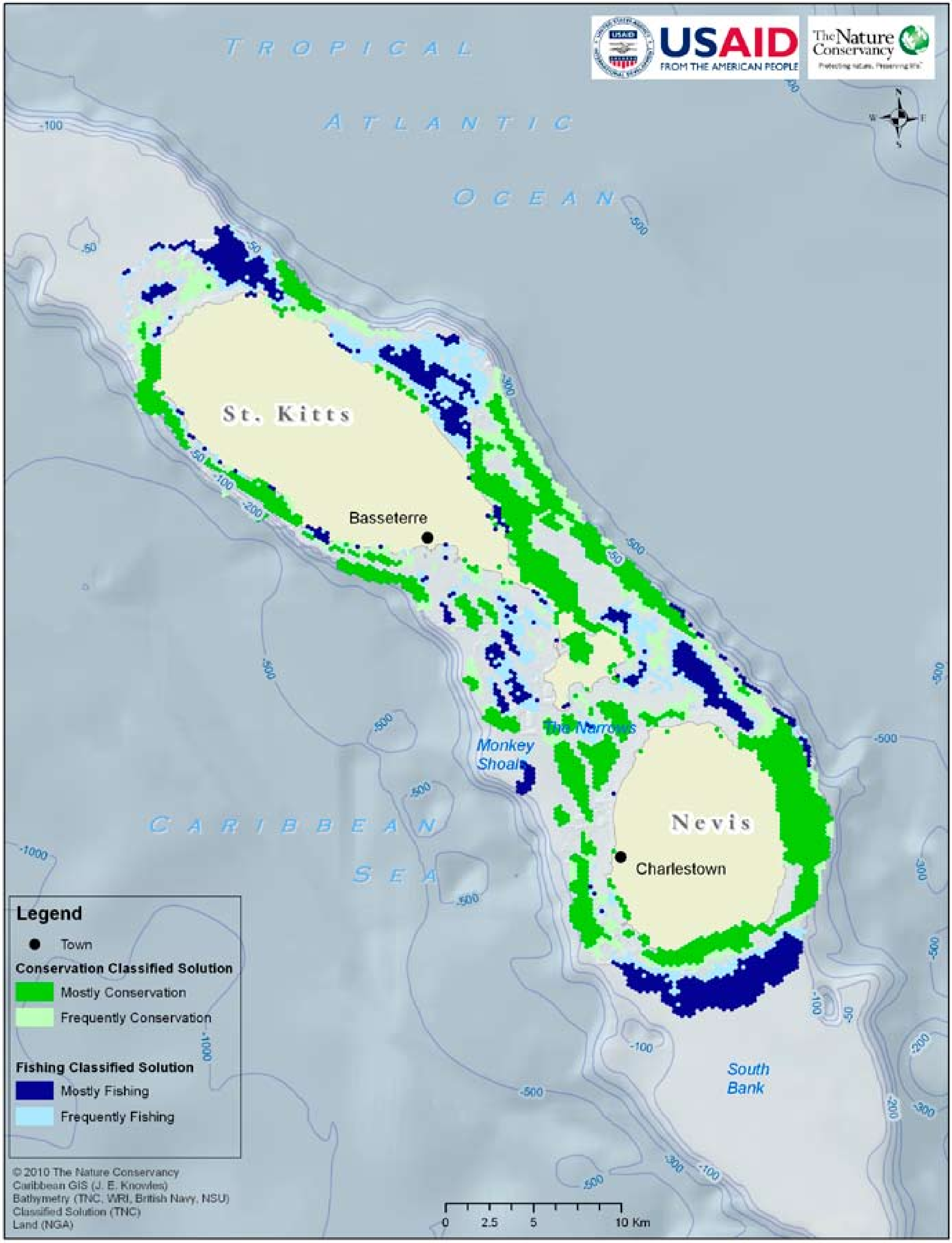
FIGURE E6. **Classified Solution:** These maps are similar to the selection frequency maps, but they integrate outputs for all four zones, categorizing each planning unit based on the number of times it was assigned or not assigned to each zone. In St. Kitts and Nevis, we focused on conservation and fishing, because tourism and industrial transportation had more fixed spatial distributions and limited footprints.



(a) Flat Goal 30% Lock: Fishing-priority and conservation-priority solutions based on the Flat Goal 30% Lock scenario using Marxan with Zones. Areas in dark blue indicate higher priority areas for reaching fishing goals, and areas in dark green represent higher priority areas for reaching conservation goals.

