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Plan for a network of Replenishment Zones (RZs) in northern Honduras

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Overview

Project objective

Protect 20% of fishable waters in northern Honduras through the establishment of a network of RZs for fisheries management and biodiversity conservation.

Baseline

Honduras has committed to protect 20% of its fishable waters, which have been defined by the government as waters shallower than 200 m. The country does not count with an official bathymetry or coastline datasets. Enquires were directed to different Honduran governmental agencies (SINIT, ICF, and Secretaria de Relaciones Exteriores) by Jimmy Andino from CEM. Although there is no local bathymetry dataset, the Secretaria de Relaciones Exteriores (Oficina de Fronteras Maritimas) suggested using GEBCO to set this important baseline. Therefore, here fishable areas were calculated using the global GEBCO (General Bathymetric Charts of the Ocean, Weatherall et al. 2015) 2014 grid dataset at 30 arc seconds spatial resolution and coastline using a habitat map recently available for northern Honduras (Purkis 2016).

Region of study

The entire Honduran Caribbean includes 58,245.49 km^2 of fishable areas. This planning exercise covers the area from the border with Guatemala to the border of Gracias a Dios Department. The region includes 9,263.84 km^2 of fishable waters and 10,229 square planning units of 1 km^2 (Figure 1, top). Fishable waters cover most of shallow consolidated habitats mapped in the region (Figure 1, middle). To secure protection of all habitats in all environments, the region was divided in two sections: the continental shore and offshore (Figure 1, bottom), which have different environments and biological communities.

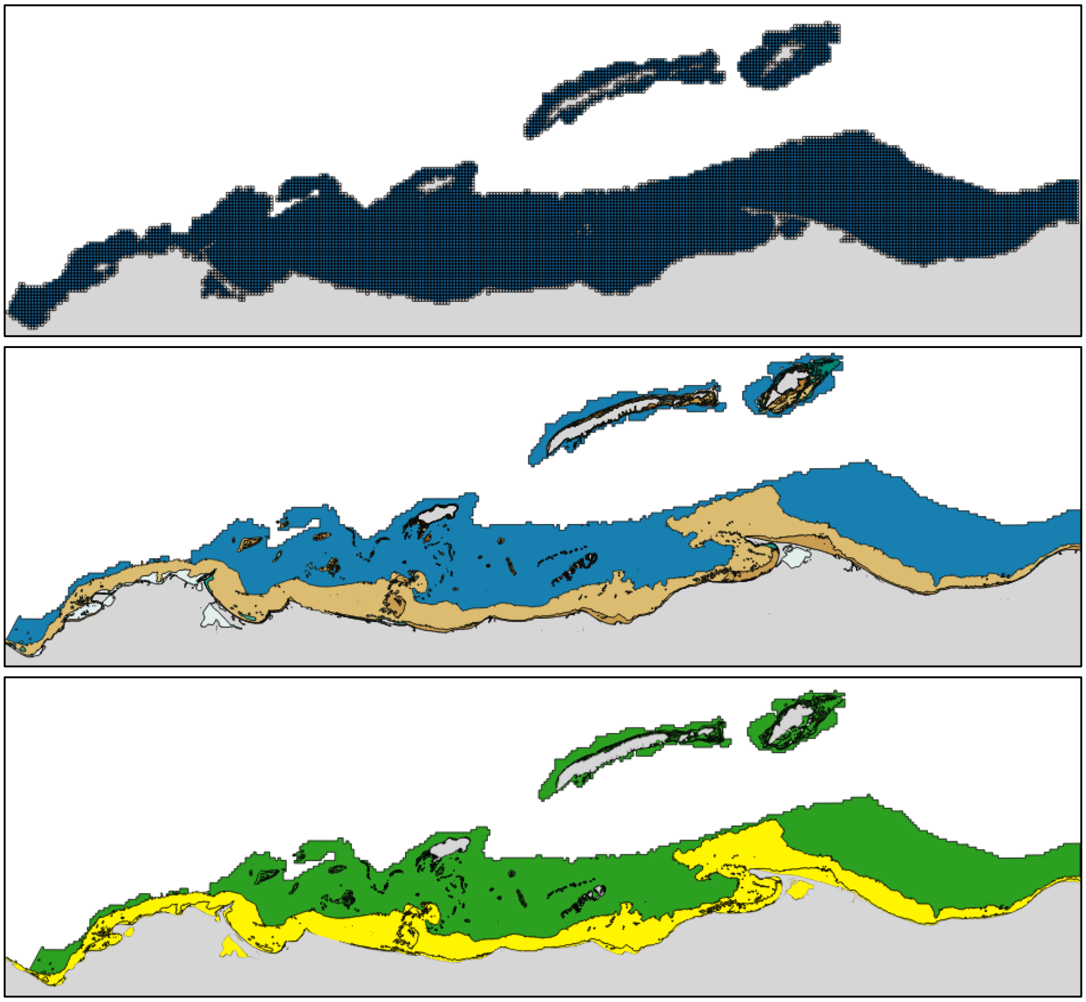

Figure 1. Northern shore of Honduras. Region of study showing: (top) fishable areas (less than 200 m depth in blue) and 1 km^2 planning units in black; (middle) fishable areas and shallow marine consolidated habitats; (bottom) ecologically distinct regions, the continental shore (in yellow) and offshore (green).

Current status of the system of RZs in northern Honduras

The system of RZs in northern Honduras[1] includes 11 distinct RZs covering 46.06 km^2 (Figure 2). RZs are very small, with a median size of 3.45 km^2. All RZs are located over shallow waters potentially accessible to fishing, covering 0.50% of fishable areas in this region of the Honduran Caribbean.

[1] Note this spatial layer was elaborated with a different coastline. Area calculations were done for the projection used throughout this project (EPSG 32616)

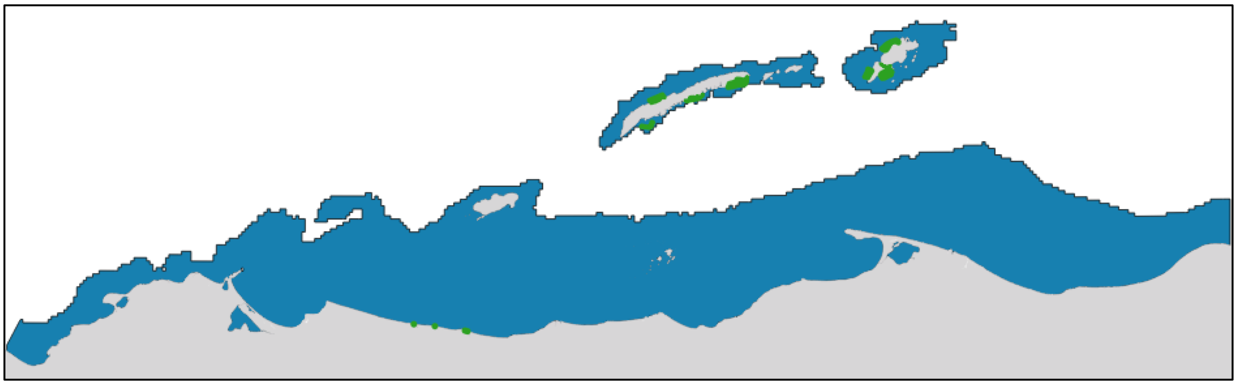

Figure 2. Northern shore of Honduras showing fishable area in blue and current RZ network in green. RZ size has been exaggerated for visibility. Data on RZs from Chollett 2015.

Description of overall plan

Main elements considered during planning for northern Honduras are highlighted in Table I. Planning for this region focuses on achieving biodiversity and fisheries objectives and follows the philosophy adopted by the Mesoamerican Region (Table II: Green et al. 2017). Fisheries focal species were yellowtail snapper, conch and lobster. These three species were considered when identifying the minimum size of an RZ (*Section 1*), but only yellowtail snapper was used as a model species to identify the RZ network that would maximize economic fisheries gains through larval spillover.

RZs in northern Honduras will protect all spawning aggregation sites and all sites of high abundance of *Acropora* spp., given their relevance for fisheries and biodiversity respectively (*Section 3*). The proposed network of RZs will include all previous RZs in the country. Overall, RZs will cover 20% of each habitat type in each ecological region (*Section 2*).

RZs will be avoided around ports, areas of high urban or watershed influence, and areas highly used by fishers. The last three threats were given equal importance during planning, while ports had double the weight (*Section 4*).

The elements described above for northern Honduras were used as inputs for an optimization algorithm (Marxan, *Section 7*). Choosing a reserve network out of a fixed number of planning units is a complex problem and optimization tools allow assessing the problem in a quantitative way and finding not optimal (the overall best), but good solutions. Marxan is a freely available conservation planning tool that allows guiding marine spatial planning. First conceived in 2000, it is the most widely used tool globally. For example, it was used to guide the recent planning for protected areas in Belize (Cruz et al. 2016).

Marxan allows to address the problem of meeting "targets" at a minimum "cost". In this sense, targets are the amount of each feature in the map that the tool is instructed to select (i.e. in northern Honduras 20% of each habitat in each ecological region) and costs are flexible incorporating any type of information that needs to be traded-off against conservation and avoided to minimize conflict (i.e. in this project, the four described uses and threats). Marxan also provides the ability to "lock in" certain sites that will always be included into the solution (in northern Honduras, previous RZs, sites with high abundance of Acroporids and spawning aggregation sites).

Marxan produces multiple "good solutions": RZ network configurations that attempt at meeting the targets while minimizing the costs. Here, 1000 good solutions were produced and assessed to choose a final set of five that will maximize economic benefits while allowing the sustainability of yellowtail snapper fisheries, using data on yellowtail larval connectivity (*Section 5*) a population model (*Section 6*) and the approach described in Chollett et al. (in press). This final set of 5 solutions is presented here and can be used to start conversations with stakeholders, refine inputs and re-run the analyses if desired, to identify a final network of RZs that will allow to minimize social, economic and cultural impacts.

Main input datasets (habitat maps, yellowtail larval connectivity and population model) were produced specifically for this project. Other datasets were collected from the literature or expert opinion in a case-by-case basis. Description of all datasets and suggestions for future work can be found in the section of *Background information.* All input and output layers are provided as a companion to this document (*Section 8*).

Table I. Elements included during planning for RZs in northern Honduras

Planning units	1 km^2
Focal species	Yellowtail snapper, conch and lobster
Targets	Habitats (marine consolidate + mangrove forest) – protect 20%
	Spawning aggregation sites – protect 100%
	Areas of high abundance of Acropora – protect 100%
	Previous RZs – protect 100%
Costs	Ports (2 x weight)
	Urban influence
	Watershed influence
	Fishing influence

Table II. Ecological principles to guide the setting of RZs in northern Honduras. Biophysical design principles to guide the establishment of RZs in the MAR were identified during two regional workshops (Green et al. 2017). These regional principles were tailored for Honduras after discussion with CEM in February 2017 (changes highlighted in italics).

