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Effort reallocation of illegal fishing operations: A profitable scenario for the municipal fisheries of Danajon Bank, Central Philippines

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ABSTRACT

The northern section of the Danajon Bank, which is located in the Central Visayas islands of the Philippines is a shallow, tropical reef system that supports a multi-species fishery that is primarily artisanal and subsistence in nature. A persisting management and regulatory challenge in the area is the continued use of illegal fishing gears that are deemed destructive by either their manner of operation or technical design. In this study, we used a dynamic simulation model – Ecopath with Ecosim (EwE) – to explore the potential biological and socio-economic consequences of a hypothetical successful ban on the illegal fisheries in the area under two main scenarios: without fishing effort reallocation and with fishing effort reallocation. The highlight of the study relates to the profit-income analysis whereby the calculated increases in harvestable group biomasses did not necessarily translate into expected increases in overall yields and profits, but showed noteworthy impacts at the per capita level of specific fishing operations. The magnitude and direction of profit income changes varied for the two scenarios. All in all, the removal of illegal fisheries can be a "profitable" endeavor without necessarily having to sacrifice fisheries jobs through a reallocation of displaced illegal fishers to the legal fishery types. By doing so, the weighted average per capita net profit income in the Danajon municipal fisheries could be increased substantially (38%) compared to the present day reference level. To operationalize the fishing effort reallocation, we advocate the use of the fisheries licensing system that is already in place and to translate our findings into numbers of fishing license quantities to be allocated among the allowable fishery gear types. To conclude, the use of a per capita yield and profit incomes analysis provides relevant, objective, and practical policy advice for the management of small-scale and subsistence fisheries where alternative livelihood options may be limited.

1. Introduction

The impacts of illegal fisheries have been extensively discussed in fisheries and ecosystems management literature to include not only the bio-physical effects, but also, the socio-economic drivers and consequences (Agnew and Barnes, 2004; MRAG, 2005; Sumaila et al., 2006). Worldwide, illegal fisheries contribute to huge annual economic losses amounting to at least $10 bn (Agnew et al., 2009). As yet, this conservative estimate is exclusive of the unregulated artisanal catches that provide the majority of the food requirements and livelihood needs of many small-scale fishing communities in developing country settings (Akpalu and Normanyo, 2014; Le Manach et al., 2012; Varkey et al., 2010). In the Philippines, illegal fishing is often cited as the primary issue that jeopardizes the sustainability of fisheries resources and causes dissipation of economic rent (Green et al., 2003; Israel, 2004). These illegal activities include in general the bio-physically destructive fishing such as blast and poison fishing, sectoral-based regulated fishing of commercial fishing operations (i.e. use of fishing vessels >3GT) within municipal waters (i.e. all waters extending up to 15 km from the coastline), and technical-based regulated gears (e.g. seining and other forms of active gears within municipal waters) as defined in the Philippine

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Table 1
Prohibited activities in the Philippine Fisheries Code (R.A. 8550 as amended by R.A. 10654) relating to capture fisheries.

Section, title	Key elements
Section 86. Commercial fishing vessels fishing within municipal waters	- “Municipal waters” refer to all bodies of water within 15 km from the coastline, and are delineated for the priority use of municipal fisherfolk. “Municipal fishing” is defined as fishing using vessels of three (3) gross tons or less, or fishing not requiring the use of fishing vessels. - Fishing with the use of vessels with 3.1 gross tonnage and above are considered as commercial fishing, and are therefore not allowed within municipal waters.
Section 92. Fishing Through Explosives, Noxious or Poisonous Substance, and/or Electricity	- “Explosives” apply not only to dynamite, but also all other chemical substances and devices that either contain combustible elements or cause an explosion. - “Noxious or Poisonous” substances include plant extracts, sodium cyanide, cyanide compounds and other chemicals with similar effects to fish and/or any other aquatic species. - “Electrofishing” refers to the use of electricity generated by batteries, electric generators, and other sources of electric power. - Prima facie evidence of actual use includes (1) the discovery of explosives, noxious or poisonous substances, and/or electrofishing devices and (2) the discovery of fish caught or killed by such means on board a fishing vessel, or in the possession of any fisherfolk, boat operator, boat official or fishworker.
Section 93. Use of Fine Mesh Nets	- “Fine mesh nets” are currently defined as those with mesh sizes less than 3 cm between 2 opposite knots of a full mesh when stretched. - Exemptions apply to nets used in the capture of fish and other fishery species that are by nature small, and yet are already mature such as anchovies (Engraulidae), gobies (Gobiidae), and sergestid shrimps (*Acetes* sp.) to name a few.
Section 95. Use of active gears in municipal waters and bays	- An “active fishing gear” is defined as any fishing device characterized by gear movement, and/or the pursuit of target species by towing, lifting, and pushing the gears, surrounding, covering, dredging, pumping and scaring the target species to impoundment - All forms of trawls, purse seines, Danish seines, ring nets, bag nets, drive-in nets, round-haul seines, and motorized push nets are considered as active fishing gears (FAO 201, s. 2000).
Section 97. Ban on Muro Ami and any of its variations	This prohibition refers to “muro ami” fishing and similar operations that require diving and other physical or mechanical acts to pound coral reefs and other habitats, meant to entrap, gather and catch fish.
Section 98. Illegal use of superlight within municipal waters	This refers to any fishing activity employing light from halogen or metal halide bulb/s, which may be located above the sea surface or submerged in water, in order to aggregate fish for capture.

Fisheries Code (Table 1). While some success has been documented in tackling the problem by scaling-up localized fisheries enforcement (Armada et al., 2009) and increasing the capabilities of local government units (LGUs) for coastal resource management (Pinat and Green, 2004), illegal fisheries remain by and large the main management challenge in the Philippine municipal fisheries sector.

1.1. The case of Danajon Bank municipal fisheries

The Danajon Bank municipal waters as defined in this study fall within the geographical coordinates 124°7.977′ and 124°39.4513′ Latitudes and 10°0.0146′ and 10°22.0002′ Longitudes (Fig. 1). It has a delineated surface area of 1227 km^2, is relatively shallow (5 m average depth), and is characterized by predominantly muddy-sandy substrates. The management and use of the marine waters, component habitats, and resources therein fall under the jurisdiction of four coastal towns in the northern section of the island province of Bohol whereby 43% of 540 villages and towns are either coastal or island villages, and 50% of population are either directly or indirectly engaged in fishing (Armada et al., 2009).

