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# Some guidelines for a reform in Mexican fisheries

*Miguel Ángel Cisneros-Mata*[*]

Under a gradually increasing rate of exploitation and capital investment, fished stocks will generally experience a reduction in natural production followed by a decline in biomass, overexploitation (OE) and overcapitalization (OC). An aggravating problem is a growing rate of illegal, unreported and unregulated (IUU) fishing. There is an urgent need for fisheries reforms which should take into consideration economic and social aspects. This study identified elements for a reform in 28 Mexican fisheries, determined their present status, and identified challenges to recover biomass and economic value. A data-poor approach was applied using published material and data for the 28 species or for similar species. Schaefer logistic bionomic models were developed to ascertain optimal and economic optimal stock size (stock size for maximum profit), economic yield and carrying capacity, for various discount rates and catchabilities to reflect technological improvements. A fishery-specific entry coefficient, which takes into consideration an index of governance, was estimated to reflect feasibility that new effort would increase after a reform. Industrial fisheries are more specialized than artisanal fisheries; the tuna fishery is the most specialized one followed by sardine, shrimp and pelagic red crab, whereas the geoduck, lobster and green abalone are the most specialized artisanal fisheries. Global optimal yield and profits of the 28 fisheries are inversely related to the stock size relative to $B/B_{msy}$ and discount rate, and directly related to catchability and first-hand price. The economic optimum implied increased yields and overexploitation, in agreement with economic theory in open access situations. An integral Mexican fishery reform should rebuild fished stocks to decrease the optimum yields and implement mechanisms to increase added value, and promote technological improvements. In some instances, optimum yield will have to be close to zero, depending on biological rates of growth.
**Key words**: Mexican fisheries reform, discount rate, IUU fishing.

## Algunas directrices para la reforma de pesquerías mexicanas

A medida que las tasas de explotación e inversión de capital crecen, la producción natural y la biomasa de los *stocks* pesqueros tienden a decrecer y generar sobrexplotación (SE) y sobrecapitalización (SC). La situación es más grave por la creciente tasa de pesca ilegal, no reportada y no regulada (INDNR). Hay una necesidad apremiante de reformas pesqueras que consideren aspectos económicos y sociales. El presente estudio determinó el estatus de 28 pesquerías mexicanas e identificó elementos necesarios para una reforma pesquera, así como retos para recuperar sus biomasas y valor económico. Con un enfoque para situaciones de poca información, se utilizaron datos publicados, además de diversas fuentes para las 28 especies o especies similares. Se desarrollaron modelos bionómicos logísticos de Schaefer para investigar los tamaños biológicos y económicos óptimos, el rendimiento económico y la capacidad de soporte ante diversos valores de tasa de descuento y coeficientes de capturabilidad para reflejar mejoras tecnológicas. Para cada pesquería se desarrolló, asimismo, un coeficiente de entrada que incorpora un índice de especialización para prever la posibilidad de que crezca el esfuerzo pesquero una vez instrumentada una reforma. Las pesquerías industrializadas son más especializadas que las artesanales. La pesquería de atún es la más especializada, seguida de la de sardina, de camarón y una potencial de langostilla; las pesquerías artesanales más especializadas son las de almeja *Panopea*, langosta y abulón. El rendimiento económico y la rentabilidad de las 28 pesquerías juntas varían en relación inversa con la tasa de descuento y $B/B_{mrs}$, así como en relación directa con la capturabilidad y el precio de primera mano. El óptimo económico implica mayores capturas y sobrexplotación, lo que está acorde con la teoría económica en situaciones de acceso abierto. Una reforma mexicana integral debe reconstruir los *stocks* para reducir los óptimos económicos, además de instrumentar mecanismos para aumentar el valor agregado y promover mejoras tecnológicas. En algunos casos, el óptimo económico deberá ser de casi cero, dependiendo de las tasas de crecimiento biológico.
**Palabras clave**: Reforma pesquera mexicana, tasa de descuento, pesca INDNR.

[*] Centro Regional de Investigación Pesquera - Guaymas. Instituto Nacional de Pesca. SAGARPA. Calle 20 Sur Núm. 605, Col. Cantera, Guaymas, Sonora, México. CP 85400. *miguel.cisneros@inapesca.gob.mx*

## Introduction

Fished species are renewable resources and as such they must be utilized with caution. Under a gradually increasing rate of exploitation and capital investment, targeted stocks will inevitably experience a reduction in natural production followed by a decline in biomass to a point of economic extinction and overcapitalization which results in population risk due to demographic or environmental stochasticity, and ecological or ecosystem compromise (Anderson & Seijo 2010).

Managing overfished and overcapitalized fisheries can become an overwhelming task (Matthiasson 1996). Overcapitalization (OC) refers to excess numbers of fishing boats and gear, landing and processing infrastructure, and, seldom considered, complex socio-economic and even political webs of commitments and expectations of harvest having to do with job sources, industry supply, and commercial trade. Managing of overcapitalized artisanal fisheries is further complicated because they are massive sources of direct and indirect jobs and because they are closely tied to culture (Seijo *et al.* 2009).

In open-access scenarios, overcapitalized firms or industries will fall to the urge of capturing sufficient fished resources to satisfy their needs, be it operation of their boats, processing plants, and social capital or trade commitments. Although OC might not always be a sufficient condition for overexploitation (OE) of targeted resources, OE is almost generally inevitable. OC can thus in *de facto* open access fishing systems be considered as a spiral leading to excess fishing mortality, OE of fish resources, and ultimately to injection of perverse subsidies to fishing systems, particularly when subsidies are coupled to fishing effort (Sumaila 2013, Telesetsky 2013).