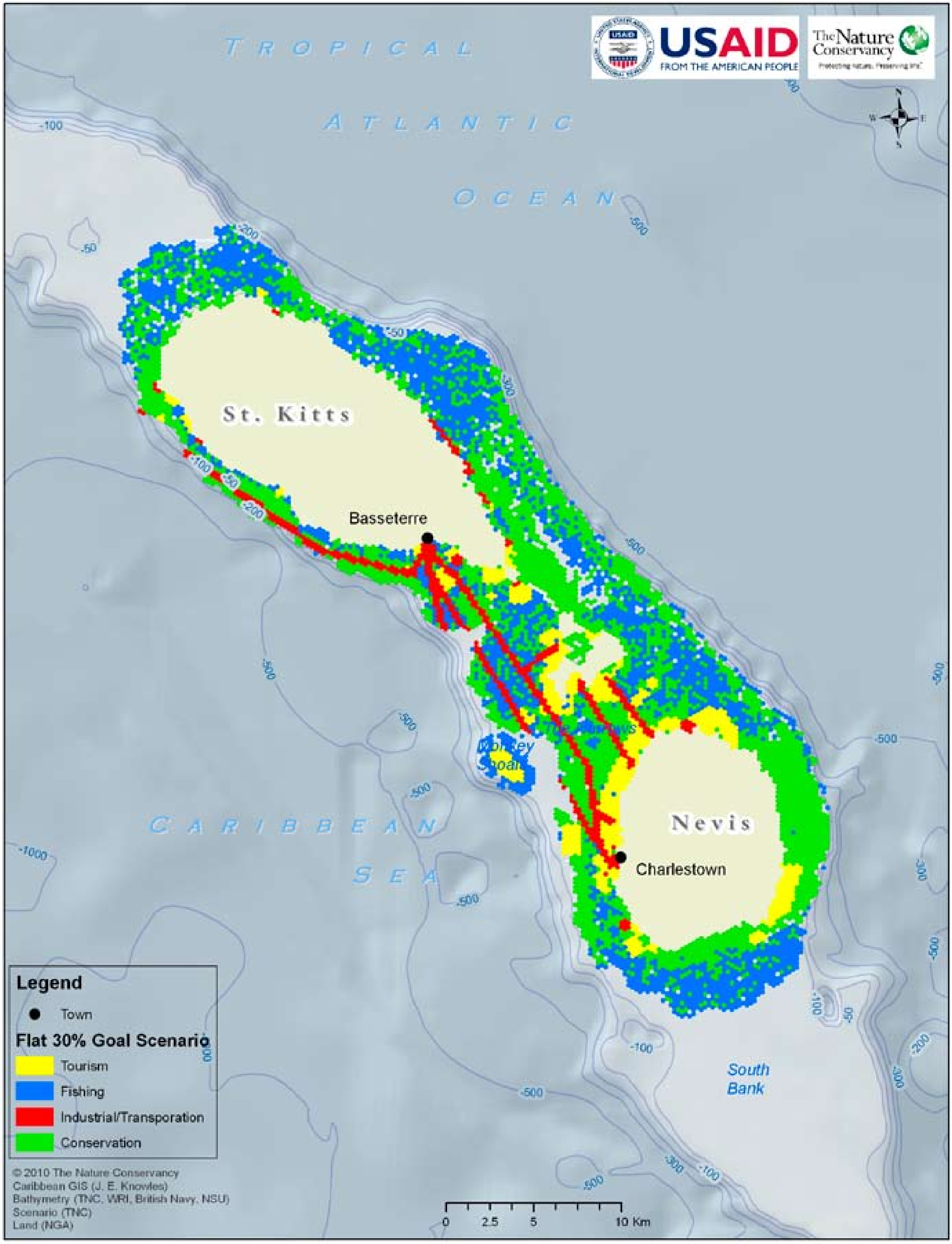


(b) Flat Goal 60% No Lock: Fishing-priority and conservation-priority solutions based on the Flat Goal 60% No Lock scenario using Marxan with Zones. Areas in dark blue indicate higher priority areas for reaching fishing goals and areas in dark green represent higher priority for optimally reaching conservation goals.

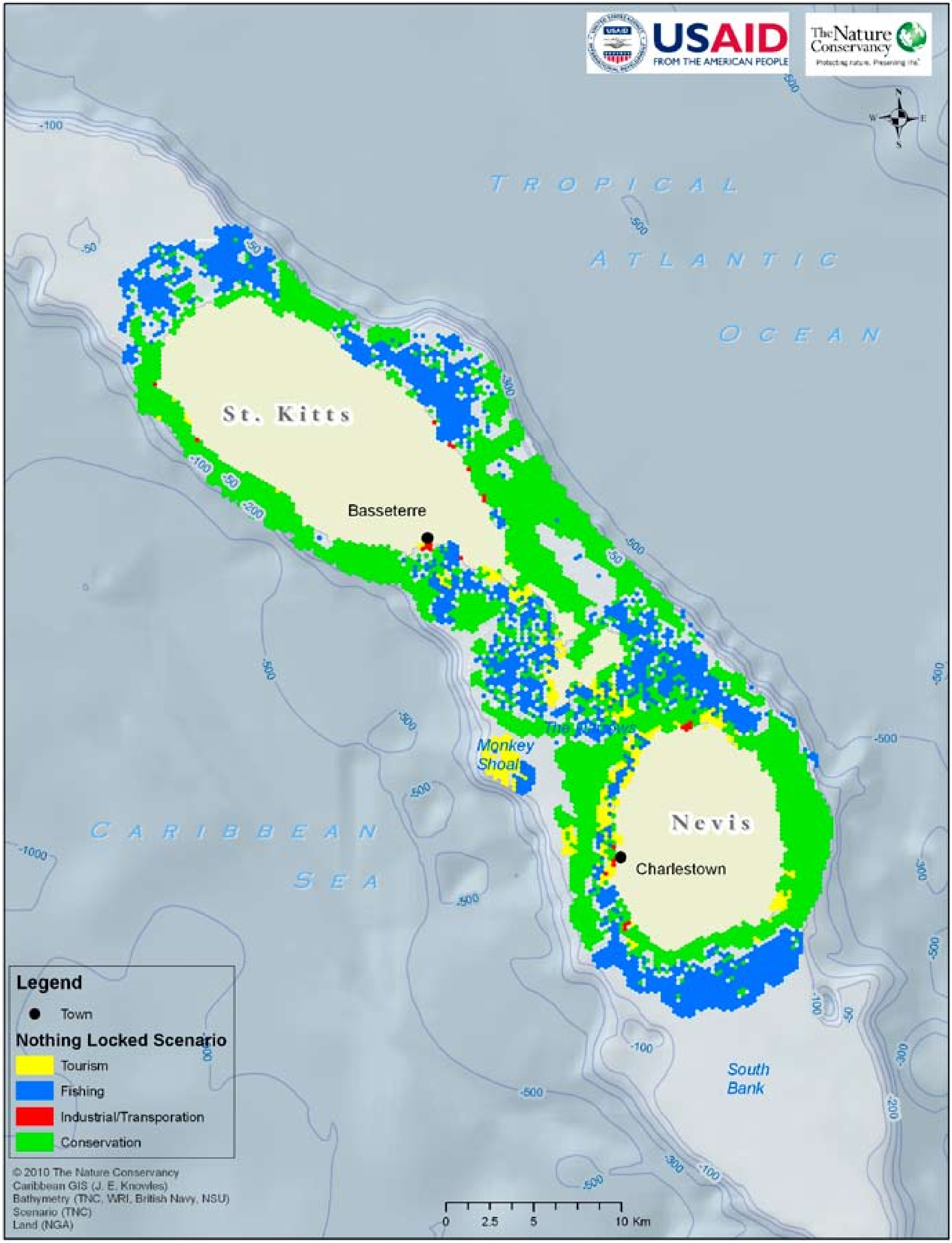


(c) Variable Goals Reduced Lock: Fishing-priority and conservation-priority solutions based on the Variable Goal Reduced Lock scenario using Marxan with Zones. Areas in dark blue indicate higher priority areas for reaching fishing goals, and areas in dark green represent higher priority areas for reaching conservation goals.