Municipal fishing is legally defined as any fishing activity that takes place within the country’s delineated municipal waters with fishing vessels not exceeding 3 Gross tons. The municipal fishing activities in Danajon Bank are largely artisanal and subsistence in nature where simple hook and lines, gillnets, fish pots, and corrals-weirs are the dominant gears (Christie et al., 2006; Fragillano, 2010). The illegal fisheries types identified and singled out for evaluation in this study are fishing activities that are prohibited either in the national Fisheries Code or in local fishery ordinances. Namely, these include the blast fishing operations, bottom trawling (within 15 km waters), Danish seines (within 15 km waters), round-haul seines (within 15 km waters, use of fine mesh netting), beach seines (use of fine mesh netting), and spear fishing with the aid of a compressor, also known as “hookah” diving, which is associated with poison fishing and physical damage to living reefs. Collectively, the illegal fisheries in Danajon Bank contribute to nearly one-fourth of the total annual municipal fisheries yields and one-third of the overall net profit incomes generated from fishing (Bacalso, 2011). Their average catch per unit of effort (CPUE, kg/unit/operation) are also among the highest, ranging from 25 kg to over 100 kg, while most of the legal fisheries average less than 10 kg/unit/operation. These high extraction rates have been suggested to suppress the recovery of depleted predatory fish biomasses in the system (Bacalso and Wolff, 2014). In effect, the illegal operations in Danajon Bank are depriving the legal operations of potentially larger gains from fishing. Within this context, this study aims to quantify the potential biomass, livelihoods, and net profit impacts of a hypothetical successful ban on illegal fishing operations in the Danajon Bank. To do so, an Ecopath base model of the Danajon Bank municipal fisheries (Bacalso and Wolff, 2014) was used to simulate scenarios of a hypothetical successful ban on illegal fishing operations. Focusing on selected biological and socio-economic parameters from the dynamic simulation model Ecosim (Christensen and Walters, 2004; Walters et al., 1997), this study then evaluated the impacts of illegal fisheries removals on overall fisheries gains relative to the status quo. Specifically, Ecosim was used to estimate the relative changes in biomass structure, the corresponding changes in yields and fishing fleet values, and subsequent changes in net profit incomes and direct fisheries employment.

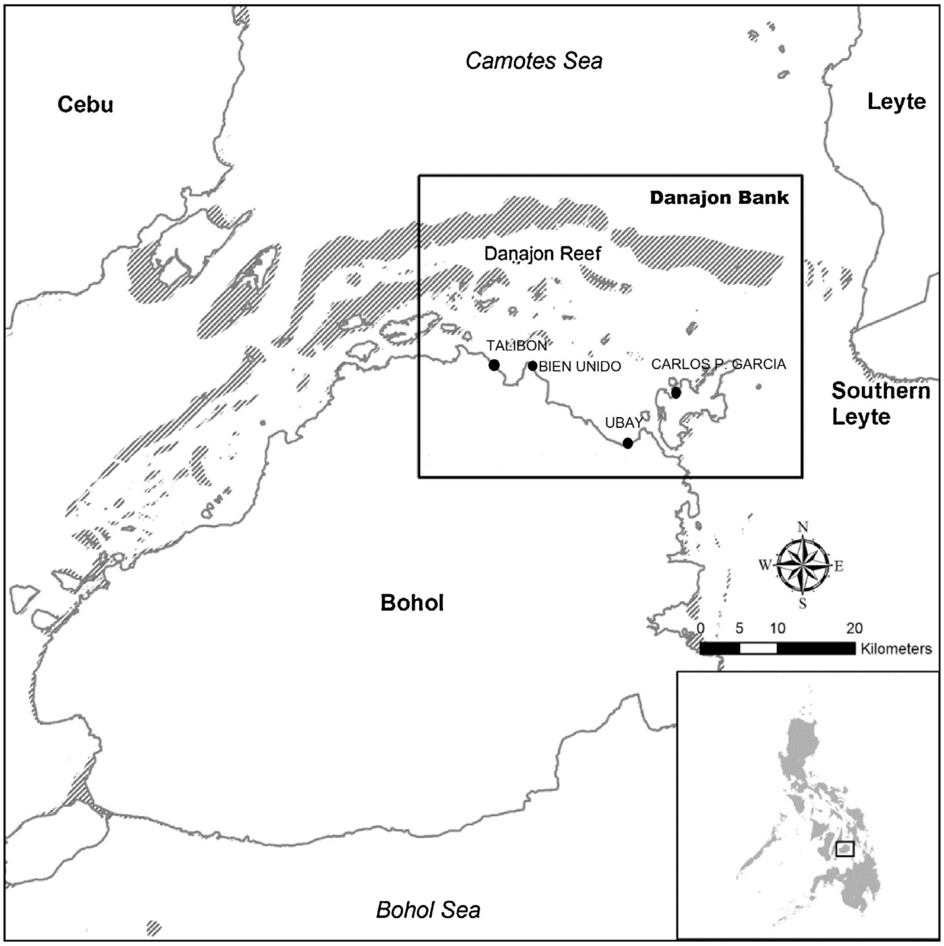

Fig. 1. The Danajon Bank area (boxed).

2. Methods

2.1. Ecosim modeling

Ecosim is a time-dynamic simulation model built on the assumptions and linear equations used to construct Ecopath models. Built on a series of differential equations (Walters et al., 1997), the Ecosim master equation is as follows (Christensen et al., 2005; Christensen et al., 2008):

$$\frac{dB_i}{dt} = g_i \sum_j Q_{ji} - \sum_j Q_{ij} + I_i - (M_i + F_i + e_i)B_i \tag{1}$$

where dB_i/dt represents the growth rate during the time interval dt of group (i) in terms of its biomass B_i, g_i is the net growth efficiency (production/consumption ratio), M_i represents the non-predation or “other” natural mortality rate, F_i is fishing mortality rate, e_i is emigration rate, I_i is immigration rate, and $e_i{\cdot}B_i - I_i$ is the net migration rate. The two summations estimate consumption rate. The first expresses the total consumption by group (i), while the second represents the predation by all predators on the same group (i). The consumption rates, Q_{ij} are calculated based on the “foraging arena” concept (Walters and Christensen, 2007; Walters et al., 1997), where the biomasses (B_i) are divided into vulnerable and invulnerable components. The transfer rate between these two components is what determines if control is top-down (i.e. Lotka–Volterra), bottom-up (i.e. donor-driven), or of an intermediate type, hereby represented in the following equation:

$$c_{ij} = \frac{v_{ij} \cdot a_{ij} \cdot B_i \cdot B_j}{v_{ij} + v'_{ij} + a_{ij} \cdot B_j} \tag{2}$$

where c_{ij} is the consumption of group j on group i, v and v' represent the rates at which groups change behavior thereby making them either vulnerable or invulnerable to predation, and a_{ij} represent the effective search rate of predator j for prey i.