An aggravating problem now widely recognized in fisheries management is the pervasiveness of illegal, unreported and unregulated (IUU) fishing. It has been estimated that a great proportion of the world's fishing catches fall into this category. A recent study suggests that IUU fishing in Mexico can total up to 50% of reported catches, particularly in small scale fisheries (Cisneros-Montemayor *et al*. 2013). The main reasons for IUU fishing are *de facto* open access to fisheries, poor governance and weak enforcement by governmental agencies.

Sound fisheries management seeks to maximize both future yield and social wellbeing. Therefore, fisheries reforms must take into consideration economic and social aspects relevant to all parties involved in a given fishery (Ainsworth *et al*. 2011). Reaction of key actors to a fisheries reform will depend on their current profits and how they foresee results in the short and medium term (Sumaila *et al.* 2012).

It can be hypothesized that acceptance of current management schemes will be proportional to the perceived trade-off between the amount of efforts that diverse fishing systems require to overcome particular challenges, and expected benefits from a reform. Our objective here was to identify key elements for a reform in Mexican fisheries. For a diverse array of 28 fisheries, the present status and challenges for a reform to recover biomass and economic value were determined.

## Methods and materials

We studied a set of 28 Mexican fisheries representative of different climatic regions and ecological environments, and estimated gain in profits after a reform was implemented relative to *status quo*. Our analyses included life-history parameters and demographic traits, estimates of illegal harvest, economic variables, and management characteristics. For the 28 fisheries, the following parameters were considered:

$B_t/B_{msy}$ = current biomass relative to biomass that returns the maximum sustained yield (msy)
r = intrinsic growth rate of the species (/y)
$C_{MAX}$ = largest catch recorded in the fishery (t)
FI = current illegal fishing rate
$\delta$FC = reformed fishery fixed costs as a fraction of original costs
$\delta\pi$ = post-reform fraction of profits increase
$\phi$ = entry coefficient, *i.e.*, feasibility to enter a fishery once a reform is implemented
q = catchability coefficient
$\gamma$ = discount rate (/y)
CPUE = mean catch per unit effort (t/day)

c = costs of fishing = unit costs (USD/day) x number of days
p = unit price of landed fish (USD/t)
$\tau$ = revenues = p x CPUE (t/day)
$\pi$ = profits (USD/day) = p - c

Price, costs and revenues refer to 2012 Mexican Pesos (MXP) and an exchange rate of MXP 13.00 per USD 1.00 considered. Unit price data of landed fish (p) as well as maximum recorded catch ($C_{MAX}$) were taken from official data by the Mexican government (CONAPESCA 2012[1], DOF 2004, 2010, 2012). The annual intrinsic rate of population growth (r), when available, was gathered from published reports, otherwise taken from similar species or guessed taking into account ecological and biological elements of the species. $B_t/B_{msy}$ was not an input parameter but a sensitivity analysis was performed to ascertain the effect of different relative stock levels. The effect of increase in a fishery's profits given that a reform is implemented ($\delta\pi$) was also assessed through a sensitivity analysis for all 28 fisheries. Catchability was estimated as CPUE/$B_t$ and a technological change was subsequently assessed. Illegal fishing rates were obtained through a written survey among Mexican experts including public servants, members of the conservation sector and fisheries researchers (Cisneros-Montemayor *et al*. 2013).

Unit of fishing effort was defined as the number of fishing days in an average trip of a fishing vessel. Total effort is considered as the mean length of effective days of the fishing season. Acknowledging the multi-species nature of fishing fleets, we considered some fisheries as "shared" among the same vessel. Shared fisheries represent the number of different fisheries that a given fishing unit is used in. Some vessels are used mainly but not solely in a given fishery, hence for each fishery we assigned numbers to reflect this fact.

No investment costs were considered in the present study; investment can be overwhelming in the case of industrialized fisheries and are much lower in most artisanal fisheries. Fixed costs prorated for each day of fishing effort were considered as an amount of Pesos which enable a fishing vessel to fish during the season. Fixed costs (FC) were estimated as:

$$\text{FC} = \varepsilon\,(\text{FS})\,(\text{GC}) / (\text{ED}) / (\text{SF}) \qquad \text{Ec. 1}$$

where: $\varepsilon$ is a fixed amount for pangas (USD 153.85 or MXP 2 000) or boats (USD 769.23 or MXP 10 000), FS is an index reflecting of how relatively specialized are fisheries, GC is a measure of relative gear complexity, ED is the number of days of fishing effort for each fishery, and SF is the number of fisheries shared by a vessel.

For the previous calculations, each fishery was classified based on: *a*) intensiveness of the act of extracting fish (incorporates the notion of hazardous risks), *b*) complexity of assembling a fishing unit and of its operation, and *c*) complexity of administrating one fishing unit. Except in the case of tuna and sardine, which are highly specialized fisheries, fixed costs were considered to be shared among the number of fisheries that a given vessel and all or part of the gear are used for. Finally, a mean relative specialization index has computed as the arithmetic mean of the three indices; this was regarded as a measure of governance indicating how feasible would be to enforce fishery reform.

Salaries for fishers were considered as part of variable costs in all fisheries. Fishers per boat were taken as the average number of crew members in a fishing vessel for a specific fishery; for those fisheries where both artisanal fishing vessels (pangas) and industrial vessels (boats) participate, the number of crew members was averaged. Informal interviews among vessel owners and fishers indicated that, generally, 60% of revenues are divided over the number of fishers plus one share for the owner of the panga. Hence, our estimate does not consider this last share as salary but as profit for the owner of the panga, which might be used to pay for fixed costs (maintenance of gear, motor and panga). For artisanal fisheries, salaries per fishing trip (SA) were estimated as:

$$\text{SA} = 0.6\,\pi\left(1 - \frac{1}{\text{NF}+1}\right) \qquad \text{Ec. 2}$$

1. CONAPESCA. 2012. Registro y estadística pesquera y acuícola. http://conapesca.gob.mx/wb/cona/registro_y_estadistica_pesquera_y_acuicola.

where: $\pi$ = revenues and NF = number of fishers per panga. For industrial fisheries, salaries were estimated as 60% of revenues per trip.