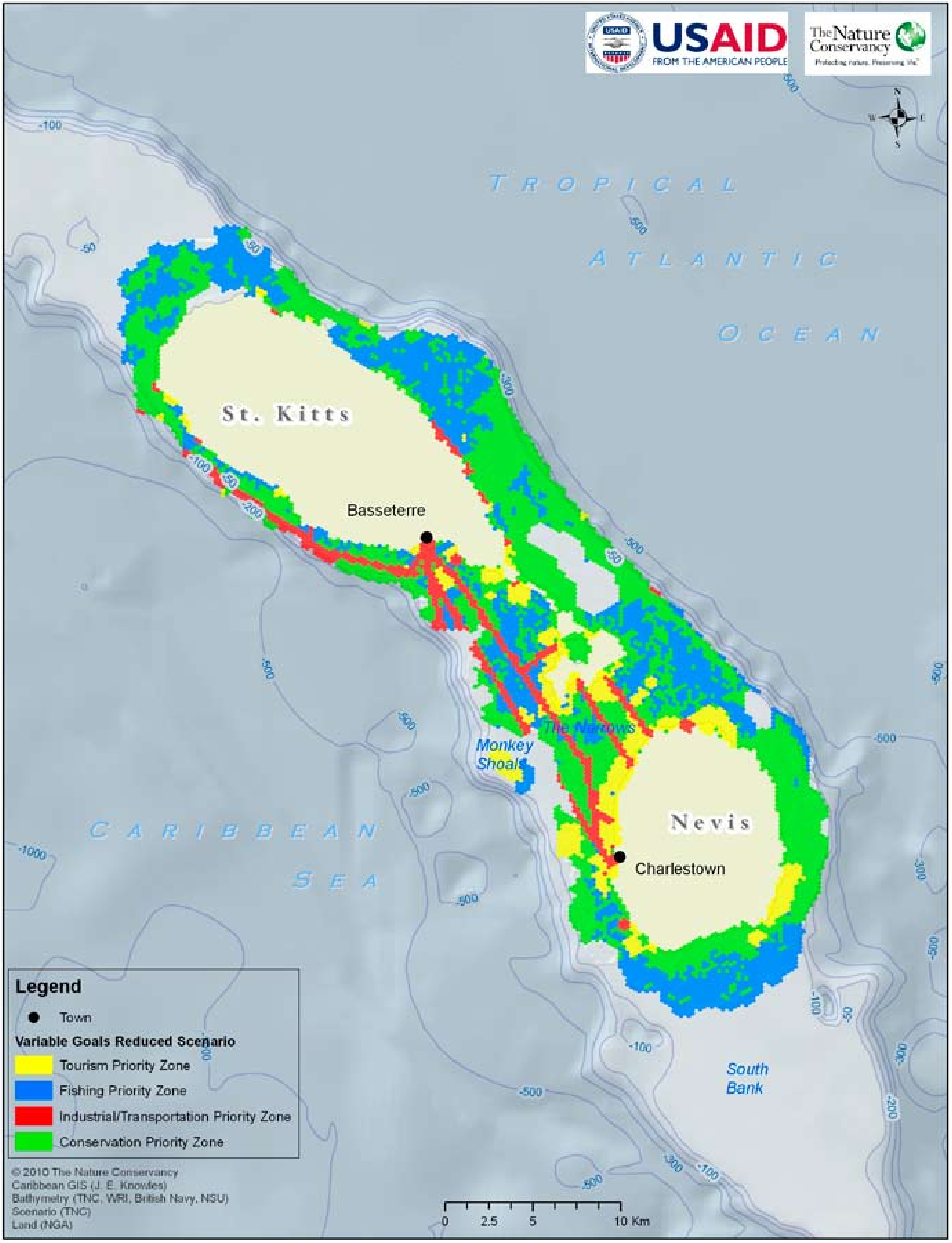
FIGURE E7. Best Solution: These maps represent the final, best (i.e., most compatible, least conflict) zoning configuration out of a set of 100 repetitions for each scenario. The "best solution" maps, often referred to as the most efficient solutions, represent the configuration of zones that best reduces overall conflict when trying to achieve zoning objectives and goals. It should be noted that the "best solution" maps represent only one solution amongst a set of different possible solutions. The terminology best and most efficient is linked to the mathematical efficiency of this solution, but should not be treated as an ideal scenario.



(a) Zoning Solution for the Flat Goal 30% Lock scenario: Optimized zoning solution for the Flat Goal 30% Lock scenario using Marxan with Zones. In this scenario, all features and activities for each zone were set to a 30% goal except for tourism and industrial/transportation uses that were locked into their respective zones.



(b) Zoning Solution for the Flat Goal 60% No Lock scenario: Optimized zoning solution for the Flat Goal 60% No Lock scenario using Marxan with Zones. In this scenario, all features and activities for each zone were set to a flat 60% goal and no planning units were intentionally locked into the solution.



(c) Zoning Solution for the Variable Goals Reduced Lock scenario: Optimized zoning solution for the Variable Goal Reduced Lock scenario using Marxan with Zones. In this scenario, all features and activities for each zone were set to goals defined in stakeholder workshops, except for tourism and industrial/transportation uses that were locked into their respective zones.

RESULTS AND DISCUSSION

Evaluating the Scenario Output Maps

A comparison of the best solution maps from each scenario reveals the location of core fishing and conservation areas, although the extent and size varies between scenarios. These areas represent the locations where fishing and conservation objectives can be met while minimizing conflict between uses. As an example of the type of analysis that could help support zoning decisions, we report below on the fishing intensity and habitat abundance for the four core fishing and five core conservation areas that were repeatedly identified in each of the model scenarios. Please note that the analysis reported here is by no means comprehensive; additional analysis should be implemented to continue to evaluate the scenario outputs generated.

Four core fishing areas emerged from the Marxan with Zones analysis (Figure E8):

1) northern bank (north of St. Kitts),

2) northeastern Atlantic side of St. Kitts,

3) southeastern Atlantic side near The Narrows, and

4) southern bank (south of Nevis).