2.2. Vulnerability settings

In Ecosim, the flow control or vulnerability (v) settings are critical in making definitive conclusions out of the simulation results. Literature on multi-species Ecosim simulations has demonstrated the differential effects of the bottom-up and top-down flow control assumptions (Gasalla and Rossi-Wongtschowski, 2004; Pitcher and Cochrane, 2002). A well-defined time series data on either the catches or the biomasses of the functional groups that comprise the Danajon Bank would have allowed for the estimation of the different flow controls that govern the trophic interactions between these groups (Christensen et al., 2008). In the absence of reliable time-series information, several v settings (between 1 and 100) were explored in a series of initial Ecosim simulation runs. At complete bottom-up flow control ($v<2$), responses of both predator and prey group biomasses to simulated changes in fishing effort were extremely small to make any meaningful observation. On the other hand, v settings from 15 onwards produced more pronounced fluctuations particularly in several predator group biomasses, and with corresponding prey groups even dropping out of the system completely (Fig. A.1). Vulnerability settings in between, however, produced initial results of biomass trajectories that, although were of varying magnitudes, shared fairly similar trends. In addition, the simulations from these intermediate v settings showed that most of the biomass fluctuations occur within the first 5–10 years following effort reduction and stabilizes thereafter. Alternatively, Cheung (2001) and Cheung et al. (2002) have demonstrated that there is a linear relationship between group flow control settings and their estimated trophic levels (TL):

$$v_i = 0.1515 \times TL_i + 0.0485 \quad (3)$$

Subsequent authors have likewise found that setting the vulnerabilities proportional to the trophic levels of the groups (vTL) as a likely more realistic option to use in Ecosim simulations when information on flow controls is absent (Buchary et al., 2002; Chen et al., 2008; Fulton and Smith, 2002; Mackinson, 2002). We tested this approach for the present model and explored the functional groups' responses. The shapes of the simulated response of the functional group biomasses under the vTL setting resembled the biomass trajectories simulated using the intermediate flow controls (v7–v10, see Fig. A.1), reflective of a mix of bottom-up and top-down flow control settings. Concomitantly, the most responsive groups were consistent throughout the various vulnerability inputs. Thus, in the absence of sufficient time series information to calibrate for the groups' trophic vulnerabilities, the simulations assumed the flow controls that were proportional to the groups' estimated trophic levels.

2.3. Estimating fisheries values

The annual fishing investments inputs refer to the fixed (capital) and variable (effort-related) costs per Ecofleet. The fixed and variable costs were then entered into the model as percentages of the estimated total annual market value of the fishery, which was computed as the sum of the fixed costs, the variable costs, and the average value of the landed catch per Ecofleet. The model then computed for the %Profit as the %Total market value (=100%) minus the %Fixed costs and %Variable costs (Table A.1). Annual net profits per fishing unit operation were computed by dividing the overall net profits for each fleet type by the known number of fishing units for that fleet. Per capita net profits for every fleet type were computed by dividing the estimated net profit per unit by the average number of fishers involved per fishing unit, assuming equal distribution of net gains and losses. The number of fishing gear units and fishers were obtained from fisheries inventory surveys (Fragillano, 2010). Harvest and fishing investment figures were computed from the catch monitoring data and key informant interviews (Bacalso, 2011; Fragillano, 2010). Estimated landed values of the various fishery groups per fleet type were computed as the weighted mean of off-vessel or landing prices of the different species groups in the catch. The prices were determined from actual catch surveys and fishers interviews, taking special care to capture the price differences for the same species groups landed by different fleet types.

2.4. Two alternative scenarios

Two scenarios simulated the system's response to the complete removal of illegal fishing operations; the first, with no reallocation of displaced illegal fishing effort, and second, with a reallocation of displaced illegal fishing effort to the remaining legal fleets. In the first scenario, a complete removal of all illegal fleet types results in reduced overall number of fishers and fishing gear units operating in the system. In the second scenario, however, the number of illegal fishers and correspondingly, their fishing effort were merely shifted from the illegal to legal fishing activities. The rationale for this scenario is to maintain the total number of fisheries jobs. This was thought of under the context of a typical municipal Philippine fisheries setting where marginalized fishers have little or no immediate alternative means of livelihood.

Catch similarities served as basis for fishing effort reallocation from illegal to legal fisheries activities. Here we assumed that by reallocating the displaced illegal fishers to legal fishing activities that targeted the same or fairly similar species groups would not necessitate drastic shifts in the fishers' conventional fishing grounds. Allowing them to catch the same fishery species would likewise mean the maintenance of already established market linkages for their respective catches. In this manner, we can anticipate a higher acceptability of the proposed effort reallocation. Furthermore, earlier work involving simulating fishing effort shifts and effects of fisher behavior had demonstrated the natural inclination of displaced illegal fishers to shift to the allowable gear type that yields the highest economic returns (Bacalso, 2005). This resulted in a substantial growth in fisheries extractions by that legal gear, and consequently, disastrous stock reductions for its targeted species. With these main assumptions, a cluster analysis was performed to establish fishing gear groups by catch resemblance (Fig. A.2). Fishing effort was standardized by the average number of fishers involved per fishing unit. The calcuated number of displaced fishers from the illegal fisheries was then distributed proportionately to the identified legal gears with similar fishery targets, thereby increasing the total number of legal fishing gear units (Table A.2). While the time horizon of the simulations is 20 years, the focus of the analyses is on the third year following the complete removal of illegal fisheries. This is in consideration for real management and policy constraints in the Danajon Bank wherein the term of office for elected local government executives is only 3 years. Only the trophic impacts of illegal fishing removals are quantified in the Ecosim simulations. Comparisons are made on the resulting biomass structure, direct fisheries job losses and gains, increments (+/−) in fisheries yields, and increments (+/−) in net profit incomes per fleet type and at the per capita level.

3. Results

3.1. Impacts on group biomasses

The Ecosim run simulations of relative change in functional group biomasses for year 3 following a hypothetical successful ban on illegal fishing operations in the Danajon Bank are presented in Fig. 2. The trends in biomass response to illegal fishing removals are fairly similar for both scenarios, but show marked differences in the magnitude of change.

3.1.1. Scenario 1: no effort reallocation scenario

Overall, the collective system biomass increase appears negligible (at 0.13% relative to the baseline total system biomass) (Fig. 2). The functional groups that showed the most positive response are the small reef sharks (452%), followed by the groupers and other piscivorous reef fishes (324%), the planktivorous reef fishes (135%), and rays (111%). Among the pelagic functional groups, notable biomass increases were estimated for the small tunas and tuna-like species (80%), barracudas (38%), and belonids (34%). The increase in both pelagic and demersal predatory fish biomasses directly and indirectly impacts the prey fish and invertebrate biomasses. For example, the halfbeaks-flyingfishes and mackerels-scads decreased in biomass (−18% and −15%, respectively), due primarily to increased predation mortality by the tuna group. This in turn resulted in an indirect slight positive impact on the biomass of the sardines (6%) and anchovies (1%), which subsequently benefits the predatory pelagic fishes. As for the benthic and