For each fishery, the pre-season cost of raw materials (RM) prorated per fishing trip was estimated as:

$$RM = \beta\ (GC)/ED \qquad \text{Ec. 3}$$

where: $\beta$ is a fixed quantity for pangas (USD 15.38 or MXP 200.00) or boats (USD 153.85 or MXP 2 000.00), GC is an index reflecting complexity of the fishing system, and ED is the number of days of fishing effort for each fishery. For fisheries where both pangas and industrial boats are used, $\beta$ was averaged.

To estimate cost of fuel and oil we assumed that pangas use 4-stroke outboard engines and 50 l of fuel are consumed in an average day of fishing effort; we also considered that oil is replaced before the beginning of the fishing season a cost of USD 53.85 (MXP 700.00). For industrial sardine, shrimp, hake, squid and pelagic red crabs, fishing boats we considered a mean consumption of 900 l per day and USD 769.23 (MXP 10 000.00) in oil and filters pre-season costs, and prorated by the length of the season in number of days. For all vessels, fuel was considered at a subsidized average (year 2012) price of USD 0.77 (USD 10.00) per liter (WWF 2013).

The daily cost of food in a fishing trip was assumed to be USD 3.08 (MXP 40.00) per fisher in a panga and USD 11.54 (MXP 150.00) for industrial fishing boats. For fisheries where both pangas and industrial boats are used, daily food cost was computed as the non-weighted arithmetic mean.

Revenues were computed as the product of catch rate times the average price of landed fish. To estimate revenues, price per kilogram of landed fish was taken as the official price of landed resources reported by CONAPESCA (2012). Mean profits per unit effort (USD/day) were computed as revenues [t x (USD/t)/d)] minus costs per day (USD/day).

*Effect of fisheries reform*

The fisheries entry coefficient ($\phi$) was estimated to reflect the feasibility that new effort units will be added to the fishery after reform implementation. For its calculation $\phi$ was assumed directly proportional to expected increase in price after reform ($\delta$p) and a current illegal fishing rate (FI), and inversely proportional to how specialized the fishery is and to the efficiency of enforcement (sf):

$$\phi = \frac{(\delta p)\ (FI)}{(specialization)\ (sf)} \qquad \text{Ec. 4}$$

The efficiency of enforcement (sf) is a relative measure or index of how feasible it will be to enforce a given fishery after a reform has been implemented and allows weighing enforcement actions. For example, sf = 0.5 if enforcement reduces illegal catch by ½, the entry coefficient decreases in the same proportion. For the present study we considered a 10% increase in price in all fisheries.

We explored the dynamics of the 28 stocks using Clark's (1976) static bionomic model based on a Schaefer logistic general production model:

$$N^* = \frac{K}{4}\left[\frac{c}{pqK} + 1 - \frac{\Upsilon}{r} + \sqrt{\left(\frac{c}{pqK} + 1 - \frac{\delta}{r}\right)^2 + \frac{8c\Upsilon}{pqKr}}\right] \qquad \text{Ec. 5}$$

where: N* = economic optimal stock size (stock size for maximum profits, t), K = carrying capacity (t), $\gamma$ = discount rate (/y) and the rest of the parameters defined above.

The discount rate is used to account for the fact that revenues received in the future decrease relative to their present value. It reflects a person's willingness to trade current for future consumption of a good or asset (Clark 1976, Lingh Teh 2011). Discount rates can be as high as 200% /y for artisanal fisheries (Lingh Teh 2011) and much smaller rates, as low as 5%-10% for fisheries in general (Pascoe *et al*. 2011, Midani & Lee 2014, Cheung & Sumaila 2015, Canada gazette 2016[2]).

For the logistic model, the population growth rate as a function on population size ($N_t$) is (Clark 1976, Anderson & Seijo 2010):

2. Canada gazette 2016. Government of Canada. http://www.gazette.gc.ca/rp-pr/p1/2016/2016-02-06/html/reg1-eng.php

$$f(N_t) = rN(1\text{-}N_t/K) \qquad \text{Ec. 6}$$

Also, when $N = N^*$, the economic optimal fishing effort $F^* = f(N^*)/qN^*$ (Clark 1976). It is therefore important to note that optimal fishing effort is inversely related to $q$ and $N^*$ and directly related to growth rate.

## Results

The 28 fisheries and stocks included in the present study are listed in *table 1*. The combined landings of these fisheries amount to over 75% of Mexico's marine fisheries for year 2012. Most stocks considered are fished in northwest Mexico, particularly the Gulf of California. Although the pelagic red crab is not currently fished in Mexico, it was included in the study to ascertain a management strategy for a virgin stock.