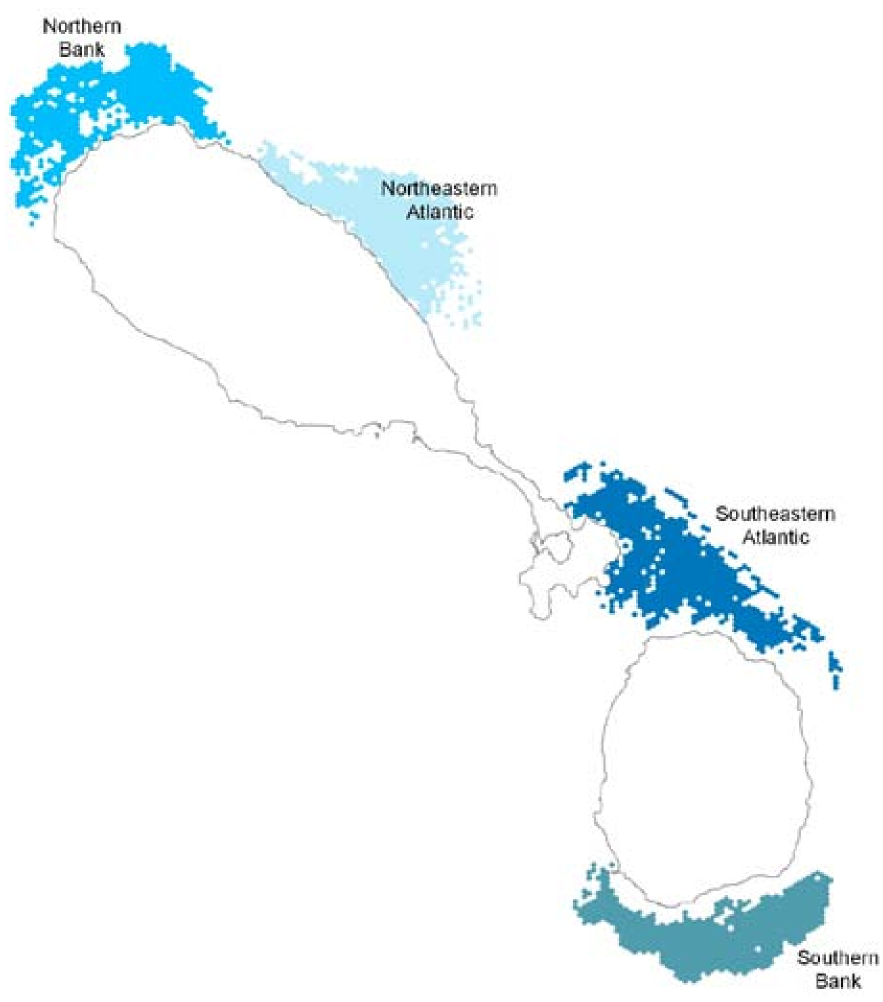


FIGURE E8. Core fishing areas identified in each of the three scenarios.

Similarly, five core conservation areas emerged (Figure E9):

1) western Caribbean side of St. Kitts,

2) northeastern Atlantic side of St. Kitts (off and to the north of Black Rocks),

3) eastern Atlantic side of St. Kitts,

4) eastern Atlantic side of Nevis, and

5) western Caribbean side of Nevis and the Narrows.

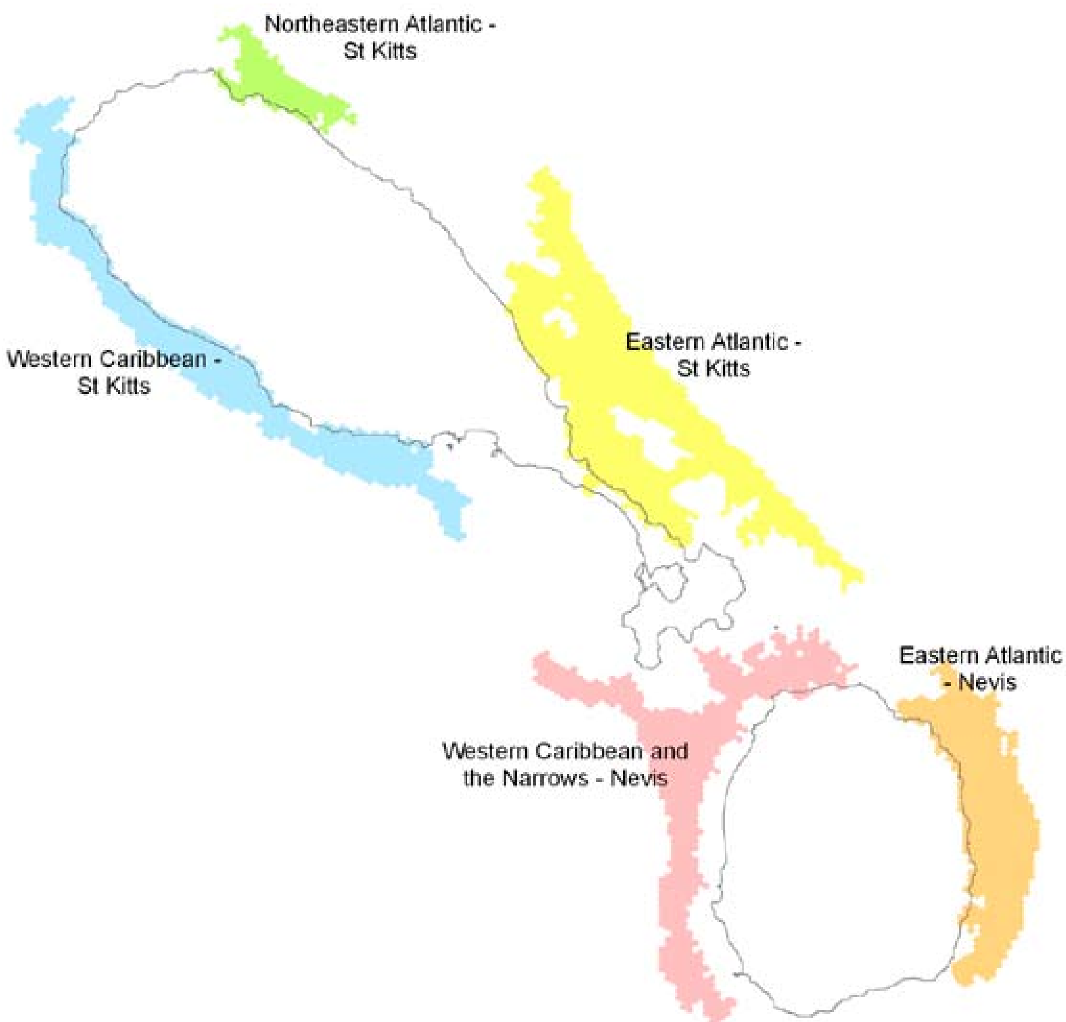


FIGURE E9. Core conservation areas identified in each of the three scenarios.