MAR Biophysical Design Principle	**Honduran Design Principle**
Habitat representation	
1. Represent 20-30% of each major habitat type in RZs	1. Represent *20%* of each major habitat type in RZs
Risk Spreading	
2. Protect at least three replicates of each major habitat in RZs in each ecologically distinct region of the MAR	2. Protect at least three replicates of each major habitat in RZs in each ecologically distinct region
Protecting Critical, Special and Unique Areas	
3. Protect areas of importance during the entire life cycle of focal species, sites with high endemism, sites	Protect areas of importance during the entire life cycle of focal species (*nursery and spawning aggregation*

with high abundance of rare and/or threatened species, healthy areas and areas with high habitat complexity	*areas*), and sites with high abundance of threatened species (*Acropora* spp.)
Incorporating connectivity	
4. The size of RZs should be based on movement patterns of focal species	4. The size of RZs should be at least 2 km across to protect focal species during most of their life cycle (lobster, conch and yellowtail snapper)
5. Ensure RZs are close enough to allow for the movement of focal species between habitats used throughout their life cycle	5. Ensure RZs are close enough to allow for the movement of focal species between habitats used throughout their life cycle
6. RZs should include, where possible, entire ecological units	6. RZs should include, where possible, entire ecological units
7. Design RZs using compact shapes rather than elongated ones	7. Design RZs using compact shapes rather than elongated ones
8. Design a network of RZs to maintain larval connectivity within and among RZs, and to maximize dispersal to fishing areas	8. Design a network of RZs to maintain larval connectivity within and among RZs, and to maximize dispersal to fishing areas *using yellowtail snapper as focal species*
Allowing Time for Recovery	
9. RZs should be in place permanently to allow for the population recovery of all focal species and enhance fisheries production in the long term	9. RZs should be in place permanently to allow for the population recovery of all focal species and enhance fisheries production in the long term
Adapting to Changes in Climate and Ocean Chemistry	
11. Address the threats of rising sea temperatures and sea levels and changes in ocean chemistry by: a. Risk spreading b. Increasing percent habitat representation c. Increasing protection of key species that increase ecosystem resilience (e.g. parrotfish)	11. Address the threats of rising sea temperatures and sea levels and changes in ocean chemistry by: a. Risk spreading
12. Prioritize the protection of coastal habitats that have greater probability of surviving sea level rise	-This planning focuses on fishable areas-
Minimizing and Avoiding Local Threats	
13. Prioritize placing RZs where there are low levels of threats now and in the future (e.g. in areas influenced by healthy rivers vs. areas with unnaturally high levels of sediment, nutrient and pesticides).	13. Prioritize placing RZs where there are low levels of threats (areas influenced by high sediment input, ports, urban areas and fishing areas)

Proposed network of RZs in northern Honduras

An initial set of RZ networks was identified using Marxan with optimized parameters (SPF= 90, BLM= 0.0001, see *Section 7*) and 1000 runs. Of those, 50 solutions didn't meet all targets (i.e. protected 20% of each habitat) and were excluded from subsequent analyses.

These 950 "good" solutions were assessed using the dynamic population model for yellowtail snapper to quantify yield and persistence. The resource is highly sustainable and all networks are persistent (values of Per_d =1, see *Section 6*), therefore, RZ networks were chosen so to maximize spillover (i.e. yield) of yellowtail snapper.

The 950 "good" solutions have a boundary length of 1,383.21±144.41 km (mean and standard deviation), costs of 84.85±3.25, and produce a yellowtail snapper yield of 407.18±6.70 kg (Figure 3).

To put these values into context we can use several reference points:

• Maximum possible boundary length of a RZ network = 40,916 km^2
Therefore, the suggested reserve networks are about 30 times more clumped than having isolated RZs.

• Average cost of a RZ network = 216.89[3]
Therefore, the suggested networks are 60% cheaper than average.

• Average yield of a RZ network = 384.15[4]
Therefore, increases in yield of the suggested solutions are only marginal, of 6%. This marginal increase is related to the fact that the network was chosen initially to minimize costs, not to optimize yield. Selecting a network of RZs that would maximize yield above all would have required a different methodological approach (e.g. Chollett et al. in press) which was not possible in northern Honduras given than most target areas for protection are not habitat for yellowtail snapper.

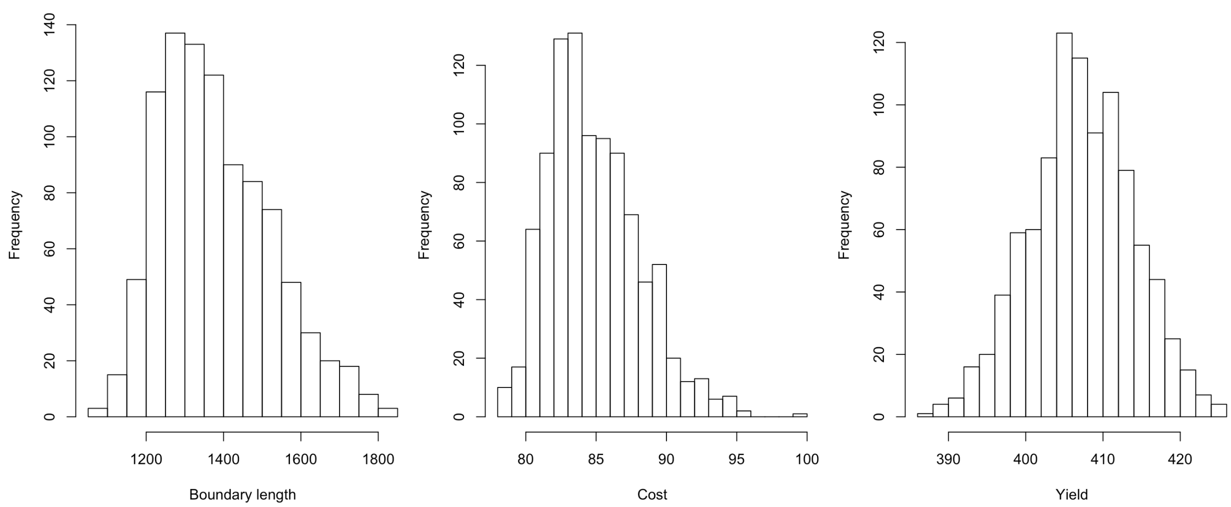

Figure 3. Boundary length (in km), costs and yield (in kg) of yellowtail snapper of best Marxan 950 feasible solutions. Together with the targets, boundary length (i.e. the perimeter of the RZ network) and cost are the variables used by Marxan to identify what areas to protect (see *Section 7* for more detail), and lower values are better. Yield is one of the output variables of the population model for yellowtail snapper, and indicates the contribution of recruits within the RZ network to harvestable biomass over their lifetime (see *Section 6*), the higher the yield, the more productive the RZ network.

[2] In 20 % of fishable area there are 2046 planning units of 4 km boundary length (perimeter) each. The network with maximum boundary length would be one of isolated 1 km^2 planning units.
[3] In this project costs are given in arbitrary units ranging between zero and one (see *Section 4*). The average cost of a planning unit in northern Honduras is 0.106, meaning that in average, an RZ network covering 20% of the area costs 216.89.
[4] The average yield of 100 RZ networks covering 20% of the region at random is 384.15

The 950 solutions have a consistent distribution along the north shore of Honduras (Figure 4), with some areas being commonly chosen by the program indicating the algorithm is selecting (near) optimal solutions. This also implies that although there is variability among the 950 solutions, they are all relatively similar.

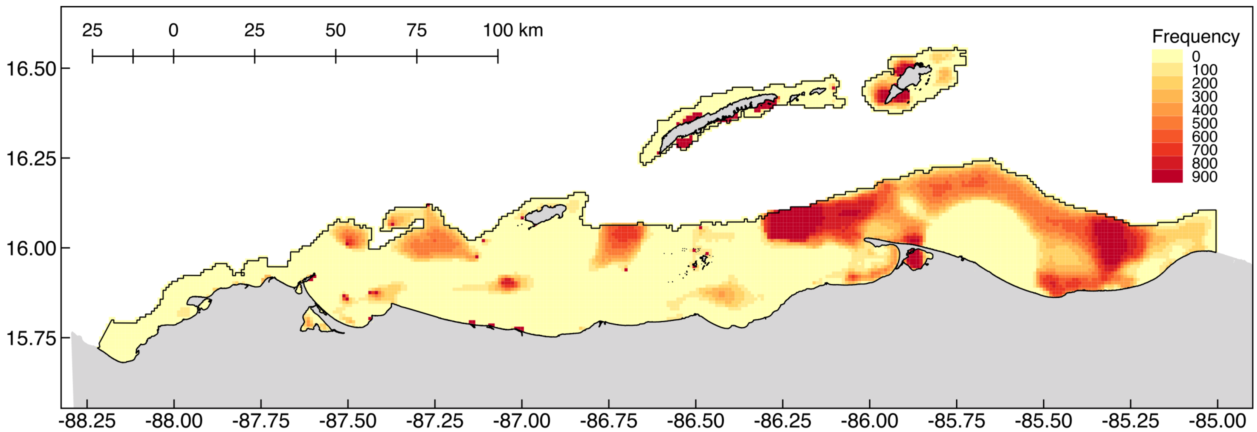

Figure 4. Frequency of Marxan solutions, indicating how some areas are constantly chosen by the tool

The five best solutions in terms of yield are shown in Figure 5, and their characteristics depicted in Table III. The best solution represents an 11% increase in spillover and is 65% cheaper than average. This solution is 33 times more compact than a system of isolated RZs.