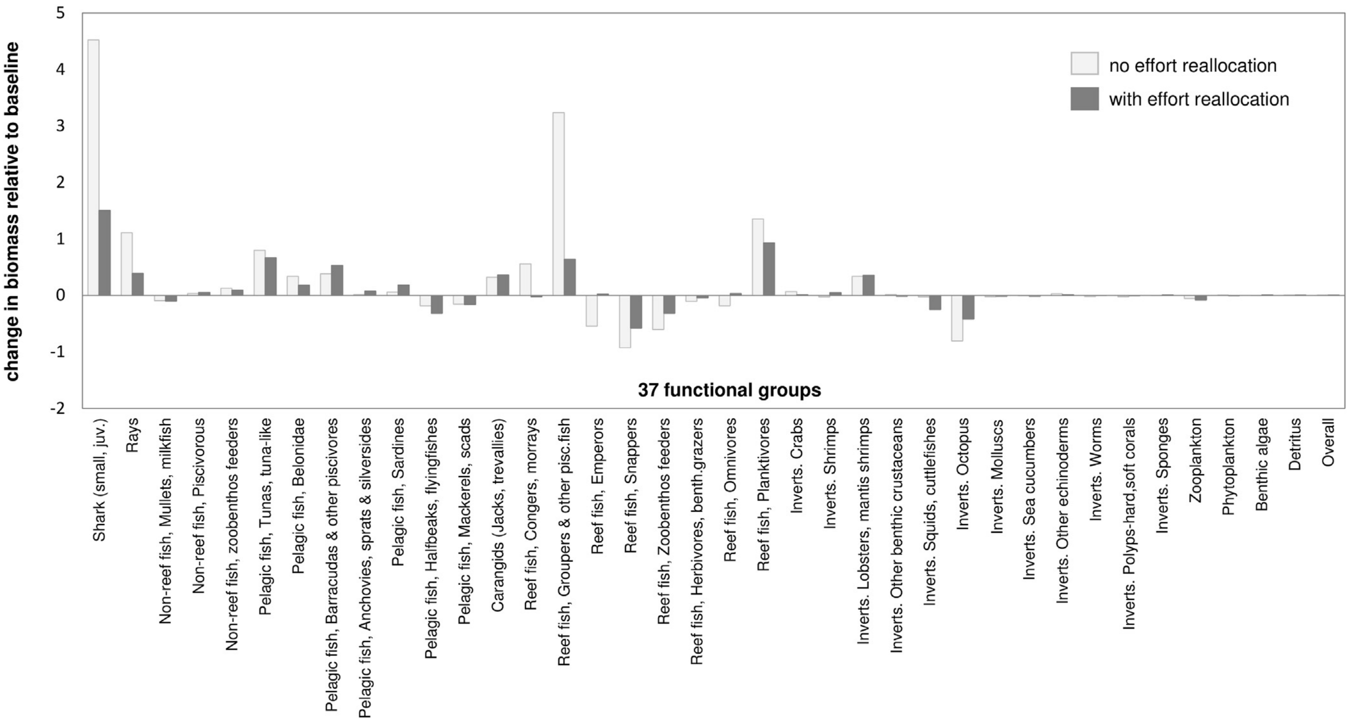

Fig. 2. Estimated changes in group biomasses within year 3 of a hypothetical successful ban on illegal fishing in the Danajon Bank (light bars: no effort reallocation; dark bars: with effort reallocation of displaced illegal fishers).

reef-associated groups, biomass reductions were noted for either the prey or the direct competitors of the small reef sharks and groupers, such as the snappers (−92%), zoobenthos feeding reef fish (−60%), emperorfish (−54%), omnivorous reef fishes (−18%), octopus (−80%), and squids-cuttlefish (−2%). Indirectly, this situation is seen to benefit the congers-morrays (56%), transient jacks and trevallies (32%) and other benthic crustaceans such as the lobsters-mantis shrimps (34%) and crabs (7%), due not only to reduced predation, but also, to reduced competition for benthic resources.

3.1.2. Scenario 2: with effort reallocation scenario

In this scenario, the collective system biomass increase remains negligible, but slightly higher than the scenario with no effort reallocation (at 0.56% relative to the baseline total system biomass) (Fig. 2). The functional groups that showed the most positive response are the same as those under scenario 1, but at much lower magnitudes (small reef sharks, 150%; groupers and other piscivorous reef fishes, 64%; the planktivorous reef fishes, 93%; rays, 39%). The pelagic predatory groups such as the tunas and belonids similarly demonstrated notable increases in biomass (at 66% and 18% respectively). This time, however, the biomass increase of the barracudas is higher (at 53%) compared to its increase under scenario 1. Likewise, the biomass decrease for the halfbeaks-flyingfishes and mackerels-scads are comparatively larger (−32% and −13%, respectively), while the increase in sardine and anchovy biomasses are also larger (18% and 8%, respectively). Consistently, the biomasses decreased for both the snappers (−58%) and zoobenthos feeding reef fish (−32%), while the biomasses for the emperorfish and omnivorous reef fishes showed a slight increase (about 3%) this time. The biomass increase for the transient jacks and trevallies and the lobsters-mantis shrimp groups are fairly similar to their estimated biomass increase in scenario 1. On the other hand, the biomass of the congers-morrays decreased instead (−2%). This time, the squids-cuttlefish demonstrated a more significant decrease in biomass (−25%), while the decrease in octopus biomass is nearly half of that observed in scenario 1.

3.2. Impacts on fisheries jobs

3.2.1. Scenario 1: no effort reallocation

The removal of any fisheries sector entails losses in employment. Of the 6 illegal fishing fleets identified, the compressor fishing operations directly employs the most number of fishers, followed by the Danish seines, then the blast fishing operations, the beach seines, the round-haul seines, and the bottom trawls. A successful ban on all these illegal fishing operations in Danajon Bank would reduce the overall fishing effort by 385 illegal fishing units, but will leave an estimated 1810 fishers jobless, which is an equivalent job loss of 11% relative to the baseline numbers (Table 2).

3.2.2. Scenario 2: with effort reallocation

When fishing effort of the displaced illegal fishers were reallocated to the remaining legal fishing operations, the total number of fishers remained the same, but resulted to an additional 1106 new fishing units (Table 2). Direct employment remains highest for the crab fishing, gillnet and trammel nets, and hook and line fishing operations. The traditional spear fishery absorbed all displaced compressor fishers, thus incurring the largest increase in both fishing units and direct employment among all fleet types. Fishing units and direct employment likewise increased, albeit less drastically, for the barriers-corrals, stationary liftnets, and fish pot fleets that accommodated the displaced fishers from the seining operations, and the surface and mid-water gillnets that accommodated the displaced blast fishers.

3.3. Impacts on yield and per capita profits

The relative changes in total harvests and corresponding net profits of the various fishing operations by year 3 following the removal of the illegal fisheries are presented in Fig. A.2. The equivalent net annual and monthly profits per individual fisher per fleet are shown in Table 3.

Table 2

Estimated number of fishing units and number of fishers directly employed per fleet type. Compared are the figures in the baseline Ecopath model, under the scenario with no effort reallocation, and scenario with effort reallocation.