Fishing intensity, or the level of fishing activity as reported in the fishing surveys, can also be evaluated across scenarios for each of the four core fishing areas (Figure E10). This allows for an assessment of the relative importance of each area for specific fisheries. For coastal demersals, the southeastern area (0.65) and southern banks (0.68) achieved the highest intensity levels, while deep demersals had the highest representation in both the northern and southern bank (0.27) across all three scenarios. Overwhelmingly, coastal pelagic fishing reaches the highest intensity levels across all three scenarios in the northeastern area (0.50). Conch and lobster achieve high levels of intensity for both the southeastern and southern bank with the highest—0.28 for conch, 0.42 for lobster—being in the southern bank for Scenario 2: Flat 60 No Lock.

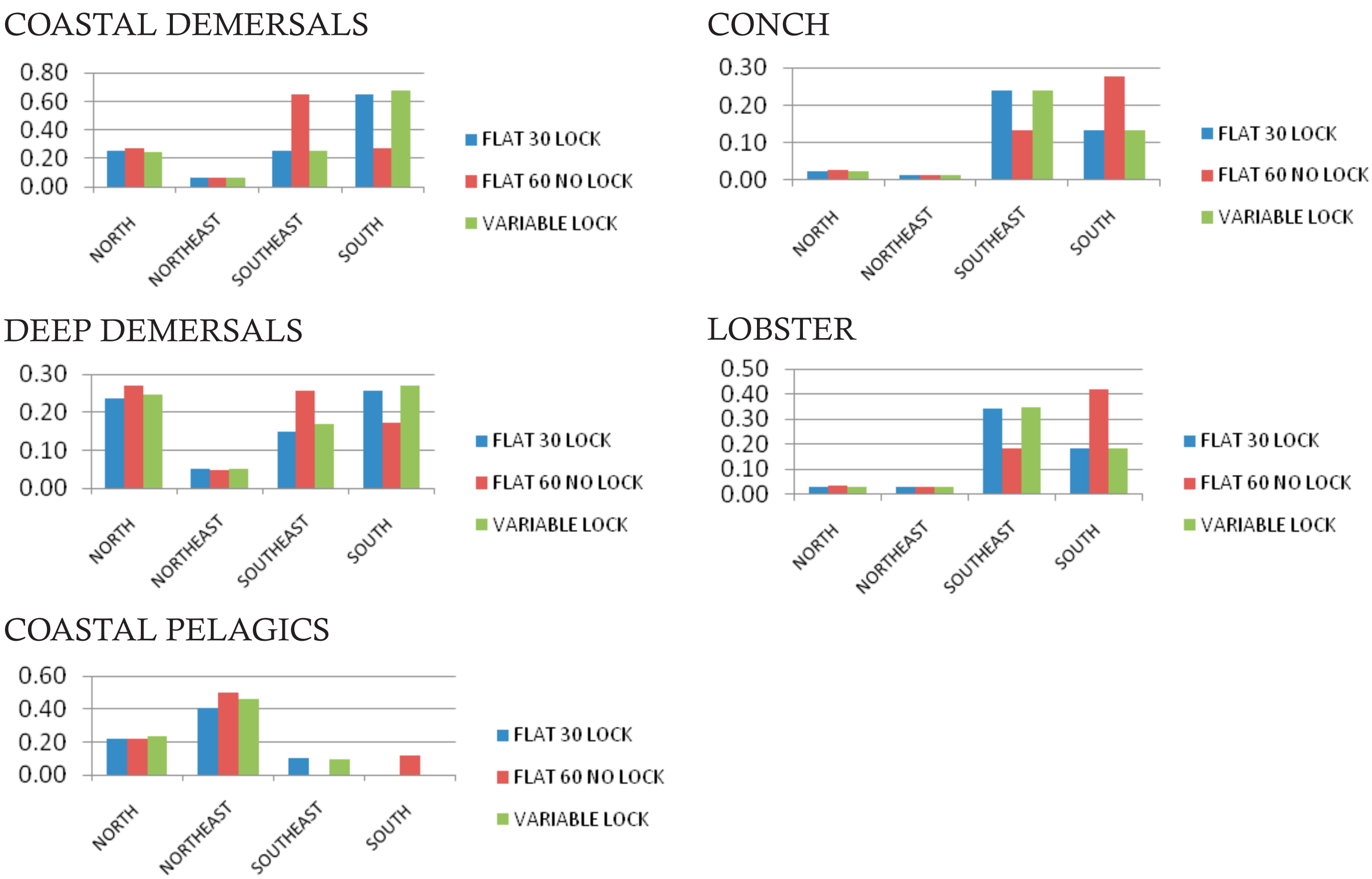
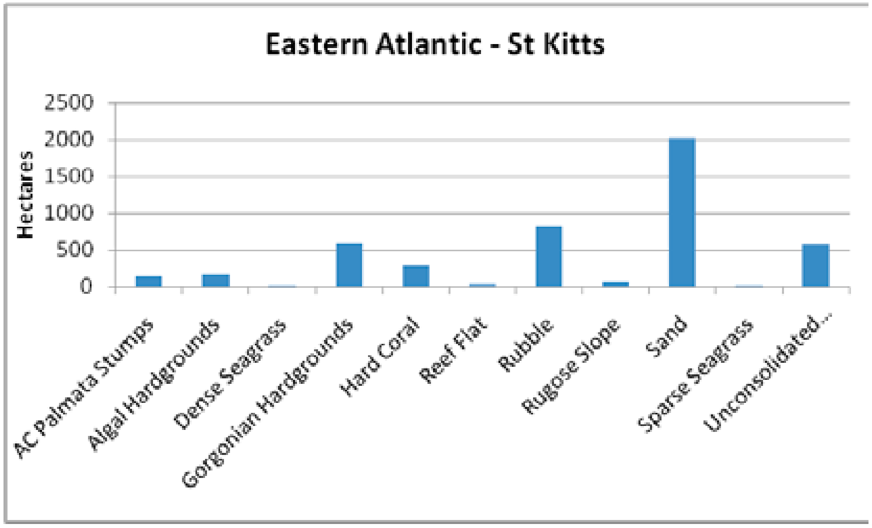
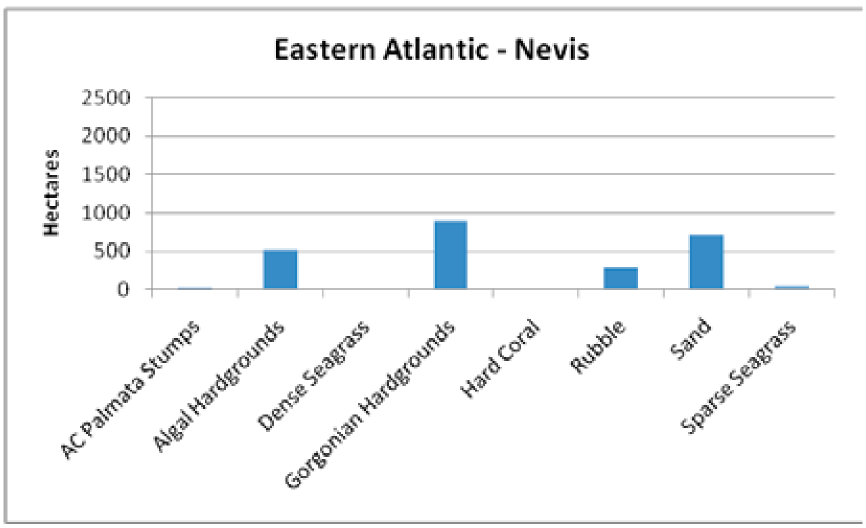
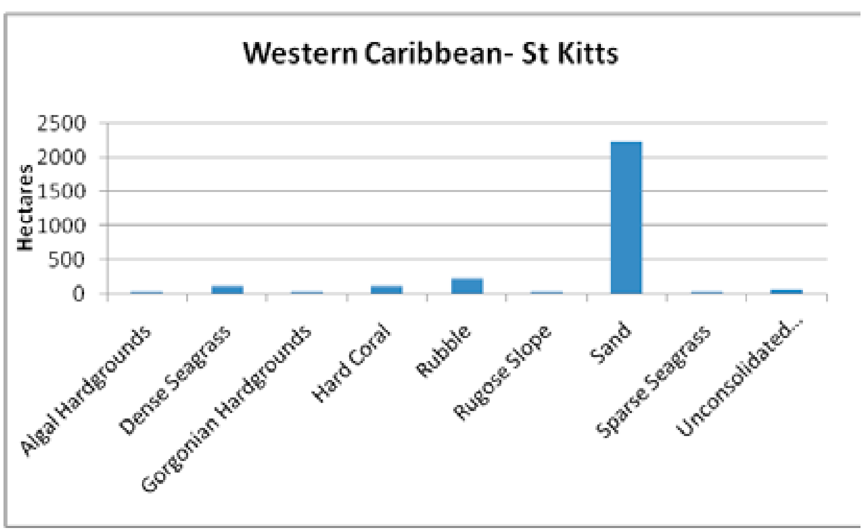