Table III. Best five solutions in terms of yield for yellowtail snapper

Run number	Score	Cost	# Planning Units	Boundary length (km)	Yield (kg)
454	206.45	82.25	1941	1242	425.33
758	219.26	85.26	1939	1340	425.14
410	210.74	81.34	1930	1294	425.03
241	205.49	82.69	1943	1228	424.52
700	227.90	84.70	1945	1432	423.49

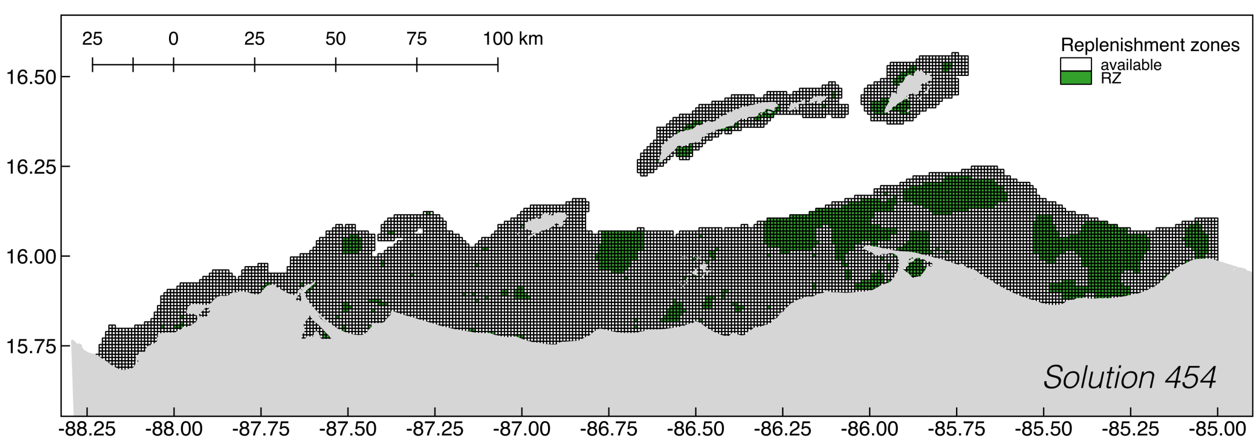

Figure 5. Best solutions in terms of yield for yellowtail snapper. RZ indicates suggested and established RZs.

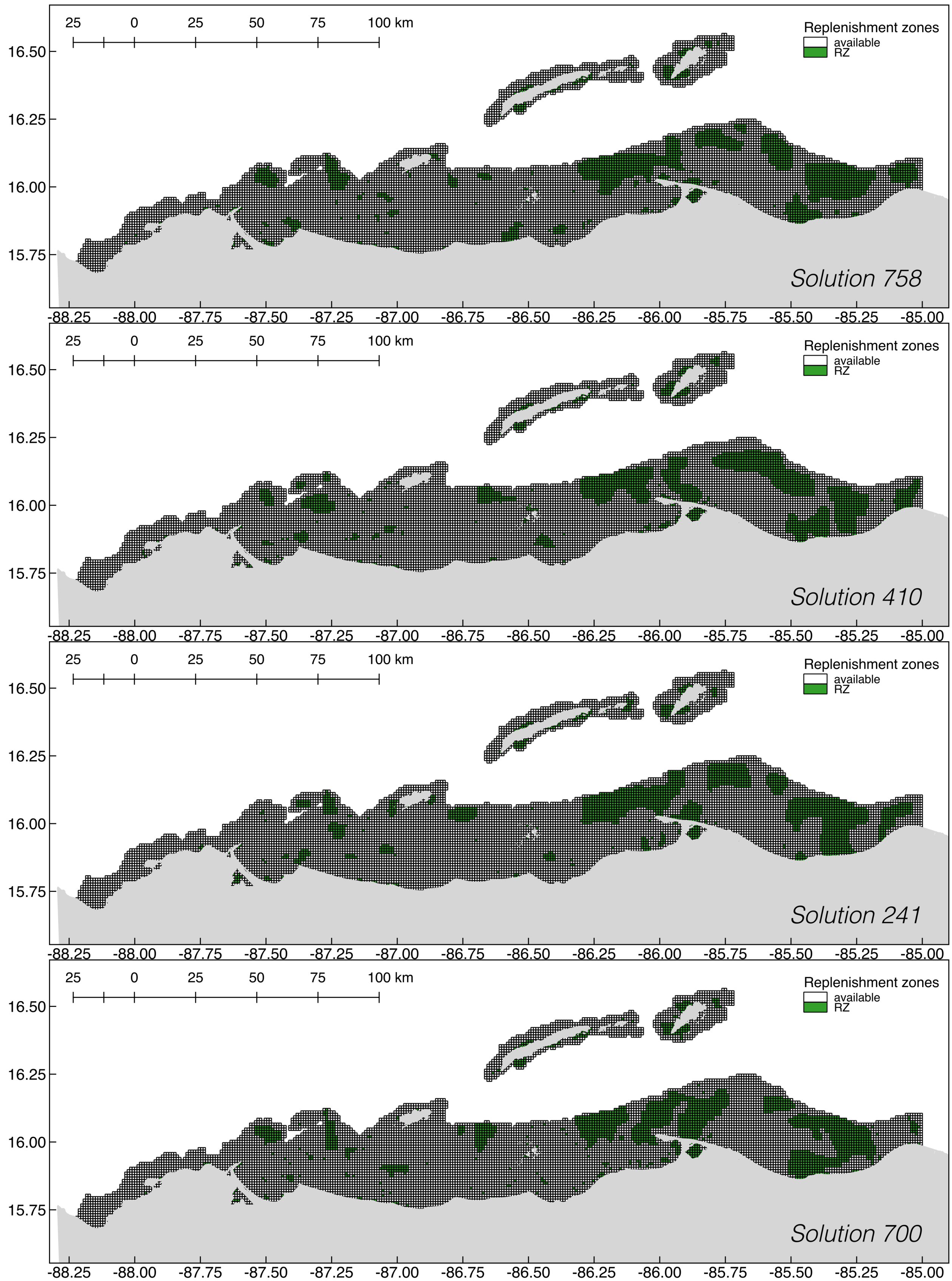

Figure 5. (cont) Best solutions in terms of yield for yellowtail snapper. RZ indicates suggested and established RZs.

Future steps

- *Refine the location and validate SPAGS.* The list included here is inaccurate and should be revised before finalizing the plan and implementing protection.

-*Revise RZ network options with stakeholders and refine plan.* Ideally, a few options should be discussed with stakeholders, changes to input data or parameters applied, and a final proposal presented for approval before implementation.

- *Ensure MAR guiding principles are applied during implementation.* Particularly principles 4-7.

- *Include additional management measures to ensure protecting focal fishery species during key stages of their life cycle* (e.g. closing seasons during spawning times for conch and lobster), given that the current minimum size of RZs (4 km^2) does not protect focal species during their entire life cycle.

- *Include Caldera del diablo in the RZ network.* This SPAGS was not included in this modelling exercise because is not in fishable areas as operationally defined, but should be protected.

- *Map deep habitats and add as conservation targets explicitly if improving this exercise.*

- *Refine layer of fishing use if improving this exercise.* Of all cost input layers, the one describing fishing influence is arguably the most important and should be refined to identify an RZ network that minimize conflict with this important stakeholder group.

Background information

1. Focal species

After consultation with CEM there were identified three main focal species of economic interest in northern Honduras: yellowtail snapper, lobster and conch. According to biophysical principles for the establishment of networks of RZs (Green et al. 2017) to protect these species planning units should be at least **2 km** across to protect them during their daily activities, and **20 km** across to fully protect them during all their life stages (Table 1.I).

> *Recommendations:* It could be very difficult to gain support to implement RZs as large as 20 km across. Therefore, we suggest using RZs of a minimum of 2 km across (4 km^2) and include additional management measures to ensure protecting the species during key stages of their life cycle (e.g. closing seasons during spawning times for conch and lobster).

Table 1.I. Movement patterns (km) of focal species in Honduras

Species	Daily movement	Ontogenetic shifts	Seasonal (spawning)	Reference
Conch	0.012-0.25	0.4-0.7	0.17-0.4	Reviewed in Green et al. 2017
Lobster	0.2-1	1-10	0.5-10	Reviewed in Green et al. 2017
Yellowtail snapper	1	?	?	Farmer and Ault 2011; Herbig et al. (in prep)

Review on yellowtail snapper

Parameters for conch and lobster were gathered from existing literature (Green et al. 2017), however, for this project we reviewed the little information available on yellowtail snapper. Juveniles show high site fidelity, and home ranges in seagrass of only 6.3 m^2 (Watson et al. 2002). Home ranges of adults have been calculated between 1.44 and 2.7 km^2, with adults moving moderate distances (up to about 1 km, Farmer and Ault 2011; Herbig et al. in prep). Lindholm et al. (2005) also report high-site fidelity for adults of this species.

It is known this species recruits in seagrass areas and then migrates to reef areas, but the spatial scale of these movements has not been described. Herbig et al. (in prep) suggest the species migrates to spawn during summer, when all the fish tagged in their study were outside the extensive array system along the Dry Tortugas. Spawning movements, however, have not been quantified for this species. Jennifer Herbig and Alejandro Acosta (Florida Fish and Wildlife Conservation Commission), specialists in the species, were not able to provide more information on this issue.

2. Target habitats

Marine habitats were identified using a map produced from satellite imagery for this project (Purkis 2016). From this exercise all habitat classes were taken into account but “deep-water” which was uninformative and removed from the analysis. Mapping of marine habitats was complemented with the mapping of mangroves on land by Giri et al. (2011), who mapped mangrove forests using Landsat (30 m) satellite imagery. All fishable areas not included in the previous two maps were labeled as "deep habitat".

The study region was then split in two ecologically different regions: the continental shore and offshore (Figure 1, bottom), therefore including 26 different conservation features (Table 2.I).

Other datasets considered: for mangroves, Arrivillaga and Windevoxhel (2008) which is less comprehensive.

Recommendations: The habitat map for marine habitats used as input for this planning exercise (Purkis 2016) was produced using optical satellite imagery and therefore only maps shallow (~30 m) areas. There is no information in the country of distribution of deep habitats. It would be desirable to revise priorities for protection of deep habitats if this information becomes available.
Giri et al. (2011) mapped the distribution of mangroves using satellite imagery for the period 1997-2000. The distribution of mangroves is likely to be different today. A newer dataset has been produced by the ICF but is not yet available (Mayra Nuñez, CEM, pers. com). It would be desirable to revise priorities for mangrove protection once this, or another better dataset, becomes available.