Fishery-related input parameters used in calculations are listed in *table 2*. For most stocks information was available in reports or publications. Sardine has had the maximum-recorded catch followed by yellowfin tuna and squid. Mollusks and crustaceans have the largest market price and sardine the lowest price per ton. Sardines and yellowfin tuna have the highest CPUE. For the pelagic red crab, costs were considered equal those of shrimp, assuming that a trawl fishery with similar sized boats could be used in

**Table 1**

List of Mexican fished stocks considered in the present study

| *No.* | *Stock* | *Common name* | *Region/zone* |
|---|---|---|---|
| 1 | *Sardinops sagax = S. caeruleus* | Pacific sardine | Gulf of California |
| 2 | *Litopenaeus stylirostris* | Blue shrimp | Gulf of California |
| 3 | *Scomberomorus* spp. | Sierra, Spanish mackerel | Sonora |
| 4 | *Carcharhinus limbatus* | Black tips shark | Mexican Pacific |
| 5 | Various species | Gulf of Mexico Sharks | Mexican waters in Gulf of Mexico |
| 6 | *Thunnus albacares* | Yellow fin tuna | Eastern Tropical Pacific |
| 7 | *Dosidicus gigas* | Jumbo squid | Northwest Mexico |
| 8 | *Octopus bimaculatus* | Octopus | Gulf of California coasts of Sonora and Baja California |
| 9 | *Seriola* spp. | Yellowtail | Baja California, Baja California Sur, Sonora |
| 10 | *Stomolophus meleagris* | Jellyfish | Sonora and Sinaloa |
| 11 | *Panopea globosa* | Geoduck | Gulf of California |
| 12 | *Cynoscion othonopterus* | Gulf curvina | Upper Gulf of California |
| 13 | *Merluccius productus* | Hake | Gulf of California |
| 14 | *Atrina tuberculosa* | Penshell scallop | Kino Bay, Sonora |
| 15 | *Lutjanus peru* | Red snapper | Gulf of California, Baja California Sur, Sonora and Sinaloa |
| 16 | *Panulirus interruptus* | Red lobster | Baja California and Baja California Sur |
| 17 | *Epinephelus morio* | Mero | Campeche Bank |
| 18 | *Centropomus robalito* | Robalo, Constantino | Sinaloa |
| 19 | *Coryphaena* spp. | Dorado | Sonora to Chiapas |
| 20 | *Haliotis fulgens* | Green abalone | Pacific northern, Pacific Baja California Peninsula |
| 21 | *Isostichopus fuscus* | Sea cucumber | Gulf of California |
| 22 | *Callinectes bellicosus* | Brown swiming crab | Sonora and northern Sinaloa |
| 23 | *Strombus gigas* | Pink/Queen conch | Mexican Caribbean |
| 24 | *Megapitaria squalida* | Chocolate clam | Sinaloa and Baja California Sur |
| 25 | *Lyropecten subnodosus* | Mano de leon scallop | Baja California Sur |
| 26 | *Hexaplex nigritus* | Black murex snail | Northern Sonora |
| 27 | *Pleuroncodes planipes* | Pelagic red crab | Pacific southern Baja California |
| 28 | *Balistes polylepis* | Triggerfish | Sonora |

7-day average trips. The number of shared fisheries should be interpreted as the number of stocks generally fished by the same fishing unit (boat and gear) although not necessarily the same crew size. Five stocks (sierra, yellowtail, jellyfish, robalo and triggerfish) were considered shared among artisanal fisheries for a total of five stocks. In some instances, stocks were considered to be shared between artisanal and industrial fishing units (shrimp, squid, hake, and pelagic red crab). Still in a few cases, stocks were considered to be shared by some but not all pangas of the same site; these stocks were assigned a 1.5 and are meant to represent the most profitable fisheries (geoduck, lobster and abalone).

Biological input parameters are shown in *table 3*. Jumbo squid, octopus and sardine had the highest intrinsic rate of growth and black tips

**Table 2**
Fishery-related parameters considered in the present study

| *No.* | *Stock* | *Unit effort (days/trip)* | *Effort (days/y)* | *Shared fisheries*[a] | *Fishers/ vessel* | $C_{MAX}$*(t)* | *Price (USD/t)* | *Cost (USD/ day)* | *CPUE (t/day)* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Pacific sardine | 2.5 | 100 | 0 | 11 | 550 000 | 54.69 | 2 823.08 | 48.00 |
| 2 | Blue shrimp | 12 | 40 | 2 | 7 | 10 000 | 7 031.25 | 1 411.54 | 0.20 |
| 3 | Sierra, Spanish mackerel | 1 | 30 | 5 | 2 | 3 000 | 1 200.00 | 118.92 | 0.05 |
| 4 | Black tips shark | nd | ND | ND | ND | 1 860 | 790.00 | 695.57 | 0.40 |
| 5 | Gulf of Mexico Sharks | ND | ND | ND | ND | 300 | 2 000.00 | 53.51 | 0.40 |
| 6 | Yellow fin tuna | 25 | ND | 0 | ND | 149 000 | 736.87 | 5 646.15 | 32.00 |
| 7 | Jumbo squid | 3[b] | 80 | 3 | 7 | 120 000 | 390.00 | 1 182.60 | 4.50[c] |
| 8 | Octopus | nd | ND | ND | ND | 650 | 4 492.19 | 94.96 | 0.04 |
| 9 | Yellowtail | 1 | 30 | 5 | 2 | 2 525 | 886.35 | 99.27 | 0.15 |
| 10 | Jellyfish | 1 | 20 | 5 | 3 | 35 000 | 234.38 | 362.69 | 2.50 |
| 11 | Geoduck | 1 | 80 | 1.5 | 3 | 2 000 | 8 000.00 | 581.98 | 0.15 |
| 12 | Gulf curvina | 1 | 50 | 3 | 3 | 5 953 | 937.50 | 695.57 | 1.55 |
| 13 | Hake | 2[d] | 50 | 3 | 3.5[e] | 200 | 625.00 | 494.53 | 1.00[f] |
| 14 | Penshell scallop | 1 | 50 | 2 | 3 | 40 | 17 187.50 | 278.77 | 0.04 |
| 15 | Red snapper | 1 | 100 | 2 | 2 | 1 100 | 2 790.00 | 100.25 | 0.09 |
| 16 | Red lobster | 1 | 80 | 1.5 | 3 | 1 700 | 11 090.00 | 295.97 | 0.05 |
| 17 | Mero | 1 | 80 | 3 | 2 | 20 000 | 2 950.00 | 138.72 | 0.08 |
| 18 | Robalo, Constantino | 1 | 50 | 5 | 1 | 500 | 2 560.00 | 42.60 | 0.03 |
| 19 | Dorado | 1 | 35 | 3 | 2 | 6 705 | 2 343.75 | 185.05 | 0.08 |
| 20 | Green abalone | 1 | 80 | 1.5 | 3 | 3 000 | 21 520.00 | 431.69 | 0.04 |
| 21 | Sea cucumber | 1 | 40 | 3 | 3 | 48 | 3 906.25 | 82.50 | 0.03 |
| 22 | Brown swiming crab | 1 | 100 | 3 | 2 | 7 600 | 1 093.75 | 77.77 | 0.07 |
| 23 | Pink/Queen conch | 1 | 20 | 3 | 2 | 450 | 6 250.00 | 174.23 | 0.05 |
| 24 | Chocolate clam | 1 | 40 | 4 | 2 | 1 100 | 350.00 | 90.65 | 0.12 |
| 25 | Mano de leon scallop | 1 | 40 | 3 | 3 | 300 | 10 937.50 | 293.27 | 0.05 |
| 26 | Black murex snail | 1 | 40 | 3 | 2 | 800 | 3 125.00 | 95.58 | 0.04 |
| 27 | Pelagic red crab | 7 | ND | ND | ND | 1 000 | 700.00 | 1 411.54 | 1.43 |
| 28 | Triggerfish | 1 | 100 | 5 | 2 | 700 | 1 562.50 | 76.08 | 0.05 |