		Baseline		Scenario 1: no effort reallocation			Scenario 2: with effort reallocation		
Fleet name	Fisher/unit	N fishing units	Total direct employ.	N fishing units	Total direct employ.	%diff. from baseline employ.	N fishing units	Total direct employ.	%diff. from baseline employ.
Barriers, corrals	1	515	751	515	751	0	611	890	19
[a]Beach seines	3	62	159	62	0	−100	62	0	−100
[a]Blast fishing	4	55	200	55	0	−100	55	0	−100
[a]Bottom trawls	2	35	72	35	0	−100	35	0	−100
Cephalopod jigs, lures	1	449	449	449	449	0	467	467	4
Crab fishing gears	1	2427	3084	2427	3084	0	2441	3102	1
[a]Danish seines	3	80	260	80	0	−100	80	0	−100
Diving for crabs, shells, etc.	2	809	1214	809	1214	0	821	1232	1
Fish pots	3	370	1009	370	1009	0	421	1148	14
Hook and lines	1	2082	2409	2082	2409	0	2202	2548	6
[a]Round haul seine	19	4	75	4	0	−100	4	0	−100
Scoopnets with light	2	155	299	155	299	0	164	316	6
Set gillnet, trammel net	2	1099	2528	1099	2528	0	1115	2565	1
Spear, no compressor	2	390	585	390	585	0	1086	1629	178
[a]Spear, with compressor	7	149	1044	149	0	−100	149	0	−100
Stationary liftnet	4	57	220	57	220	0	67	258	18
Surface, midwater gillnet	3	631	1986	631	1986	0	695	2188	10
OVERALL	3	9369	16,344	9369	14,534	−11	10,475	16,344	0

[a] Illegal gears.

Table 3

Estimated equivalent per capita net profit incomes (annual and monthly, in Philippine pesos PHP, 1USD:PHP43) for the various Ecofleets within year 3 following the simulated removals of illegal fishing operations in the Danajon Bank under scenarios without and with fishing effort reallocation. Highlighted in **bold** are values ≥±20% of baseline net profit estimates.

		Baseline			Scenario 1: no effort reallocation			Scenario 2: with effort reallocation		
Fleet name	fisher/ unit	N gear units	profit/fisher/ year	profit/fisher/ month	N gear units	profit/fisher/ year	profit/fisher/ month	N gear units	profit/fisher/ year	profit/fisher/ month
Barriers, corrals	1	515	25,510	2126	515	25,766	2147	611	**32,945**	**2745**
[a]Beach seines	3	62	31,812	2651	62	**−975**	**−81**	62	**−975**	**−81**
[a]Blast fishing	4	55	153,097	12,758	55	**−3124**	**−260**	55	**−3124**	**−260**
[a]Bottom trawls	2	35	12,716	1060	35	**−5182**	**−432**	35	**−5182**	**−432**
Cephalopod jigs, lures	1	449	5009	417	449	**2683**	**224**	467	**−3587**	**−299**
Crab fishing gears	1	2427	12,945	1079	2427	14,998	1250	2441	13,421	1118
[a]Danish seines	3	80	116,431	9703	80	**−3382**	**−282**	80	**−3382**	**−282**
Diving for crabs, shells, etc.	2	809	6661	555	809	7076	590	821	6759	563
Fish pots	3	370	17,456	1455	370	16,733	1394	421	19,223	1602
Hook and lines	1	2082	17,595	1466	2082	**12,414**	**1035**	2202	16,754	1396
[a]Round haul seine	19	4	4089	341	4	**−8544**	**−712**	4	**−8544**	**−712**
Scoopnets with light	2	155	11,922	994	155	12,706	1059	164	**17,863**	**1489**
Set gillnet, trammel net	2	1099	28,412	2368	1099	28,885	2407	1115	31,920	2660
Spear, no compressor	2	390	44,263	3689	390	54,800	4567	1086	**120,893**	**10,074**
[a]Spear, with compressor	7	149	50,733	4228	149	**−5657**	**−471**	149	**−5657**	**−471**
Stationary liftnet	4	57	6036	503	57	**7482**	**624**	67	**9530**	**794**
Surface, midwater gillnet	3	631	9841	820	631	9492	791	695	10,093	841
OVERALL	3	9369	[b]19,202	[b]1,600	8984	[b]15,858	[b]1,322	10,475	[b]26,506	[b]2,209

[a] Illegal gears.
[b] Weighted average.

3.3.1. *Scenario 1: no effort reallocation*

With all illegal fisheries removed, the total yield from the remaining fisheries is less 25.4% from the baseline (Fig. 3a). At the fleet level, the legal fisheries that are seen to incur some increase in yields are the traditional spear fishery (8.2%), crab fishery (7.1%), and stationary liftnets (4.9%). On the other hand, the hook and lines and cephalopod jigs-lures demonstrate yield reductions by 19% and 10%, respectively. In terms of net profits, a substantial 34.6% overall profit loss relative to baseline values is estimated under this scenario. With ceased operations, the illegal fisheries continue to incur losses from their initial capital investments from year 0 (i.e. sunk costs). The reduced yields by the hook and lines and cephalopod jigs-lures corresponds to reduced profits by 29% and 46%, respectively. On the other hand, the three gear types that are seen to incur the highest net profits under this scenario are the stationary liftnets (24%), traditional spear fishery (24%), and the crab fishery (16%) (Fig. 3b). These are similarly reflected at the per capita net profit level estimates assuming equal distribution of profit gains and losses per fisher in a fishing unit. All in all, the weighted average per capita net profit income under this scenario is 17% less compared to the baseline figure.

3.3.2. *Scenario 2: with effort reallocation*

Under this scenario, the total fisheries yield is reduced by only 14.6% (Fig. 3a). At the per fleet level, however, several more operations are seen to incur notable increases in yields, particularly the traditional spear fishery (161%), stationary liftnets (22.5%), barriers and corrals (20%), scoopnets with light (13.7%), and the surface-midwater gillnets (11%). While the estimated decrease in yield by the hook and lines is now lower (−3.3%), that by the cephalopod jigs-lures is larger (−24%). These yield reductions correspond to only a 4.7% net profit loss for the hook and lines

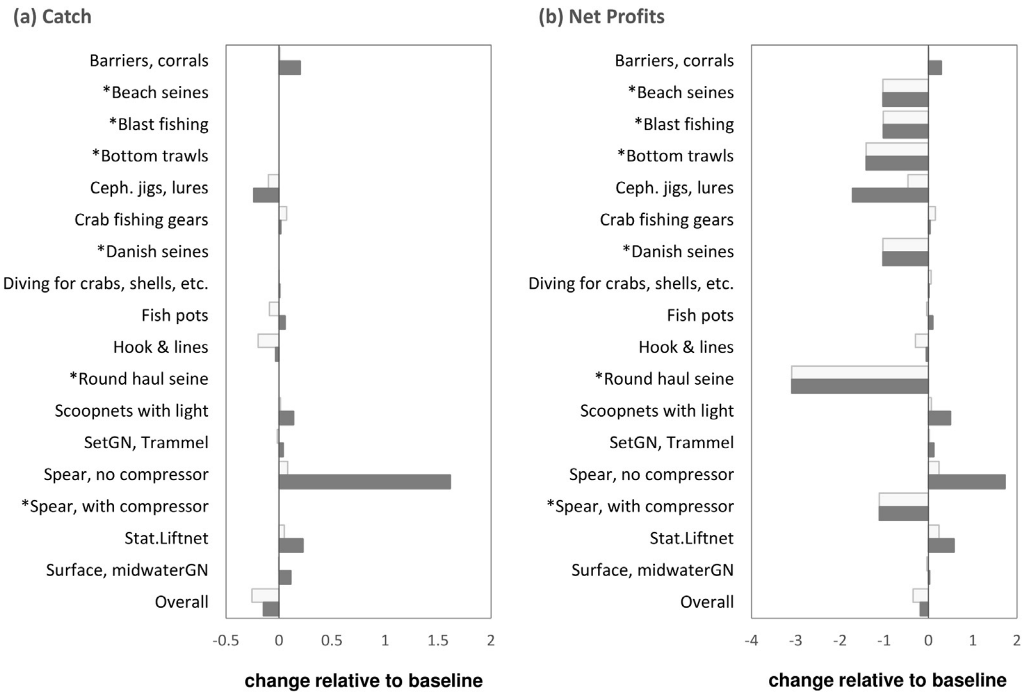

Fig. 3. Estimated changes in (a) catches and (b) net profits within year 3 of a hypothetical successful ban on illegal fishing in the Danajon Bank (light bars: no effort reallocation; dark bars: with effort reallocation of displaced illegal fishers). Illegal fisheries (*).