Table 2.I. Habitats included

Id	Habitat	Region	Abbreviation
1	Aggregate-patch-reef	continental shelf	apr_c
2	Aggregate-patch-reef	offshore	apr_o
3	Aggregate-reef	continental shelf	ar_c
4	Aggregate-reef	offshore	ar_o
5	Aggregate-reef-with-algae	continental shelf	arwa_c
6	Aggregate-reef-with-algae	offshore	arwa_o
7	Deep habitat	offshore	dh_o
8	Individual-patch-reef	continental shelf	ipr_c
9	Individual-patch-reef	offshore	ipr_o
10	Intertidal-vegetation	offshore	iv_o
11	Mangrove	continental shelf	m_c
12	Mangrove	offshore	m_o
13	Mud	continental shelf	mu_c
14	Mud	offshore	mu_o
15	Pavement-with-gorgonians-and-turfing-algae	continental shelf	pwg_c
16	Pavement-with-gorgonians-and-turfing-algae	offshore	pwg_o
17	Pavement-with-sand-channels	continental shelf	pws_c
18	Pavement-with-sand-channels	offshore	pws_o
19	Reef-rubble-with-algae	continental shelf	rr_c
20	Reef-rubble-with-algae	offshore	rr_o
21	Sand	continental shelf	s_c
22	Sand	offshore	s_o

23	Seagrass	continental shelf	sg_c
24	Seagrass	offshore	sg_o
25	Sand-with-algae	continental shelf	swa_c
26	Sand-with-algae	offshore	swa_o

3. Target priority areas for conservation

Three priority areas for conservation were identified by CEM: nursery areas, spawning aggregation sites, and areas with high abundance of *Acropora* sp. Protection of nursery areas will be ensured by habitat representation of seagrass and mangrove habitats (20% protection). Spawning aggregation sites and areas with high abundance of acroporids will be all fully protected.

Entire planning units containing any of these two attributes, together with the previous RZs, will be "reserved" in Marxan and will be necessarily selected as RZs. **This implies that to achieve targets current RZs might need to be expanded.**

Spawning Aggregation Sites (SPAGS)

Protecting spawning aggregation sites is key to allow the persistence of some fisheries species. Following current protection efforts in Belize, and ongoing efforts in Mexico, this planning exercise endeavored to protect all SPAGS in the region.

A list of known spawning aggregation sites for the Caribbean shore of Honduras was compiled (Table 3.I, Figure 3.1). The list was produced from literature review (search in google scholar and GCFI proceedings: Honduras + [spawning + aggregation] / [agregacion + desove]) and expert opinion. Conversations during May-July 2017 with: Steve Canty (Smithsonian Institution), Mayra Nuñez, Mariela Ochoa, Cristhian Perez (Centro de Estudios Marinos), Andres Alegria (Universität Bremen), Stephen Box (Rare), Calina Zepeda (TNC), Macio Aronne (Monumento Natural Marino Cayos Cochinos), Antal Borscsok (Tela Marine), Nicholas Bach (Roatan Marine Park), Ian Drysdale (HRI). Networking through Mayra Nuñez and Iliana Chollett.

In spite of efforts to compile precise information, **this list is inaccurate and should be revised**. After CEM's request, these SPAGS sites have been included in the plan towards the establishment of a network or RZs in the north shore as a preliminary step, on the knowledge **that sites need to be validated before finalizing the plan and implementing protection.**

Sites in Cayos Cochinos and Roatan have been assessed by stakeholders that have long experience in the region, but all other sites should be considered as 'unvalidated', given that no direct evidence of spawning has been provided for the sites. Sites should be validated to (1) confirm location; (2) confirm the site is actually a spawning site and (2) assess status of the SPAGS.

A spawning aggregation site has been defined as a: "repeated concentration of conspecific marine animals gathered for the purpose of spawning, that is predictable in time and space. The density/number of individuals participating in a spawning aggregation is at least four times that found outside the aggregation" (Domeier 2012). Therefore, to properly distinguish a spawning aggregation from other forms of aggregation it is important not only to document high abundance, but also evidence of spawning (e.g. spawning observations or histological information: Domeier 2012). There have been developed standardized methods to collect direct and indirect indicators of spawning (Colin 2012) which should be methodically applied to the Honduran sites to confirm them as spawning aggregation sites and secure their protection. **A project tackling this issue is a research priority in the country.**

If protecting a SPAGS by itself, it is recommended to set a buffer of at least 1 mile around the SPAGS as defined in Belize (Heyman and Requena 2003). Even if sites have low abundances and SPAGS seem to have collapsed (as is the case with the Elbow in Utila: Box 2010) it is recommended to protect these collapsed sites under the rationale that their fish populations could recover after protection and the site become an active aggregation again (Erisman et al. 2017, Semmens et al. 2008).

Note that the Guanaja site, "Caldera del diablo" is outside the fishable areas defined in Honduras, and therefore not included in this plan.

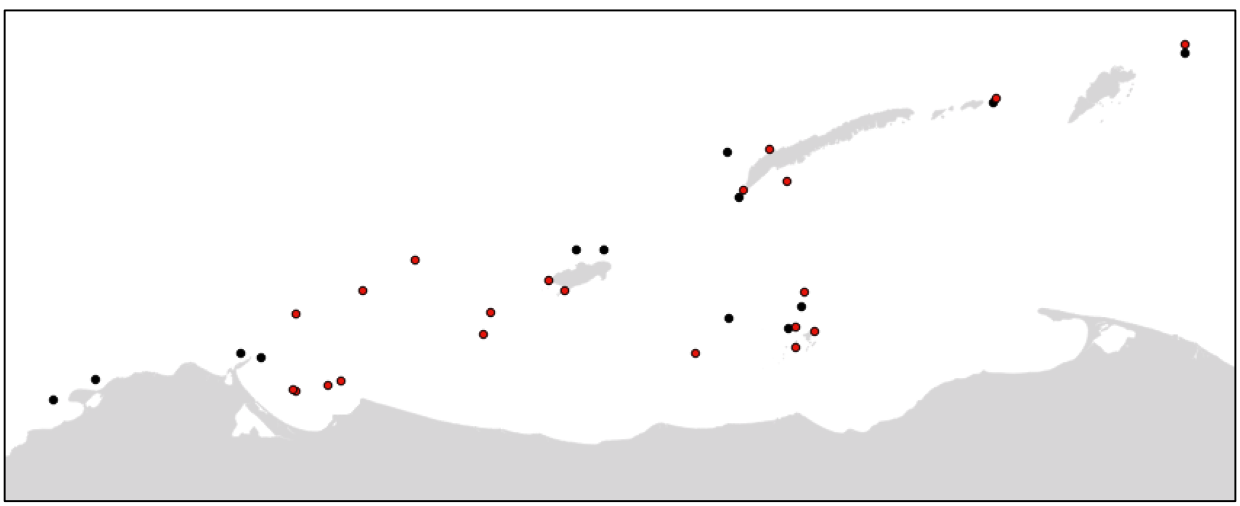

Figure 3.1. SPAGS in Honduras identified in this study in red. Sites in black indicate SPAGS according to Arrivillaga & Windevoxhel (2008, data from C Zepeda).

Table 3.I. Known spawning aggregations in the Honduran Caribbean. Status: active/presumed/unknown/collapsed. When "presumed", there are indications of high abundance but active aggregation behavior has not been recorded. In grey sites of special concern where coordinates are for the bank, not for the aggregation site.

Site	Coordinates from source	Latitude	Longitude	Status	Reference and comments
NORTH SHORE					
Banco Vietnam /Nueva Escocia	16.126833° -87.265667°	16.126833	-87.265667	Presumed	Heyman and Requena 2003. A Borscsok indicates current fishing activity. Coordinates for the bank by S Canty
Banco Capiro	15.86415 -87.50662	15.86415	-87.50662	Presumed	Heyman and Requena 2003. A Borscsok indicates current fishing activity. Coordinates for the bank by A Borscsok
Punta Sal	16°01',. 069 87°30'. 440	16.01781667	-87.50733333	Presumed	Fuentes and Paz 2002. A Borscsok indicates current fishing activity
Izopo	16°03'. 979 87°22'.350	16.06631667	-87.3725	Presumed	Fuentes and Paz 2002. A Borscsok indicates current fishing activity
PN Jeannette Kawas 1	15°51'30" y 15°52'30" 87°29'30" y 87°32'00	15.86666667	-87.5125	Presumed	Fuentes and Paz 2002 reports as collapsed. A Borscsok indicates current fishing activity
PN Jeannette Kawas 2	15° 51' y 15° 54' 87' 24' y 87° 29'	15.875	-87.44166667	Presumed	Fuentes and Paz 2002 reports as collapsed. A Borscsok indicates current fishing activity
PN Jeannette Kawas 3	15° 52' y 15° 54' 87° 24' y 87° 26'	15.88333333	-87.41666667	Presumed	Fuentes and Paz 2002 reports as collapsed. A Borscsok indicates current fishing activity
Lanteros Bank	15.976750° -87.129000°	15.976750	-87.129000	Presumed	Heyman and Requena 2003. A Borscsok indicates current fishing activity. Coordinates for the bank by S Canty
UTILA					
Blackfish Point [1]	15.939500° -86.702167°	15.939500	-86.702167	Unknown	Heyman and Requena 2003. Coordinates for the bank by S Canty
Boot Bank	16.020000° -87.113833°	16.020000	-87.113833	Unknown	Heyman and Requena 2003. Coordinates for the bank by S Canty
The Elbow	16.0862 -86.9981	16.0862	-86.9981	Collapsed	Box 2010. C Perez provided approximate location "North of Raggaede Cay", here depicted 100 m north of the Cay.
South East Bank	16°03.891' 86°57.875'	16.06485	-86.96458333	Presumed	Box 2010. Large groupers seen, but no aggregations. Coordinates by C Perez, who indicates current fishing activity for grouper
ROATAN					
Grouper's joy (Barbareta)	16.27.01.00 - 86.05.48.60	16.45027778	-86.09683333	Active	Fonseca et al. 2004 (in Box and Bonilla2008). Roatan Marine Park rangers and navy detected illegal activity and confiscated gear and fish at this site in early 2017. Coordinates by N Bach, who indicates is currently active.
Cordelia Bank[2]	551507 1800504 (NAD 27)	16.2858322	-86.5179084	Active	Drysdale 2009 (coordinates); Canty and Box 2013. Drysdale describes high abundance but not specifically spawning behaviour. Canty and Box describe low

					abundance, reproductive behaviour but no specifically spawning. N Bach indicates is currently active. Outside no take area.
Texas in West End[3]	16.26656389 -86.60498889	16.26656389	-86.60498889	Active	Drysdale 2009. Describes high abundance but not specifically spawning behaviour. N Bach indicates is currently active. Coordinates from N Bach
Lawson rock, Sandy bay	16.34812738 - 86.55240285	16.34812738	-86.55240285	Active	Site identified by N Bach (pers. com.), with tiger groupers, active from February to April. Site between 100-120 feet and has about 500 adults. Roatan Marine Park has been watching the aggregation for the past 3 years, film crew last year
GUANAJA					
Caldera del Diablo	16° 33’.500” 85° 43’.000”	16.55833333	-85.71666667	Active	Fine 1990, 1992 in NMFS 2014; Box and Bonilla 2004; Fuentes 2002 (coordinates); According to early records this site was eradicated in the early 1990s, however, the site is currently active according to fishers (M Ochoa)
CAYOS COCHINOS					
Punta Pelícano	553477 1763513	15.9504	-86.500305	Active	Aronne 2009; HCRF/USAID 2014. Coordinates provided by M Aronne, they are not the same ones described in report. Part of SZC4 zone, fishing not allowed between December and March according to management plan, but not enforced. Currently under monitoring
Mariposales	553604 1768293	15.993608	-86.49901	Active	Aronne 2009; HCRF/USAID 2014. Coordinates provided by M Aronne, they are not the same ones described in report. Part of SZC4 zone, fishing not allowed between December and March according to management plan, but not enforced. Unmonitored since 2009
La Grupera	557619 1767289	15.984441	-86.461511	Active	Aronne 2009; HCRF/USAID 2014. Coordinates provided by M Aronne, they are not the same ones described in report. Part of SZC4 zone, fishing not allowed between December and March according to management plan, but not enforced. Unmonitored since 2009
Roatán Banks	555383 1775906	16.062391	-86.482207	Active	Aronne 2009; HCRF/USAID 2014. Coordinates provided by M Aronne, they are not the same ones described in report. Part of SZC4 zone, fishing not allowed between December and March according to management plan, but not enforced. Currently under monitoring