*a*) Fixed costs shared with other fisheries; *b*) Average: 1 days for pangas, 5 days for boats; *c*) (30 000 kg/boat)/(5 days+3 000 kg/panga/days); *d*) Average: 1 days for pangas, 3 days for boats; *e*) Average: 1 fisher per panga, 5 per boat; *f*) (300 kg/boat)·(3 days per boat +100 kg/day per panga).
ND = not determined; in these cases, other data were available to estimate the remaining input parameters.

**Table 3**

Biological input parameters for analyses

| *No.* | *Stock* | $B/B_{msy}$ | *r(/y)* | *Comments, sources* |
|---|---|---|---|---|
| 1 | Pacific sardine | 0.8 | 1.1 | Profit/vessel is >40%, so important increase of price with reform not expected. May expect a stop in effort entry to the certified fishery (Cisneros-Mata *et al*. 2000, Arreguín-Sánchez 2006, DOF 2010, 2012). |
| 2 | Blue shrimp | 0.7 | 0.6 | Costs much higher (ca. 40%) for industrial than artisanal sector (Cisneros-Mata *et al*. 2000, Cabrera 2004[a], CONAPESCA 2008b, García-Juárez *et al*. 2009, DOF 2010, 2012, Meraz-Sánchez *et al*. 2013). |
| 3 | Sierra, Spanish mackerel | 0.5 | 0.7 | Due to open-access and being an opportunity resource, difficult to the enforce reform (Cisneros-Mata *et al*. 2000, DOF 2004, 2010). |
| 4 | Black tips shark | 0.4 | 0.3 | Catch rough estimate: 300 pangas, with CPUE of 3.105 kg/year in 2011, double that quantity (Campos-Pérez 1999, Arreguín-Sánchez *et al*. 2006, DOF 2010). |
| 5 | Gulf of Mexico Sharks | 0.4 | 0.4 | Several species considered in this study. |
| 6 | Yellow fin tuna | 0.9 | 0.7 | Cisneros-Mata *et al*. (2000), Arreguín-Sánchez (2006), CONAPESCA (2008a), blueocean.org, DOF (2004, 2010, 2012), IATTC (2013). |
| 7 | Jumbo squid | 0.8 | 1.2 | Cisneros-Mata *et al*. (2000), Arreguín-Sánchez (2006), DOF (2010, 2012), Marsh & Fox (2007). |
| 8 | Octopus | 0.3 | 1.2 | Short-lived, median fecundity; eggs cared for by mother, hence high r (DOF 2004, Arreguín-Sánchez *et al*. 2006, Marsh & Fox 2007, Leporati 2008, Escartín-Hernández 2011[b]). |
| 9 | Yellowtail | 0.8 | 0.6 | Max catch considered for BC, BCS & SON: 10%, 10%, 5%, respectively, of total catch series in CNP. Seawatch pamhelt (DOF 2010). |
| 10 | Jellyfish | 0.8 | 0.6 | Large catch rates at very low cost, albeit in short time span (DOF 2010, 2012). |
| 11 | Geoduck | 0.5 | 0.5 | Few natural predators after ca. 4 y of age. Eurythermic. Fisheries, current highest threat; subject to low frequency environmental forcing. Very high fecundity (Goodwin & Pease 1989, DOF 2010, 2012, Ramírez-Felix *et al*. 2012). |
| 12 | Gulf curvina | 0.9 | 0.6 | DOF (2010, 2012), Marsh & Fox (2007), Castro-González (2011[c]), DOF (2011). |
| 13 | Hake | 1.3 | 0.5 | 1976 Biomass: 24 000 t. Fast growing, highly fecund. Longevity >10 y, M>4/y (Padilla-García 1981, Francis 1982, Ragonese *et al*. 2012). |
| 14 | Penshell scallop | 0.7 | 0.7 | DOF (2010), Cisneros-Mata y Ulloa (2011[d]). |
| 15 | Red snapper | 0.8 | 0.5 | Cisneros-Mata *et al*. (2000), Díaz-Uribe *et al.* (2004), DOF 2010, Reddy *et al.* (2013). |
| 16 | Red lobster | 0.9 | 0.5 | Arreguín-Sánchez *et al*. (2006), Marsh & Fox (2007), Chávez & Gorostieta (2010), DOF (2012). |
| 17 | Mero | 0.8 | 0.4 | Managed with quota; highly fecund (Cisneros-Mata *et al*. 2000, Arreguín-Sánchez *et al.* 2006, DOF 2010, 2012). |
| 18 | Robalo, Constantino | 0.5 | 0.5 | Beach price from CONAPESCA. Up to 36 cm (Briones-Ávila 2005[e], Sandoval-Castellanos *et al*. 2005, DOF 2010). |
| 19 | Dorado | 0.9 | 0.7 | Catch estimate: 1 500 pangas, with CPUE of 4.47 t/year (DOF 2004, CIBNOR 2007). |
| 20 | Green abalone | 0.8 | 0.3 | Fishery recovering r from NZ: http:// otago.ourarchive.ac.nz/handle/10523/4079; K and Max C from Cisneros-Mata *et al*. (2000); current biomass from DOF (2012) Sainsbury (1977, 1982), Ponce-Díaz *et al*. (2000), Arreguín-Sánchez *et al*. (2006), Rogers-Bennett *et al*. (2007), DOF (2004, 2010, 2012). |
| 21 | Sea cucumber | 0.5 | 0.5 | Catch estimate: 100 pangas, with CPUE of 240 kg/year in 2011 double that quantity. |
| 22 | Brown swiming crab | 0.8 | 0.5 | Cisneros-Mata *et al*. (2000), Arreguín-Sánchez *et al*. (2006), DOF (2010, 2012). |
| 23 | Pink/Queen conch | 0.2 | 0.5 | Cisneros-Mata *et al*. (2000), Ehrhardt & Valle-Esquivel (2008), Chávez & Constanza-Mora (2009), DOF (2010, 2012), Basurto *et al*. (2011[f]). |
| 24 | Chocolata clam | 0.8 | 0.4 | Price is for whole clam (DOF 2012). |