but a significant 171% net profit loss for the cephalopod jigs-lures (Fig. 3b). The overall net profit of the fishery is still lower relative to the baseline values, but by only 18.5%. The profit losses incurred by the illegal fisheries are the same as in scenario 1, but percentage gains in net profits by the remaining legal fisheries are generally higher, except for the crab fisheries and the divers for marine invertebrates. Highest per capita net profit gains are estimated again for the traditional spear fishers (173%), followed by fishers operating the stationary liftnets (58%), scoopnets with light (50%), and barriers-corrals (29%). The weighted average per capita net profit income is 38% higher compared to the baseline figure.

4. Discussion

4.1. Trade-offs among functional group biomasses and fisheries implications

The short-term trajectories and magnitudes of biomass change estimated for the various functional groups comprising the Danajon Bank system are reflective of results earlier presented from a mixed trophic impacts (MTI) sensitivity analysis with the base Ecopath model (Bacalso and Wolff, 2014). The groups to benefit directly from illegal fishery removals are the groups harvested at a high rate by these gears, specifically, the predatory reef fishes and the schooling planktivorous reef fish. The immediate positive response of their biomasses to the illegal fishery removals sets off trophic cascade and bottom-up effects that impact the rest of the functional group biomasses in the system. Noteworthy is the biomass restructuring of reef fish groups at intermediate trophic levels and benthic invertebrate groups after a simulated recovery of predator fish abundance. In both scenarios, unit increases in predator fish biomasses entailed higher predation effects on the intermediate and prey group biomasses such that the absolute reductions in prey group biomasses merely offset the total biomass gains by the predator groups. The baseline biomasses of predator fish groups were concurrently already too low to begin with. Thus, even with a relative increase that is over 4 times their baseline values, the predator group biomasses remained comparatively much smaller than the lower TL groups' biomasses. In scenario 2, the increases in predator group biomasses relative to baseline values were tempered by the fishing effort of the same total number of fishers in the system, an arrangement made possible via fishing effort reallocation. This in turn resulted to similarly tempered predation effects on the intermediate and prey group biomasses, i.e. smaller biomass reductions, thereby resulting in a slightly higher positive increment in the overall system biomass. These broad system responses imply the strong influence of the harvest rates and patterns of the Danajon Bank municipal fisheries, particularly the illegal operations and their substantial harvest of the predator fish groups, in shaping the system's structure and function (Bacalso and Wolff, 2014). Furthermore, they indicate the potential for reversing the long-standing impacts of fishing in the area, based on tropho-dynamic responses (see Fouzai et al., 2012; Kruse et al., 2009; McClanahan et al., 2011; Varkey et al., 2012).

Under current conditions in subsistence and predominantly small-scale fishery settings such as in the Danajon Bank, a higher priority is given to securing livelihoods rather than to ecosystem conservation and rebuilding (Bacalso et al., 2013). Therefore, a fishery policy will be attractive to stakeholders only if the projected socio-economic fishery gains are an improvement from the status quo (Cheung and Sumaila, 2008). In both scenarios of illegal fishery removals, the legal fisheries that are likely to benefit in terms of yield are consistently those that share a similar catch composition with the illegal fleets. However, the complex tropho-dynamics that govern the biomass changes may either counter or reinforce such impacts. As expected, an increase in predatory reef fish biomasses will impact negatively the prey fish and invertebrate biomasses (Hilborn et al., 2004). This leads to a profound impact on the overall fishery yields as the latter groups are intrinsically more productive, and therefore, contribute substantially to the total catch volumes (Anderson et al., 2011; Engelhard et al., 2014; Foley, 2013). Accordingly, both scenarios resulted in reduced overall fishery yields owing to the foregone catches of illegal gears and decreased production from the lower trophic level groups. The cephalopod jigs-lures and to an extent the simple hook and lines particularly suffered due to significant reductions in the biomasses of squids, octopus, and intermediate-sized reef fishes. However, the magnitudes of trophic cascade impacts on the functional group biomasses are tempered under scenario 2 wherein the reallocation, and not removal, of fishing effort causes only a moderate increase in predator fish biomass. More importantly, fishing effort reallocation offsets the yield and profit losses overall, and effects discrete net profit increases for most of the fishing fleets without incurring any job losses. We thus put forward fishing effort reallocation, rather than fisheries decommissioning or fishery exits, as a reasonably more attractive option for policy makers, implementers, and fishers in small-scale, multi-species, and multi-gear fishery settings with limited alternative livelihood options.

4.2. On estimating fisheries values

The incorporation of fisheries benefits in terms of direct employment and net profit values has enriched our analysis of the impacts of illegal fisheries removals and their implications. Primarily, the results have demonstrated that the municipal fishery of Danajon Bank is currently operating below optimum (Cheung and Sumaila, 2008) since ecosystem structure, number of fisheries jobs, and net profit incomes can still be improved under alternative fishing effort allocation scenarios. The reallocation of illegal fishing effort to the legal fisheries presents a substantial improvement with respect to the maximization of fisheries gains relative to the status quo.

In a predominantly subsistence fishery, the act of fishing is typically not assigned a labor cost. However, a separate analysis has shown that when labor costs are included, the Danajon municipal fishery as a whole is already incurring deficits (ECOFISH, 2013). Therefore, even at the subsistence fishery level, over-capitalization is occurring in the Danajon Bank. This situation often corresponds to over-exploitation of resources and inequitable distribution of economic gains from the fishery (Arnason, 1999; Pascoe et al., 2003). The effective removal of illegal fisheries is the most logical action towards reducing overall fisheries capacity and in redistributing the fisheries benefits to intended (i.e. legal) users.

Furthermore, this study has revealed some unexpected consequences in fisheries gains and losses owing to the complex ecosystem response to fishing effort removals. These findings highlight the importance of model-based scenarios that incorporate both natural and localized socio-economic parameters to help provide more objective advice to fisheries policy and management decisions (Österblom et al., 2013). These base scenario simulations are initial steps in that direction. Current efforts are being undertaken to account for the employment and profit values for select fish species commodities beyond the fleet level through a value-chain analysis (Christensen et al., 2011). In this way, a more comprehensive analysis of the biological and socio-economic trade-offs of fisheries policies involving effort reallocations can be made.