Notes:
1 Heyman and Requena have this bank as “Nueva Escocia” but S Canty indicates it is called “Blackfish Point”
2 S Canty provided also the coordinates 16.286806, -86.518806 and N Bach 16.28476667, -86.51971111, both less than 300 m away from I Drysdale’s in opposite directions. They all fall within the same planning unit
3 Drysdale (2009) provides the coordinate 541708 1797873 (in NAD 27, or 16.2622359 -86.6096697), about 700 m away (in a different planning unit). N Bach’s, with more experience in the region, were preferred

Some other indications of aggregation sites from the literature, unverified, should be included in a future field assessment of SPAGs in Honduras:

Fuentes and Paz 2002 mention some of the sites listed in table I, and also indicate four other possible sites: "…Omoa los pescadores han observado agregaciones en el sitio conocido como La Mesona a 4.5 Km. al norte del Río Motagua, en los pedregones de Chachaguala, pedregón del Río Coto, pedregón Cañas y el Mago, pero no proporcionaron coordenadas"

Box and Bonilla 2008 suggest "Banco Campiche" as a possible aggregation site but they give no more information on status or coordinates.

Tune Bank in Utila (16°03.850', 86°57.853', coordinates from C Perez) was indicated as a possible bank by Box (2010). However, after conversations with fisherman, it was not possible to confirm this site as a SPAGS: fishers indicate the bank is a fishing location for tuna. Box (2010) also refers as a possible SPAGS a site called "Clewis Bank" in Utila but the site was unknown by fishers according to C Perez.

Box (2010) sampled a SPAGS in Utila called "Joshua's Swash" and indicated the site collapsed, but C Perez was not able to obtain coordinates. Coordinates from Box's (2010) study have been lost, after contacting both S Box, who wrote the report, and C Zepeda, who received the report in TNC, neither of them have the coordinates on file. S Box provided some approximate coordinates by looking in Google Earth, but given the imprecise nature of this method (locations fall in blue water) and the difference of S Box coordinates and the ones provided by fishers, they were not included here (according to S Box the elbow: 16.0415 -87.0018; Joshua's swash: 16.0650 -86.5623; South east bank: 16.0552 -86.5247).

Arrivillaga & Windevoxhel (2008) provide a list of 13 SPAGS for Honduras (depicted in black in Figure 3.1), sites have only coordinates and no metadata and therefore were not included in this assessment. Although there seem to be agreement for some sites (e.g. Caldera del diablo, Barbareta), some sites have not been captured by this assessment (e.g north Utila, Punta Sal) and should be explored when validating SPAGS in the country in the near future.

NMFS (2014) also provides a map of SPAGS in the country without information on coordinates or sources, it would be interesting to discuss these sites with local fishers when conducting future validation in the country.

Areas with high abundance of Acroporids

Areas with high abundance of Acroporids (*Acropora palmata* and *cervicornis*) in Cordelia (Roatan), Punta Sal and Ensenada (Tela Bay) were targeted for full protection. These areas represent some of the few remaining stands of endangered Acroporids in the Caribbean and can serve to repopulate nearby areas. Areas with high abundance of *Acropora* sp. were identified by expert opinion of CEM members, Andrea Rivera (CINVESTAV), Steve Canty (SI), and Andres Alegria (Universität Bremen).

In Banco Cordelia three areas: Cordelia and Smith Bank and Big Key were targeted for full protection (Figure 3.2, top). These banks are characterized by dense thickets of *A. cervicornis* (Purkis et al. 2006; Riegl et al. 2009) and are partially protected by the Zona de Reserva de Banco Cordelia (Figure 3.2, top).

In Tela Bay two regions were identified for full protection: the north-east section of Punta Sal and Ensenada (Figure 3.2, bottom). The area targeted for protection in Punta Sal encompasses a belt of 100 m wide along the coast enclosing more than 700 colonies of *A palmata* (Rivera et al. 2013) which were mapped by AMATELA in 2012 (spatial data provided by A Alegria). At a smaller spatial scale, the area of Ensenada has high abundance of *A. palmata*, with 174 colonies mapped in 2013 (Rivera et al. 2013). The area targeted for protection encompasses a polygon (convex hull) of 1283 m^2 enclosing 107 mapped large colonies (spatial data provided by A Rivera).

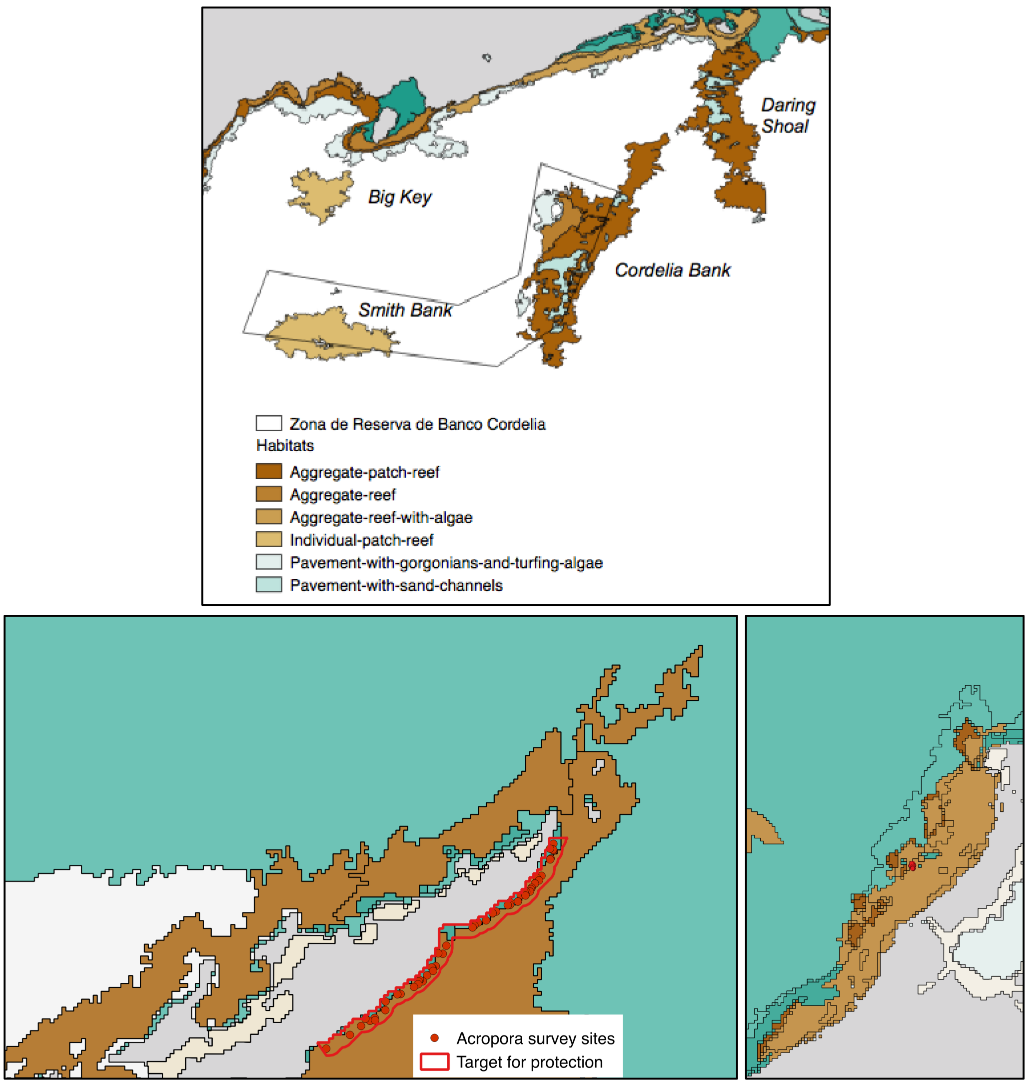

Figure 3.2. Smith and Cordelia Banks and Big Key have dense tickets of *A. cervicornis* and were targeted for protection (top). A belt of 100 m wide covering all mapped *A. palmata* colonies in Punta Sal (bottom left) and a reef area of about 1000 m^2 enclosing all mapped *A. palmata* colonies in Ensenada (bottom right) were also targeted for protection. Data of RZs from Chollett et al. (2015), data on habitats from Purkis (2016).

4. Areas to avoid (costs)

Costs were defined in terms of ports, urban areas, fishing areas and areas influenced by watersheds, added into a single value with ports having a weight of 2 and all other layers a weight of 1 (Figure 4.1).

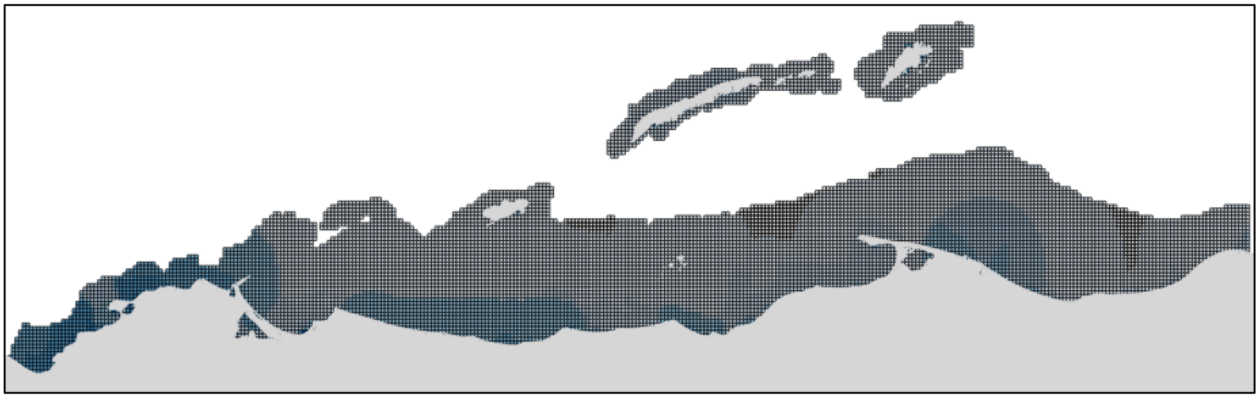

Figure 4.1. Areas to avoid. Overall costs in shades of blue.