**Table 3** (*Cont.*)

| *No.* | *Stock* | *B/B$_{msy}$* | *r(/y)* | *Comments, sources* |
|---|---|---|---|---|
| 25 | Mano de leon scallop | 0.9 | 0.5 | Biomass considered 750 t of adults (= 150 t taken, which is 20% of adult biomass); if adults are 66% of total, then total biomass is 1 125 t. K considered to be 1.5 of max biomass (1 603 t), or ca. 2 400 t (Cisneros-Mata *et al*. 2000, DOF 2010, 2012). |
| 26 | Black murex snail | 0.5 | 0.5 | Can live up to 8 y, reproduce at 2 y. Very abundant in some localities (DOF 2004, 2010, 2012, Cudney & Rowell 2008, Loaiza-Villanueva *et al*. 2011). |
| 27 | Pelagic red crab | 1.5 | 0.8 | r assumed larger than that of sardine. No price data available used 1/10 of shrimp price. http://www.cronica.com.mx/notas/2012/626105.html (Gutiérrez-García 2003, DOF 2004, Arreguín-Sánchez *et al*. 2006). |
| 28 | Triggerfish | 0.5 | 0.6 | r = 0.51/y (blueocean.org/documents/2012/06/triggerfish-grey Queen-full-species-report.pdf, www.gsmfc.org/pubs/habitat/ Tables/graytriggerfish.pdf, Ramachandran & Phillip 2010). |

[a] Cabrera MA. 2004. Caracterización y análisis económico de una pesquería artesanal de camarón en la laguna de Chabihau, Yucatán, México. *1ª Conferencia de Pesquerías Costeras en América Latina y el Caribe (COASTFISH 2004) Evaluando, Manejando y Balanceando Acciones*. Mérida, Yucatán. 21p.

[b] Escartín-Hernández FR. 2011. Guía para la elaboración del diagnóstico socioeconómico e indicadores de la pesca ribereña. Instituto Nacional de Pesca. San Francisco de Campeche. 21 al 25 de marzo de 2011. 44p. http://www.edf.org/sites/default/files/4Historic_review_shark_fishery_monitoring-Campeche_2011.pdf

[c] Castro-González J. 2011. Estimación de la biomasa de curvina golfina (*Cynoscion othonopterus*) en el Alto Golfo de California, para su recomendación de cuota de captura para la temporada de pesca 2012. INAPESCA, CRIP - Ensenada. 10p. http://www.inapesca.gob.mx/portal/publicaciones/dictamenes/doc_view/174-estimacion-de-la-biomasa-de-curvina-golfina-cynoscion-othonopterus-en-el-alto-golfo-de-california?tmpl=component&format=raw

[d] Cisneros-Mata MA, R Ulloa. 2011. Evaluación de un banco de callo de hacha liso en Bahía de Kino, Sonora en marzo de 2011. Dictamen técnico (Documento interno). Instituto Nacional de Pesca. CRIP - Guaymas. 12p.

[e] Briones-Ávila E. 2005. Un nuevo tipo de pez en el Siglo XXI. *Revista Digital Universitaria*. 10 de agosto 2005 6(8): 1-5. http://www.revista.unam.mx/vol.6/num8/art74/int74.htm

[f] Basurto M, K Cervera, M Medina. 2011. Evaluación de la abundancia de *Strombus gigas* en Banco Chinchorro y cálculo de la cuota de pesca para la temporada 2011-2012. Dictamen técnico (Documento interno). Instituto Nacional de Pesca. DGIPA. 11p.

shark, Gulf of Mexico sharks and abalone the lowest. Red pelagic crab and hake were considered in the present study to have the highest $B_t/B_{msy}$ and octopus, sharks and conch the lowest.