FIGURE E10. Fishing intensity values (0.0 is low and 1.0 is high) by fishery within each of four core fishing areas for each model scenario.

Similarly one can evaluate the amount by hectare of specific habitat types present in each conservation area and determine what areas are most important for the conservation of specific habitat types. As can be seen in Figure E11, the core conservation areas located on the eastern side of both St. Kitts and Nevis contain the highest variety of habitats when compared to the other conservation areas. Sand is usually present in the greatest quantity compared to other habitat types with the exception of the eastern side of Nevis, where gorgonian and algal hardground are present in similar quantities. Dense seagrass is present in larger quantities compared to the other conservation areas in the Western Caribbean and The Narrows conservation area near Nevis.

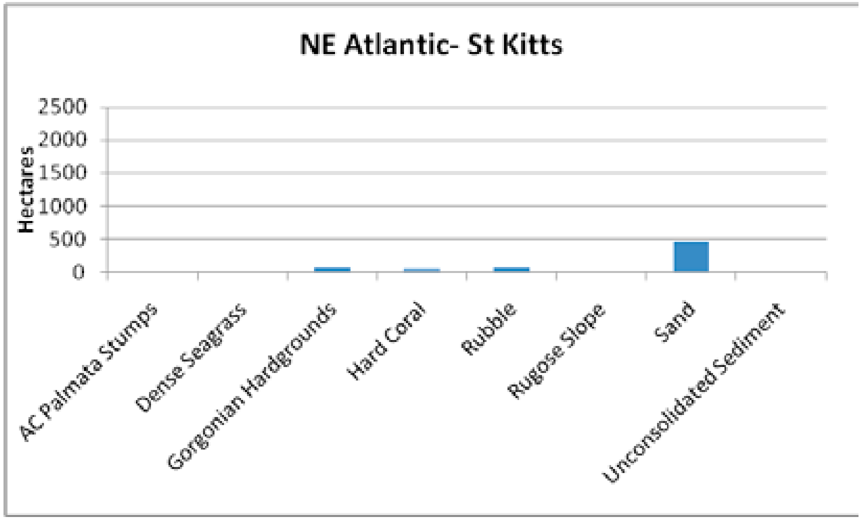






(continued on next page)

FIGURE E11. Amount of habitat by type in each of five core conservation areas.