During early conversations with CEM there were identified other uses relevant for planning in the country (areas of maritime transportation and areas of planned development), but in spite of CEM efforts it was not possible to gather the relevant information to inform those layers.

Ports

Ports were avoided by setting a buffer of 1km around ports in Honduras (Figure 4.2). Data on location of ports produced by Iliana Chollett.

Figure 4.2. Planning units depicting areas to avoid. Ports in yellow and port influence index in orange

Urban areas

Urban influence was captured by scoring each planning unit according to the proximity to populated centers (Cruz et al. 2016). To that end, the influence of each populated center was first represented with buffers of different sizes according to their population size (Table 4.I), and then the influence of nearby towns (overlapping buffers) was summed for each planning unit. These values were then scaled to calculate an index of urban influence ranging from 0 to 1 (Figure 4.3). Data on location of settlements from ICF portal ("asentamientos" layer: m1105vp001988_hn.shp).

Other datasets considered and not used: GLUDS, SINIT layer on land uses, last of the wild dataset, USGS data on bare land.

Table 4.I. Settlement hierarchy (according to Wikipedia) and spatial influence (following Cruz et al. 2016)

Settlement	Population	Influence (miles)
City	> 100,000	10
Town	1,000 - 100,000	5
Village	100 - 1,000	3

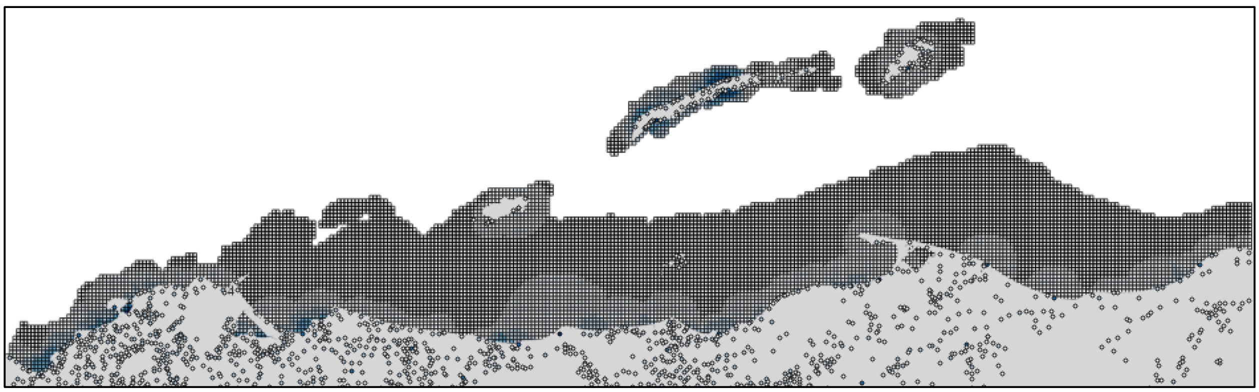

Figure 4.3. Planning units depicting areas to avoid. Urban settlements color-coded according to cities (dark blue), towns (light blue) and villages (white) and urban influence index in shades of blue

Fishing areas

Fishing influence was captured by scoring each planning unit according to the relative impact of all fishing communities. Each fishing community was assumed to have a range of 20 km (weighted as 1) and a maximum range of 40 km for fishing (weighted as 0.5, ranges follow patterns of use observed in the Utila Cays: Chollett et al. 2014). The relative impact of each community was proportional to the number of fishers living at the site. These values were then scaled to calculate an index of fishing influence ranging from 0 to 1 (Figure 4.4). Fishing communities and number of fishers in each were quantified by CEM (data provided by Sara Bonilla).

Suggestions: This is a very simple proxy of fishing influence. In reality each community uses a particular set of fishing grounds, that should be used instead of buffers, with variable effort and capture, which should be used for weighting the relative use of the fishing grounds instead of number of fishers.

Figure 4.4. Planning units depicting areas to avoid. Fishing settlements color-coded according to the number of fishers and fishing influence index in shades of red

Areas influenced by watersheds

To describe this threat, we used the layer of watershed-based pollution produced by the project Reefs at Risk Revisited (Burke et al. 2011). This spatial layer focuses on erosion and nutrient fertilizer runoff from agriculture delivered by rivers to coastal waters, and was produced including information on watersheds (catchments) discharging to coastal waters, relative erosion rates (based on slope, land cover type, rainfall and soil type), sediment delivery at the river mouth and modelled sediment plume dispersion. Watershed impact is represented in three categories: 0, 100 or 1000. For the analysis in Honduras, we rescaled these values to calculate the relative watershed influence in each planning ranging from 0 to 1 (Figure 4.5).

> *Other datasets considered but not used:* SINIT and USGS hydric networks for the country, which seemed incomplete when compared to satellite imagery for the area.
>
> *Recommendations:* Although this dataset represents a good proxy for sediment, nutrient and pollutant delivery, it does not consider actual current patterns to assess sediment dispersion, which would provide a more realistic view of sediment delivery to marine habitats in the area.

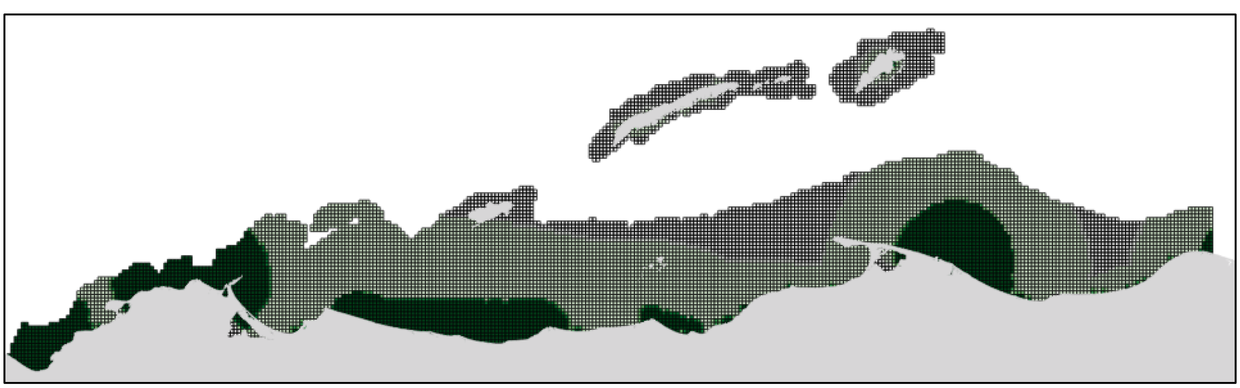

Figure 4.5. Planning units depicting areas to avoid. Watershed influence index in shades of green

5. Yellowtail snapper connectivity model

Yellowtail snapper was identified as the main focal species for planning in northern Honduras by CEM. Parameters describing the behavior of yellowtail larvae were compiled through literature review. Habitat locations in the Mesoamerican Region (MAR) were compiled using best sources available according to contacts in each country (Seleni Cruz TNC Belize, Ana Giro HRI Guatemala, Stuart Fulton COBI Mexico, Iliana Chollett Honduras). With this information larval connectivity data for the species was produced for this project by Lysel Garavelli (Harbor Branch Institute).

The main source of larvae to northern Honduras is actually northern Honduras, which contributes 54% to the larvae that settles in the region (Figure 5.1). Within northern Honduras there is a gradient, where areas inshore contribute more larvae than areas offshore, which larvae are swept by currents leaving the region. Other regions that contribute larvae to northern Honduras are Belize (30%), eastern Honduras (5%), Guatemala (4%), Nicaragua (3%) and Mexico (3%).

> *Suggestions:* this exercise includes connectivity data only for yellowtail snapper, which was produced specifically for this project. However, it would have been desirable to consider the connectivity of other focal species. Other connectivity data available for the region (e.g. Chollett et al. in press, Holstein et al. 2012) is not useful for planning in northern Honduras because they do not include all the marine habitats in the region, which were recently mapped for this project (Purkis 2016).

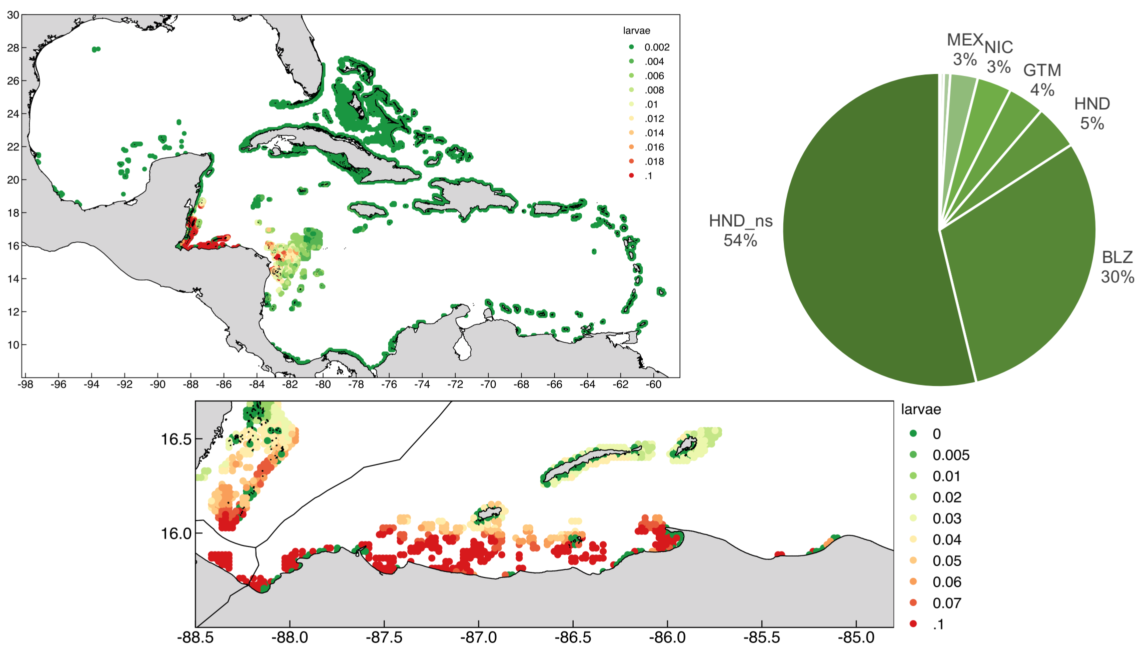

Figure 5.1. Where does larvae that seeds northern Honduras come from? Proportion of larvae contributing to northern Honduras: Caribbean wide (top); within northern Honduras (bottom)

Habitat data

Release areas for the area 8-28ºN, 59-98ºW were identified using the global location of reefs by the UNEP et al. (2010). Habitat data for the MAR was refined after contacting researchers in each country, because the global dataset underestimates habitat distribution in Belize, Honduras and Guatemala. For Belize, we used maps produced by the Coastal Zone Management and Institute of Belize, last updated in 2014. The data was provided by Seleni Cruz (TNC). For Honduras, we used habitat maps produced by the Smithsonian Institution (Purkis 2015, 2016) and included consolidated habitats as release areas. For Guatemala we used the location of reefs according to HRI, which was used as supporting information for the 2016 eco-audit (data provided by Ana Giro, HRI). For Mexico, we used the global database (UNEP et al. 2010), which according to Stuart Fulton (COBI) represents reef distribution in the country well.