*Table 4* contains an ordered classification of the 28 fisheries used as a basis to estimate fixed costs and the entry coefficient, which is a relative measure of enforcement capability. The most complex fishery is the tuna fishery followed by sardine and shrimp (Fig. 1); a potential pelagic red crab fishery is considered to be relatively specialized, whereas the geoduck, lobster and green abalone are the most specialized artisanal fisheries. Overall, industrial fisheries are more specialized than artisanal fisheries. The average specialization index resulting of the three above-mentioned indices (Fig. 1) represents a relative ease to enter a fishery and is thus a measure of open-access.

The above results reflect how newcomers are attracted and can enter a fishery. Jellyfish, yellowtail, robalo, dorado, murex snail and trigger fish resulted with the highest entry coefficients ($\phi$), followed by sierra, snapper, swimming crab and chocolata clam (Fig. 2).

All sensitivity analyses indicated that, for the set of parameter values and assumptions considered, global profits of the 28 fisheries at N* and OSY are inversely related to $B_t/B_{msy}$ and discount rate, and directly related to catchability ($q$) and price (Fig. 3). For increasing levels of biomass relative to $B_{msy}$, optimal profits always decrease (Fig. 3a, b and c); for increasing discount rate optimal profits also decrease (Fig. 3a). Profits are much more sensitive to increasing price at all levels of $B_t/B_{msy}$ considered.

A more in depth, disaggregated analysis, indicated that except for black tips shark and chocolata clam, for a 20% discount rate, maximum biological sustained yield (MSY) is constant, and optimum economic sustainable yield (OSY) for most stocks does not react to $q$ and the level of biomass varying in the range of ±10% (Fig. 4). For black tips shark and chocolata clam, if

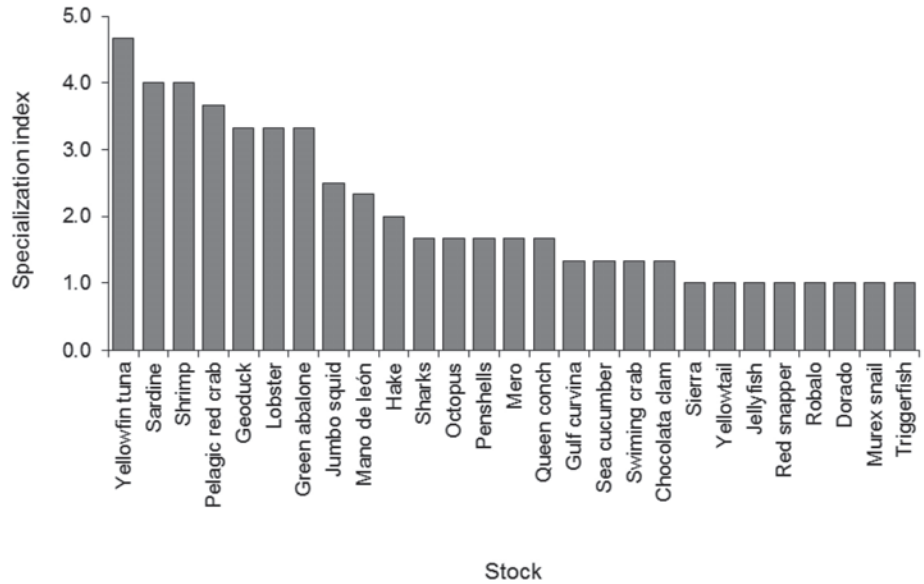


**Fig. 1.** A relative index of specialization of fisheries considered in the present study.

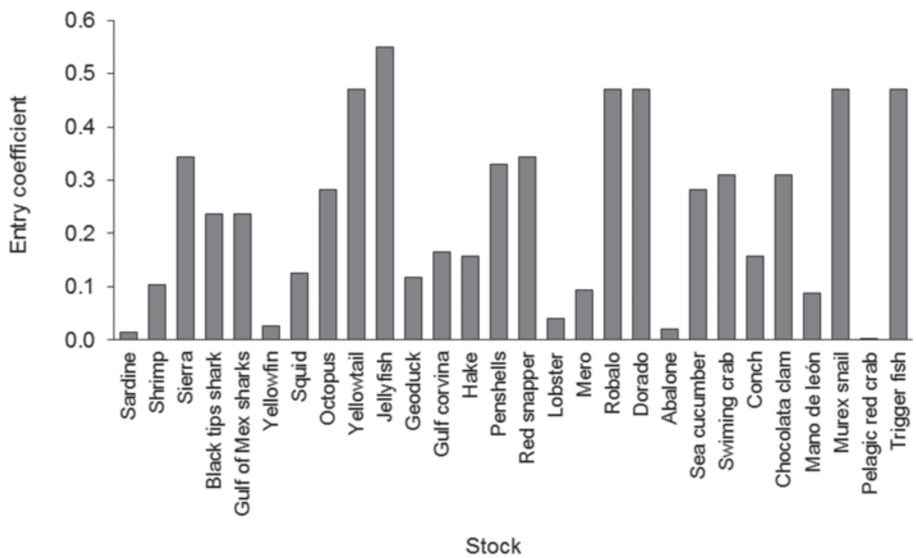


**Fig. 2.** Estimated entry coefficient for 28 Mexican fisheries.

biomass equals $B_{msy}$, OSY drops to zero (Fig. 4b); for black tips shark, OSY drops to zero when $q$ increases by 10% and OSY for chocolata clam also drops significantly (Fig. 4d).