4.3. Operationalizing the fishing effort reallocation

One of the most widely implemented methods for regulating fishing effort in industrialized fishery nations is by determining the total allowable catch (TAC) and setting fishing quotas among operators (Arnason, 1998). However, their application in small-scale tropical fisheries meets fundamental challenges. To begin with, small-scale tropical fisheries are characteristically multi-gear and multi-species, thus rendering stock-based TACs generally unsuitable (Carruthers et al., 2014). Implementing harvest caps would likewise require that landings for the particular fishery be monitored thoroughly and on a regular basis. In the Philippines, landing centers that can potentially serve as control points are likewise small-scale and overwhelmingly too many, thus the catches from the municipal fishing sector, which is primarily small-scale (operating fishing vessels <3GT), subsistence, and artisanal in nature, remain largely undocumented. This leaves the fisheries managers no choice but to rely primarily on input controls such as the establishment of limits or reduction of fishing effort, control of fishing gear types, and spatial and temporal closures. Under this context, a more workable regulating instrument to operationalize fishing effort reallocation is the existing fisheries licensing system. Presently, fisheries licenses within the Philippine municipal fishing sector are required for every individual engaged in fishing. However, setting license limitations has never been formally attempted for lack of political will to implement what could understandably be a very unpopular action that harbors weighty implications on fishers' ability to access food and livelihoods (Pomeroy, 2012), and also due to strong political pressures from the large-scale commercial fishing sector. Since fishing capacity per unit is constrained by vessel size and the gear's technical specifications, easily obtainable information on the average number of fishers per fishing unit can then be used as initial basis for the fisheries restructuring. Information from the dynamic model scenarios can then be readily translated into an equivalent range of municipal fishing license quantities to be allocated per fishing gear type. Successful implementation is however contingent on an effective monitoring system and strong fishery law enforcement to deter recurrence of illegal fishing operations.

Further, this study has demonstrated that job displacement from fisheries bans and similar effort regulations can be addressed by mere reallocation of fishing effort to the preferred fishery types. In this way, fishers remain as fishers and need not exit the fishery in the short-term. This is crucial given the low rate of success (i.e. sustainability) of alternative livelihood programs that are customarily provided in local fishing communities owing to such factors as the lack of social preparation for communities involved, the lack of long-term mentoring and basic financial and business skills development when setting up these alternative livelihood programs, the ease with which to obtain food on a daily basis and relatively constant incomes throughout the year (Salayo et al., 2008), or factors as abstract as the non-monetary satisfaction that fishers get from fishing (Pollnac et al., 2001) and the socio-cultural dimensions attached to a fishery (Williams, 2014). Furthermore, alternative livelihoods would require that fishers acquire new skills and new attitudes concerning money and investments to which subsistence fishers may be unaccustomed to. While such investments are being attempted by some current fisheries management programs, these are longer-term in nature. Moreover, the programs likewise need to be scaled up and multiplied in larger sections of the fishing population if they are expected to achieve a massive exit from the fisheries sector.

Subsequently, while this study's short-term analysis is relevant to the context of subsistence fisheries and the brief terms of office of local executives and policy makers, this does not discount the importance of long-term biological changes and their corresponding socio-economic fisheries impacts. Long-term impacts emphasize the need for prudence in applying any fisheries management measure, and additionally, sustained policy implementation. A long-term fisheries management plan that transcends political terms of office is therefore ideal, but is not common among the local government units (LGUs) in Philippine coastal municipalities for lack of explicit and practical policy-relevant scientific advice. Model scenarios demonstrating the interplay of the biological and socio-economic components of a fisheries system are useful tools with which fisheries scientists can make meaningful contributions to EAF-based management, such as in integrated ecosystem assessments (Levin et al., 2009) and management strategy evaluations (Smith et al., 2007) tailored for data-limited fisheries settings.

4.4. Model assumptions and uncertainties

The vulnerability setting (vTL) used in the model simulations yielded meaningful biological responses that can be interpreted and supported by ecological concepts and phenomena from actual case studies of fisheries systems that experience similar fisheries exploitation patterns that are present in the Danajon Bank. When substantial data points for a reliable time-series of catch and biomass information are made available in the future, the model inputs and predictions can be further refined and validated. However, the collection of fisheries data and biomass data in the Danajon Bank is currently largely project-based, and therefore, collected on a short-term basis. This is true for most of the 822 coastal municipalities in the Philippines. The National Stock Assessment Program (NSAP) of the country's Bureau of Fisheries and Aquatic Resources (DA-BFAR) is conducting serious steps to collecting and consolidating fisheries data on a national scale, but are presently only able to cover select major fishing grounds and commercial species of interest across the different regions of country. Therefore, building capacity of local stakeholders to collect even just basic fisheries information at the municipal scale is imperative.

The analyses of the study do not yet include the gears' interactions with the physical or habitat structures in the system. Such that the removal of blast fishing and bottom trawling activities, for example, may still result in additional system benefits that were not captured in the simulations. Incorporating the mediation functions (e.g. protection provided by reef structures or seagrass cover to small fishes against predation) (see Christensen and Walters, 2004) plus estimates of economic values of marine ecosystem services (Ahmed et al., 2007; Cruz-Trinidad et al., 2011; Samonte-Tan et al., 2007; White et al., 2000) can supplement our analysis of the results.

5. Conclusion

The dynamic simulations were able to reveal the direction and potential magnitudes of biomass, direct fisheries jobs, and net profit changes if illegal fishing operations cease in the Danajon Bank. These operations extract high volumes of harvestable group biomasses that correspond to lost yields and profits for the legal fisheries. We believe that this inequitable distribution of fishery benefits occurs similarly in other small-scale fishing communities in the Philippines and in developing countries where illegal fisheries are estimated to contribute substantially to the total harvests (Agnew and Barnes, 2004; MRAG, 2005; Sumaila et al., 2006). Reallocating the effort of illegal fishers to the remaining legal fishery types is seen to not only improve ecosystem structure but also facilitate a fairer distribution of fisheries benefits among the users. Effort reallocation with no job losses presents an attractive scenario for stakeholders in subsistence fisheries where alternative livelihoods are limited.

Evaluating the socio-economic consequences of fishing effort reallocation scenarios will provide much needed information toward objective decision-making for the local management and use of fisheries resources. Information at the overall fishery and fleet scales will benefit the policy makers and implementers in understanding the social trade-offs of specific effort regulations. On the other hand, information at the per-capita level (i.e. private benefits and costs) can help fishers understand better how these policies may impact them directly. Overall, these can facilitate a more inclusive decision-making and management (i.e. co-management) toward the sustainability of the fishery.

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Appendix A.

Table A.1
Cost inputs (fixed and effort-related) and model estimates of profits relative to the total annual market value of the fishery per fleet type.