Hydrodynamic model
The Hybrid Coordinate Ocean Model (HYCOM; Bleck 2002) was used to simulate the hydrodynamic currents in the Caribbean region. The horizontal resolution in HYCOM is about 8 km in the study region. We also used here one embedded domain with increasing resolution to simulate the oceanic circulation in the MAR. This domain (from 15.5ºN to19ºN and from 86ºW to 89ºW) is characterized by a 2-km grid point distance and is fed every 5 days at its boundaries by the HYCOM model. Two separate numerical models were run simultaneously and communicated at the boundaries in order to ensure continuity of their respective simulations. This simulation was run from September 2005 to December 2006. In our study, we used the year 2006 to simulate the larval dispersal for yellowtail snapper.

Biophysical model
To investigate the larval connectivity patterns of yellowtail snapper (*Ocyurus chrysurus*) in the Caribbean region, we developed a biophysical model using the Connectivity Modeling System (CMS; Paris et al. 2013). The CMS is a Lagrangian stochastic model using a 4th order Runga-Kutta integration scheme. It allows the coupling between hydrodynamic outputs, habitat, and biological factors. In the model, each particle represents a virtual larva and is characterized by its longitude, latitude, and depth. Using hydrodynamic outputs from the two models described in the previous paragraphs, particles were tracked at each time step of the model (i.e. 3600 seconds in our study). Habitat and larval biological characteristics of yellowtail were incorporated in the model using the information gathered from the literature. Using coral reef habitat location described above, two different resolutions of habitat polygons were chosen depending on the location. 2,100 4km^2 polygons were designed in the MAR and 3,588 64km^2 polygons outside in the rest of the study domain (Figure 5.2). From all the polygons, 1,000,000 particles (representing virtual larvae) were released monthly. The release depth was set to 2m to mimic the early larval stage distribution of yellowtail snapper in surface (D'Alessandro et al. 2010; Holstein et al. 2014). In the model, we selected a 40-day planktonic larval duration and a 22-day pre-competency period (Clarke et al. 1997; Cummings 2004). The settlement of the virtual larvae was therefore computed between 22 and 40 days in the habitat polygons. Following the distribution of yellowtail larvae described in D'Alessandro et al. (2010), an ontogenetic vertical migration behavior (see Table 5.I for the proportion of larvae in the water column) was included in the model. The results from the simulation are represented as connectivity matrices $C_{i,j}$ with dimension 1814x1814 polygons. Each element of the connectivity matrix represents the percentage of larvae released from polygon j that are transported to polygon i.

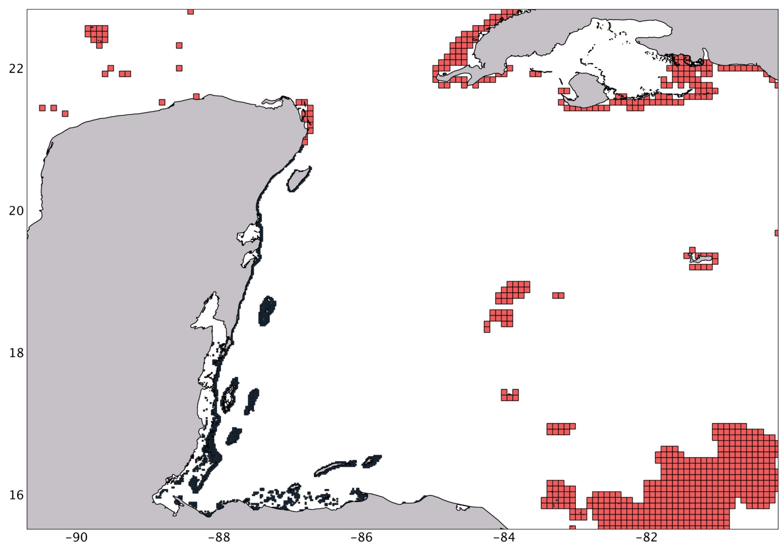

Figure 5.2. Map representing a section of the habitat polygons, showing the differences in spatial resolution of the two nested models. Red polygons are $64km^2$ and blue polygons are $4km^2$

Table 5.I. Distribution of yellowtail snapper larvae in the water column. Numbers are density probabilities (in %) at each depth (m) and time (days)

Depth\Time	1	1	10	28
5	30	10	0	0
15	40	20	10	25
25	30	20	20	25
35	0	20	25	25
45	0	20	25	25
55	0	5	10	0
65	0	5	10	0

6. Yellowtail snapper population model

Population parameters for yellowtail snapper were compiled. This information was used, together with the connectivity data, to build a spatially explicit population model for the species, that could allow assessing the sustainability of the resource (persistence) and benefits to fisheries of competing RZ networks.

Spatially explicit population model

Survival - Adults are subjected to natural and fishing mortality (Eq. 1). The survival of individuals at different ages (l_a) was calculated using the relationship given by Goodyear (1993, Eq. 1), which incorporates both natural mortality (M) and the instantaneous fishing mortality rate (F) when individuals are older than the age at first capture (t_c).

$$l_a = \begin{cases} e^{-M} & a < t_c \\ e^{-(M+F^*)} & a \geq t_c \end{cases} \quad \text{Eq. 1}$$

Fecundity - We used known relationships between total length L and age a (von Bertalanffy growth, Eq. 2), and between egg production or fecundity (f) and L (Eq. 3), to estimate egg production at a given age. Continuous values were discretized to the mean value for each age category. K, L_∞ and t_0 are the von Bertalanffy parameters for, respectively, growth rate, asymptotic length (mm) and age at which individual would be length 0 (yr). α and β are parameters for the fecundity-at-length relationship.

$$L_a = L_\infty (1 - \exp^{-K\,(a-t0)}) \quad \text{Eq. 2}$$

$$f_a = \alpha\, L_a{}^{\beta} \text{ Eq. 3}$$

Persistence and yield - For studying the effects of spatial management on spiny lobster populations the spatially explicit population model calculates two indices of the fishery's state that are independent of the stock-recruitment relationship: eggs per recruit (EPR) and yield per recruit (YPR). EPR is the number of eggs an average recruit produces over its lifetime, which approximates to the spawning stock biomass per recruit. EPR was calculated by considering fecundity (f_a) and survival (l_a) for all ages using Eq. 4 (Goodyear, 1993).

$$EPR = \sum l_a f_a \quad \text{Eq. 4}$$

Values of EPR were then used to calculate the Fraction of Natural Eggs per Recruit (*FNEPR*). This metric is the ratio of the fished (*EPR*) to the unfished (*NEPR*) reproductive potential and it is a measure of the impact of fishing on the potential productivity of the population (Eq. 5).

$$FNEPR = \frac{EPR}{NEPR} \quad \text{Eq.5}$$

With *NEPR* being quantified as in Eq. 4, and survival calculated without the influence of fishing mortality (Eq. 6):

$$l_a = e^{-M} \quad \text{Eq. 6}$$

For fished populations to persist, successive generations must replace each other, increasing the value of FNEPR. Generally, values of FNEPR are compared against threshold levels, with 20% being recommended for yellowtail snapper. Persistence was summarized using two metrics (1) Per_d, a dichotomous metric indicating the existence of at least one reserve with FNEPR values above threshold; and (2) Per_c, a continuous metric given by the sum of FNEPR values inside reserves. While it has been shown that a meta-population is likely to collapse if there is not at least one population with FNEPR values above threshold (e.g. Kaplan et al. 2006), the sum of FNEPR is a measure of larval settlement within the network commonly used for the assessment of persistence in a spatially realistic setting which allows better comparisons of competing reserve networks at similar values of Per_d.

YPR is the effect of fishing on yield, expressed in terms of the yield an average individual provides to the fishery over its lifetime. YPR was calculated using the Beverton and Holt equation (Sparre and Venema, 1998):

$$YPR = W_\infty F e^{-M(t_c - t_r)} \sum_{n=0}^{3} [U_n e^{-nK(t_c - t_0)} / (F + M + nK)] \quad \text{Eq. 7}$$

Where W_∞ is the mean asymptotic weight calculated from L_∞ and the weight-at-length relationship showed in Eq. 8, with t_r as the age at recruitment, with U=[1,-3,3,-1].

$$W_a = \gamma L_a^{\delta} \quad \text{Eq. 8}$$

Trade-offs - An optimal network of reserves was identified as the one that would maximize as much as possible both the benefit to fisheries (i.e. yield) and persistence (i.e. Per_c), subject to the condition that at least one reserve had FNEPR values above threshold (i.e. Per_d=1). To that end, we used a global criterion method in L2 (Euclidean) norm (Branke et al. 2008) to minimize the sum of squared distances of individual observations ($f_i(x)$) from their known optimal values (f_i^0, Eq. 9).

$$L_2(f) = \sqrt{\sum_{i=1:k} (f_i^0 - f_i(x))^2} \quad \text{Eq. 9}$$

This "no-preference" method was used to find a compromise solution that is as close as possible to optimal (maximum) values of yield and persistence.