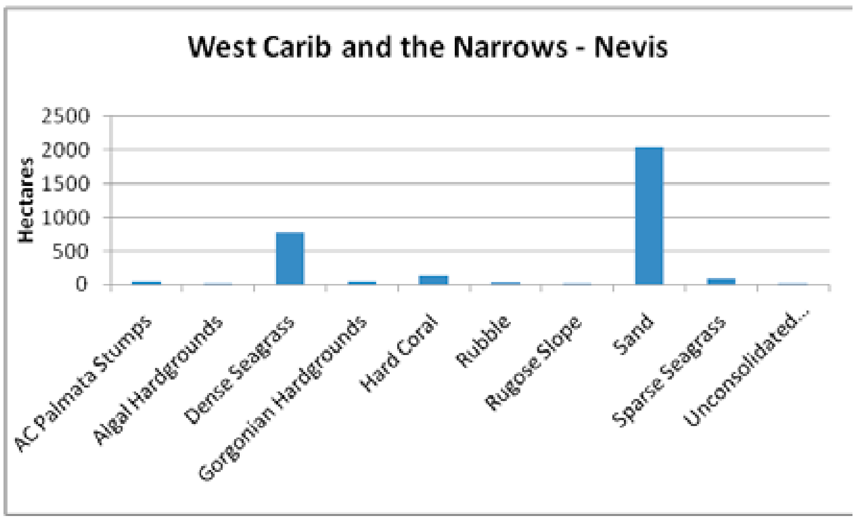


FIGURE E11 ***(continued).*** Amount of habitat by type in each of five core conservation areas.

Evaluating the Tabular Output

Marxan with Zones also produces tabular output for each scenario, reporting how much of the goal is achieved in the overall solution and the allocation of features or activities to each particular zone (usually in hectares for areas and kilometers for length). These tabular outputs are presented in Table E3. Note that while overall goals were met, not all of the individual zoning goals were met for each of the corresponding activities and features in each of the three scenarios. This may be attributed to certain planning units being unavailable because they are locked into a particular zone, the underlying constraints for a planning unit set by the assigned goal is too high, or the input scenario parameters constrained the model so not all goals could be achieved. The tables provide a way to assess gaps in goals achieved for each of the activities or features in a particular zone given the chosen input parameters, and they can be used to identify needs for either modifying goals or expanding zones to sufficiently achieve goals. They also provide a way to evaluate how much of each feature or activity is included in each zone given a zone configuration generated by a specific solution.

In reviewing model output, it is important to remember that Marxan with Zones provides decision support and is not the decision maker. The program does not provide the ultimate solution, and many of the input parameters require experimentation. Each output solution should be subject to visual inspection, and local knowledge should be incorporated to update and improve future model runs. Sensitivity analysis of parameters can improve the robustness of model outputs. Marxan with Zones was a useful tool to understand the complex spatial interactions of multiple uses and objectives within the marine shelf area of St. Kitts and Nevis. Additionally, the mapped inputs and outputs assisted in the visualization of zoned marine areas from the perspective of Kittitians and Nevisians (see Section 3.5 of main report). Using Marxan with Zones in a planning process is aligned with The Nature Conservancy's aim of choosing appropriate science-based tools to help communities make informed decisions to sustainably manage resources.

TABLE E3. Results of the three scenarios as summarized in the mvbest.txt output files from Marxan with Zones.

Scenario 1: Flat 30 Lock

Feature Name	Goal	Total Amount	Goal Met	Goal Tourism	Amount Held Tourism	Goal Met Tourism
Tourism_Anchoring	79.413	264.71	yes	132.355	184.14	yes
Tourism_Mooring	122.781	409.27	yes	204.635	325.73	yes
Tourism_Swimming_Snorklin	34.707	115.69	yes	57.845	105.69	yes
Tourism_Scuba_Diving	384.669	1282.23	yes	641.115	913.62	yes
Tourism_Jet_Ski	172.827	576.09	yes	288.045	339.78	yes
Tourism_Surfing	26.013	86.71	yes	43.355	85.71	yes
Tourism_Kite_Boarding	33.237	110.79	yes	55.395	110.79	yes
Tourism_Wind_Surfing	50.691	168.97	yes	84.485	164.06	yes
Tourism_Bird_Watching	30.018	100.06	yes	50.03	88.65	yes
				Fishing	**Amount Held**	**Goal Met**
Fishing_Coastal_Pelagics	287.456	958.185	yes	479.0926	479.1021	yes
Fishing_Coastal_Demersals	334.297	1114.32	yes	557.1612	557.1686	yes
Fishing_Demersal_Shelf	184.182	613.939	yes	306.9695	307.2624	yes
Fishing_Lobster	164.214	547.38	yes	273.69	274.3422	yes
Fishing_Conch	117.508	391.693	yes	195.8464	195.8928	yes
Fishing_Bait	23.2287	77.4291	yes	38.71455	13.8743	no
				Conservation	**Amount Held**	**Goal Met**
Conservation_Coastal_Lagoons	70.59	235.3	yes	117.65	118.74	yes
Conservation_Coral_Reef_Good	722.841	2409.47	yes	1204.735	853.05	no
Conservation_Coral_Reef_Poor	2484.74	8282.47	yes	4141.235	4141.3	yes
Conservation_Mangroves	27.006	90.02	yes	45.01	46.93	yes
Conservation_Sandy_Bottom	4905.87	16352.9	yes	8176.45	8176.98	yes
Conservation_Seagrass_Dense	929.835	3099.45	yes	1549.725	1241.84	no
Conservation_Seagrass_Sparse	110.799	369.33	yes	184.665	184.84	yes
Conservation_Turtle_Nesting_Sites	37.788	125.96	yes	62.98	32.82	no
Conservation_Nursery_Areas	709.506	2365.02	yes	1182.51	910.51	no
				Industrial Tranportation	**Amount Held**	**Goal Met**
Transportation_Cruise_Ship_Port	3.219	10.73	yes	5.365	10.73	yes
Industrial_Ports	29.433	98.11	yes	49.055	97.02	yes
Industrial_Geothermal_Vents	0.432	1.44	yes	0.72	1.4	yes
Industrial_Sand_Mining	7.815	26.05	yes	13.025	25.39	yes

Key:
Feature Name: The feature or activity for which a goal has been set. **Goal:** The total amount of hectares (for area) or kilometers (for length) that has been set for each feature or activity. **Total Amount:** This is the total amount of hectares or kilometers that the solution achieved. The Total Amount is compared to the pre-set goal to determine if the solution met the goal. **Goal Met:** "Yes" if the pre-set goal for this feature or activity was met. "No" if it was not met. **Goal Tourism/Fishing/Conservation/Industrial Transportation:** The total area (hectares) or length (kilometers) for this objective that Marxan is trying to achieve in the solution. For example, if the zone objective is tourism, this number represents the goal for hectares or kilometers of the feature or activity allocated to the tourism zone objective. **Amount Held Tourism/Fishing/Conservation/Industrial-Transportation:** This is the total area (hectares) or length (kilometers) that the Marxan with Zones solution included for an objective. This is compared to the goal to determine if the solution met the goal. **Goal Met Tourism/Fishing/Conservation/Industrial-Transportation:** "Yes" if the pre-set goal for this feature or activity was met. "No" if it was not met.