Fleet name	Fixed cost %	Effort related cost %	Profit %
Barriers, corrals	23.9	22.8	53.3
Beach seines	2.8	5.8	91.4
Blast fishing	1.8	10.0	88.2
Bottom trawls	8.7	69.8	21.5
Cephalopod jigs, lures	6.8	77.8	15.4
Crab fishing gears	23.7	31.4	44.9
Danish seines	1.9	32.7	65.4
Diving for crabs, shells, etc.	7.6	49.1	43.3
Fish pots	24.6	8.8	66.6
Hook and lines	12.9	41.6	45.5
Round haul seines	16.3	75.9	7.8
Scoopnets with light	5.6	76.6	17.8
Set gillnets, trammel nets	27.4	26.6	46.0
Spear, no compressor	1.7	7.5	90.8
Spear, with compressor	8.0	20.3	71.7
Stationary liftnets	25.0	55.1	19.9
Surface, midwater gillnets	17.4	52.2	30.4

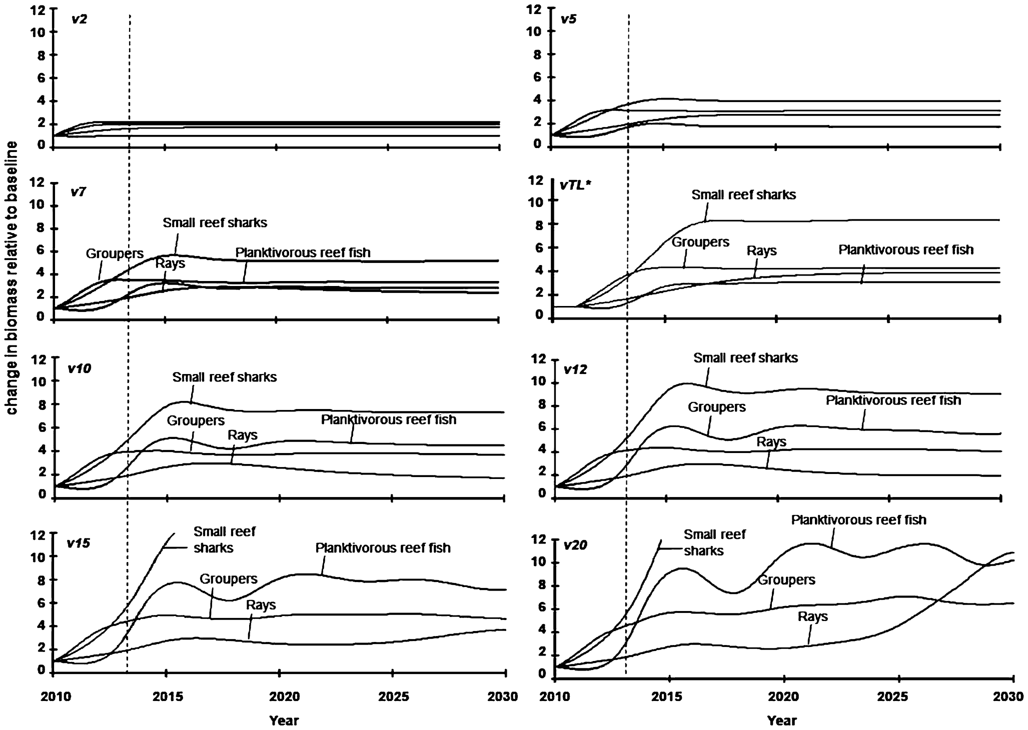

Fig. A.1. Comparison of biomass trajectories with all illegal fisheries removed under a range of flow control settings (v = 2, 5, 7, 10, 12, 15, 20 and proportion to trophic levels = vTL) in Ecosim. Only the predatory reef fish and planktivorous reef fish biomasses that consistently exhibited the strongest positive responses to simulated illegal gear removals in all vulnerability settings are shown. The parameters analyzed and presented in this study are from the 3rd year (broken line) following the hypothetical illegal fisheries ban.

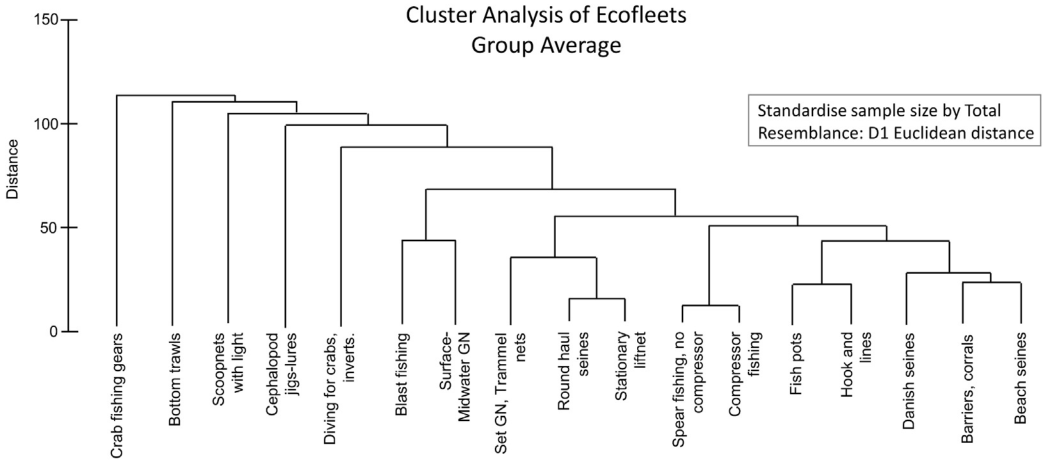

Fig. A.2. Dendogram showing resemblance of Ecofleets based on catch composition. Cluster analysis results from PRIMER6.

Table A.2

Equivalent employment losses from the removal of illegal fisheries and their reallocation to the remaining legal fishing operations. *N* refers to the number of fishing units in operation during the baseline year (2010). *f/unit* refers to average employment (i.e. number of fishers) per operation of a gear unit.

Fleet removed	N fishing units	f/unit	Equiv. Employ.	Employment reallocation to remaining fleets										
				Barriers, corrals *N* = 515, f/unit = 1.5	Ceph. jigs, lures *N* = 449, f/unit = 1	Crab fishing gears *N* = 2427, f/unit = 1.3	Diving for crabs, shells, etc. *N* = 809, f/unit = 1.5	Fish pots *N* = 370, f/unit = 2.7	Hook and lines *N* = 2082, f/unit = 1.2	Scoopnets with light *N* = 155, f/unit = 1.9	SetGN, Trammel *N* = 1099, f/unit = 2.3	Spear, no compressor *N* = 390, f/unit = 1.5	Stat.Liftnet *N* = 57, f/unit = 3.8	Surface, midwater GN *N* = 631, f/unit = 3.1
Blast fishing	55	3.6	200											64
Bottom trawls	35	2.0	72		18	14	12			9				
Danish seines	80	3.0	260	59				32	75					
Round-haul seines	4	18.0	75								16		10	
Beach seines	62	2.6	159	36				19	46					
Compressor fishing	149	7.0	1044									696		
Total	385		1810	96	18	14	12	51	120	9	16	696	10	64

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