Population parameters

To estimate EPR and YPR we used the parameters described in Table 6.I. Because no population parameters for Honduran yellowtail snapper have been compiled, we followed, when available, the advice of NOAA's South-East Data, Assessment, and Review organization (SEDAR: Muller et al. 2003) that has experience in stock assessment in the Caribbean region.

The population model included 14 size classes. Individuals become reproductively mature at 2 years, at the same time they become available to the fishery. Fecundity increases with age. Individuals experience a natural mortality rate of 0.2 yr^{-1} throughout their lives and fishing mortality of 0.25 yr^{-1} (values at Maximum Sustainable Yield.) The steepness of the spawner-recruit relationship was set to 0.8 (Muller et al. 2003).

Table 6.I. Parameters used for modelling EPR and YPR for yellowtail snapper

Parameter	Value	Definition	Reference
a_{max}	14	Maximum age (year)	Muller et al. 2003
t_c	2	Age at first capture (year)	Muller et al. 2003
t_m	1.7	Age at maturity (year)	Muller et al. 2003
M	0.2	Instantaneous natural mortality rate	Muller et al. 2003
F	0.25	Instantaneous fishing mortality rate	Muller et al. 2003
L_∞	446.5	Asymptotic von Bertalanffy length (mm)	Muller et al. 2003
K	0.527	von Bertalanffy growth parameter	Muller et al. 2003

t_0	0.6301	Age at which individual would be length 0 for von Bertalanffy (year)	Muller et al. 2003
α	266.1	Parameter of fecundity-at-length relationship	Collins and Finucana (1989*)
β	2.627	Parameter of fecundity-at-length relationship	Collins and Finucana (1989*)
γ	$4.2512\ 10^{-5}$	Parameter of weight-at-length relationship	Muller et al. 2003
δ	2.7388	Parameter of weight-at-length relationship	Muller et al. 2003

* in Cummings 2004

7. Marxan

The objective of Marxan is to minimize the total cost of the reserve network and the total perimeter of the network while meeting all targets using the equation

Score = Efficiency + clumping + penalty for not achieving conservation targets

or

Score = Cost + BLM * combined boundary length + SPF * combined target shortfall score

Where BLM is the boundary length modifier and SPF is the species penalty factor, both of which control the weighting of terms in the Marxan equation. The solution with the lowest score is the one that Marxan selects as the “best” solution.

A collection of RZ networks that meet all the targets and minimize costs was found using Marxan implemented in *ch* (package *marxanui*: Watts 2016).

Parameter calibration

Calibration of Marxan parameters was done by assessing a range of parameters and examining the results for achieving targets (indicating the need of modifying SPF) and clustering (suggesting changing BLM). The objective is to choose parameters that allow meeting all targets and have an appropriate level of clustering at the minimum values of SPF and BLM (to keep the cost of the solution low).

Marxan was initially ran with 100 replicates (runs) and baseline SPF and BLM of 0. None of the solutions met all targets, with 21 out of 26 habitat classes being underrepresented. The network had an average cost of 18.60.

First appropriate values of SPF were chosen so to meet all targets. In the baseline scenario described above, targets are not met because the cost for adding another useful planning unit is greater than the penalty for missing a target (shortfall * SPF). To calibrate SPF values we followed the advice provided by Fisher et al. (2010). We set SPFs the same for all conservation features, and iteratively adjust them until >90% of the restarts meet all the targets, which was achieved at SPFs of 90.

An overview of the parameter space (Figure 7.1) shows that values of SPF bellow 60 produce a large number of runs (> 20%) that do not meet the targets. The number of runs missing target decrease slowly afterwards, with 9% runs missing targets at SPF of 90. Costs, on the other hand, increase rapidly and plateau at values of SPF of about 10. Because even at large values of SPF (as large as 500) there are still a few runs missing targets and because it was not only one habitat consistently being missed (habitats missing were variable: ID 3, 9, 11, 13, 19, 21, 25) it was decided to fix SPF at 90 for subsequent scenarios, use a large number of runs, and discard unfeasible results (that do not meet all targets).

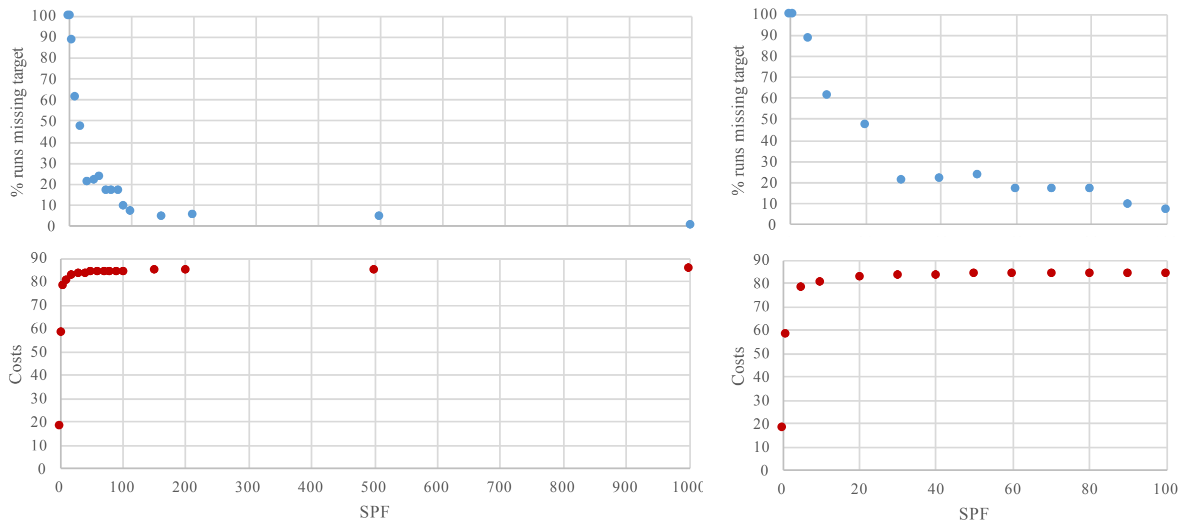

Figure 7.1. Changes in percentage of runs missing targets and cost as a function of SPF (BLM=0). Search of the parameter space with 100 runs (replicates) per parameter combination. Right panels indicate a zoom for SPF values 0-100

Then appropriate values of BLM were chosen so to provide compact (with smaller boundary lengths) but inexpensive solutions. In the baseline scenario, we ran the model 100 times with BLM of zero (and SPF=90). This provides solutions with average boundary length of 4082 km and average cost of 84.17.
Boundary length increase and costs decrease dramatically at BLM values of 0.0001 (E-04), and this value was chosen for subsequent analyses. Further increases in BLM produce solutions that decrease the boundary length but increase costs (Figure 7.2).

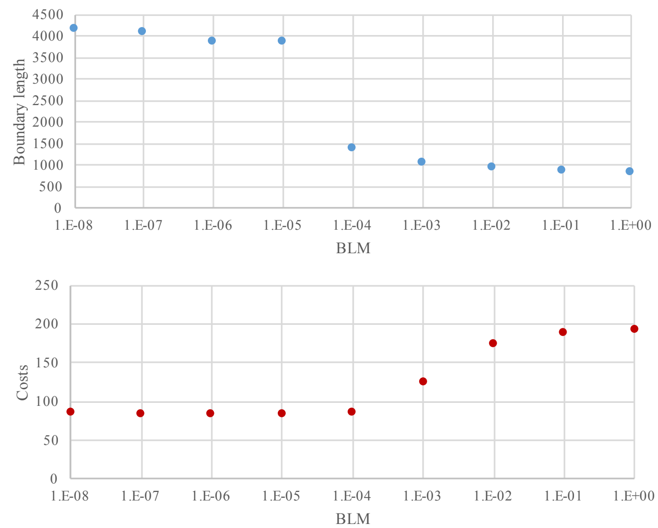

Figure 7.2. Changes in boundary length and cost as a function of BLM (SPF=90). Search of the parameter space with 100 runs (replicates) per parameter combination. Note the logarithmic scale for expressing BLM.

8. Description of companion spatial data

Table 8.I indicates an overview of spatial layers used for this project and provided as companion documentation. All spatial data in EPSF 32616.

Table 8.I Spatial layers. Unless noted, layers enclose polygon features.

Layer	Description	Path
INPUT		
Fishable area	Target area for protection, identified with the GEBCO dataset as those shallower than 200 m. Fields: area: polygon area in km^2	Input/ nsHND_fishable.shp
Planning units	Planning units of 1 km^2 covering the fishable area Fields: puid: planning unit ID {1, 10229}	Input/ nsHND_1kmgrid.shp
Land	Land areas for the region, from shallow marine habitat map (Purkis 2016), layer included for visualization purposes (i.e. not used for input in optimization). Fields: Described in report	Input/ nsHND_land.shp
Target habitats	Habitat map for the region including mangroves, shallow marine habitats and deep habitat within fishable area Fields: Zone: geomorphological zone as in Purkis (2016) Habitat: habitat as in Purkis (2016) Region: continental shore 'c' or offshore 'o' Habitat_re: string concatenating habitat and region	Input/ nsHND_habitat_full.shp

RZs	Location of previous RZs in the country (Chollett 2015) Fields: Categoria: RZ category Nombre: RZ name area_km2: RZ area in km^2	Input/ nsHND_RZs
SPAGS (point)	Location of spawning aggregation sites Fields: Site: Site name Region: Geographic region Latitude: in decimal degrees Longitude: in decimal degrees Status: {presumed, active, unknown, collapsed} -see table 3.I-	Input/ nsHND_spags.shp
Acropora sites	Location of areas with high abundance of Acroporids Fields: Site: Site name Region: Geographic region Area: polygon area in km^2	Input/ nsHND_acropora.shp
Costs	Planning units with values for cost indices Fields: puid: planning unit ID {1, 10229} i_urban: urban influence index {0,1} i_water: watershed influence index {0,1} i_fishing: fishing influence index {0,1} i_ports: port index {0,1} i_total: overall cost index {0,1}	Input/ nsHND_1kmgrid_costs.shp
OUTPUT		
Frequency of solutions	Total number of times each planning unit was selected by Marxan in the 950 runs Fields: puid: planning unit ID {1, 10229} sum: Frequecy of solutions {0, 950}	Output/ nsHND_sumtsol.shp
5 best networks	5 best RZs networks identified through Marxan and the dynamic population model for yellowtail snapper Fields: puid: planning unit ID {1, 10229} 454: results for that solution, 0 if available 1 if RZ 758: results for that solution, 0 if available 1 if RZ 410: results for that solution, 0 if available 1 if RZ 241: results for that solution, 0 if available 1 if RZ 700: results for that solution, 0 if available 1 if RZ	Output/ nsHND_bestsol.shp

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