(continued on next page)

Scenario 2: Flat 60 No Lock

Feature Name	Goal	Total Amount	Goal Met	Goal Tourism	Amount Held	Goal Met Tourism
Tourism_Anchoring	158.83	264.71	yes	132.355	133.23	yes
Tourism_Mooring	245.56	409.27	yes	204.635	205.58	yes
Tourism_Swimming_Snorklin	69.414	115.69	yes	57.845	58.2	yes
Tourism_Scuba_Diving	769.34	1282.23	yes	641.115	641.23	yes
Tourism_Jet_Ski	345.65	576.09	yes	288.045	288.42	yes
Tourism_Surfing	52.026	86.71	yes	43.355	44.34	yes
Tourism_Kite_Boarding	66.474	110.79	yes	55.395	56.52	yes
Tourism_Wind_Surfing	101.38	168.97	yes	84.485	87.75	yes
Tourism_Bird_Watching	60.036	100.06	yes	50.03	51.4	yes
				Fishing	**Amount Held**	**Goal Met**
Fishing_Coastal_Pelagics	574.91	958.1851	yes	479.0926	479.1261	yes
Fishing_Coastal_Demersals	668.59	1114.322	yes	557.1612	557.1769	yes
Fishing_Demersal_Shelf	368.36	613.939	yes	306.9695	308.726	yes
Fishing_Lobster	328.43	547.38	yes	273.69	275.822	yes
Fishing_Conch	235.02	391.6928	yes	195.8464	196.0057	yes
Fishing_Bait	46.457	77.4291	yes	38.71455	38.7326	yes
				Conservation	**Amount Held**	**Goal Met**
Conservation_Coastal_Lagoons	141.18	235.3	yes	117.65	118.74	yes
Conservation_Coral_Reef_Good	1445.7	2409.47	yes	1204.735	1204.8	yes
Conservation_Coral_Reef_Poor	4969.5	8282.47	yes	4141.235	4141.76	yes
Conservation_Mangroves	54.012	90.02	yes	45.01	45.2	yes
Conservation_Sandy_Bottom	9811.7	16352.9	yes	8176.45	8176.69	yes
Conservation_Seagrass_Dense	1859.7	3099.45	yes	1549.725	1550.05	yes
Conservation_Seagrass_Sparse	221.6	369.33	yes	184.665	184.97	yes
Conservation_Turtle_Nesting_Sites	75.576	125.96	yes	62.98	63.3	yes
Conservation_Nursery_Areas	1419	2365.02	yes	1182.51	1258.96	yes
				Industrial-Tranportation	**Amount Held**	**Goal Met**
Transportation_Cruise_Ship_Port	6.438	10.73	yes	5.365	6.91	yes
Industrial_Ports	58.866	98.11	yes	49.055	49.79	yes
Industrial_Geothermal_Vents	0.864	1.44	yes	0.72	0.6	no
Industrial_Sand_Mining	15.63	26.05	yes	13.025	13.14	yes

(continued on next page)

Scenario 3: Variable Goals Reduced Lock

Feature Name	Goal	Total Amount	Goal Met	Goal Tourism	Amount Held Tourism	Goal Met Tourism
Tourism_Anchoring	185.297	264.71	yes	132.355	184.14	yes
Tourism_Mooring	327.416	409.27	yes	204.635	325.73	yes
Tourism_Swimming_Snorkling	114.5331	115.69	yes	57.845	105.69	yes
Tourism_Scuba_Diving	1269.4077	1282.23	yes	641.115	929.2	yes
Tourism_Jet_Ski	57.609	576.09	yes	288.045	339.78	yes
Tourism_Surfing	21.6775	86.71	yes	43.355	85.71	yes
Tourism_Kite_Boarding	109.6821	110.79	yes	55.395	110.79	yes
Tourism_Wind_Surfing	25.3455	168.97	yes	84.485	164.06	yes
Tourism_Bird_Watching	70.042	100.06	yes	50.03	88.65	yes
				Fishing	**Amount Held**	**Goal Met**
Fishing_Coastal_Pelagics	670.72957	958.1851	yes	479.093	479.291	yes
Fishing_Coastal_Demersals	780.02561	1114.3223	yes	557.161	560.175	yes
Fishing_Demersal_Shelf	429.7573	613.939	yes	306.97	307.8811	yes
Fishing_Lobster	383.166	547.38	yes	273.69	273.7079	yes
Fishing_Conch	274.18496	391.6928	yes	195.846	196.9869	yes
Fishing_Bait	54.20037	77.4291	yes	38.7146	13.9805	no
				Conservation	**Amount Held**	**Goal Met**
Conservation_Coastal_Lagoons	188.24	235.3	yes	117.65	128.15	yes
Conservation_Coral_Reef_Good	2385.3753	2409.47	yes	1204.74	832.13	no
Conservation_Coral_Reef_Poor	4141.235	8282.47	yes	4141.24	4143.36	yes
Conservation_Mangroves	72.016	90.02	yes	45.01	45.2	yes
Conservation_Sandy_Bottom	9811.74	16352.9	yes	8176.45	8178.1	yes
Conservation_Seagrass_Dense	1239.78	3099.45	yes	1549.73	1371.34	no
Conservation_Seagrass_Sparse	147.732	369.33	yes	184.665	188.34	yes
Conservation_Turtle_Nesting_Sites	113.364	125.96	yes	62.98	34.84	no
Conservation_Nursery_Areas	1892.016	2365.02	yes	1182.51	997.86	no
				Industrial Tranportation	**Amount Held**	**Goal Met**
Transportation_Cruise_Ship_Port	4.292	10.73	yes	5.365	10.73	yes
Industrial_Ports	39.244	98.11	yes	49.055	97.02	yes
Industrial_Geothermal_Vents	0.216	1.44	yes	0.72	1.4	yes
Industrial_Sand_Mining	3.9075	26.05	yes	13.025	25.39	yes