## Discussion

This study was not intended to provide specific management recommendations but, rather, to describe a varied pool of significant Mexican fisheries and gain insights as to which factors might be important to account for in a reform, especially in data-poor situations. It is a known fact that at least 85% of the World's fisheries are currently overexploited, which is causing enormous economic losses (FAO 2012, Sumaila *et al*. 2012) and a reform to recover them is ever more a pressing issue. With limited resources, a key question is which fisheries would be more cost-efficiently recovered and this has to do with

**Table 4**
An *ad hoc* classification of 28 Mexican fisheries according to technical and administrative features. Black tips shark and Gulf of Mexico sharks were grouped together as "sharks"

| *Stock* | *Labor intensiveness* | *Gear complexity* | *Administrative complexity* |
|---|---|---|---|
| Yellowfin tuna | 3 | 7 | 4 |
| Pacific sardine | 3 | 6 | 3 |
| Blue shrimp | 3 | 6 | 3 |
| Pelagic red crab | 3 | 5 | 3 |
| Geoduck | 3 | 4 | 3 |
| Red lobster | 3 | 4 | 3 |
| Green abalone | 3 | 4 | 3 |
| Jumbo squid | 2 | 3.5 | 2 |
| Mano de leon scallop | 2 | 3 | 2 |
| Hake | 2 | 2 | 2 |
| Sharks | 2 | 2 | 1 |
| Octopus | 2 | 2 | 1 |
| Penshell scallop | 2 | 2 | 1 |
| Mero | 2 | 1 | 2 |
| Pink/Queen conch | 2 | 1 | 2 |
| Gulf curvina | 1 | 1 | 2 |
| Sea cucumber | 2 | 1 | 1 |
| Brown swiming crab | 1 | 2 | 1 |
| Chocolata clam | 2 | 1 | 1 |
| Sierra, Spanish mackerel | 1 | 1 | 1 |
| Yellowtail | 1 | 1 | 1 |
| Jellyfish | 1 | 1 | 1 |
| Red snapper | 1 | 1 | 1 |
| Robalo, Constantino | 1 | 1 | 1 |
| Dorado | 1 | 1 | 1 |
| Black murex snail | 1 | 1 | 1 |
| Triggerfish | 1 | 1 | 1 |

governance, biological characteristics of the targeted species, and market forces.

One aspect not covered in this study was overcapitalization of fisheries (OC), which can preclude or at least delay reforming (Anderson & Seijo 2010). OC generally follows one side of a basic economic tenet: years of good catch foster increased economic inputs to the industry either in the form of investment (*i.e.* boats, gear and plants) costs, fixed-short-term costs and variable-operational costs using private or oftentimes public resources. On the other hand, before or during years of low abundance or

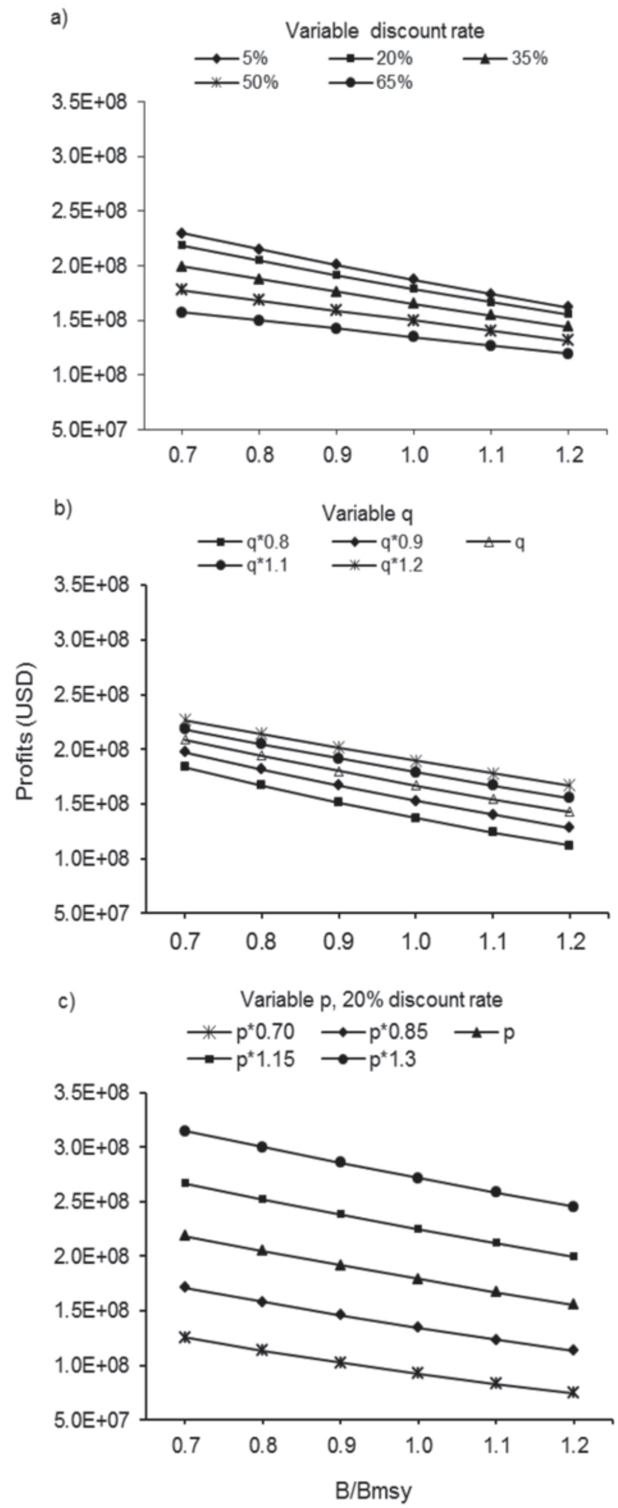


**Fig. 3.** Sensitivity analysis of aggregated optimal profits of 28 Mexican fisheries to relative biomass size, discount rate, catchability and first-hand market fish price.

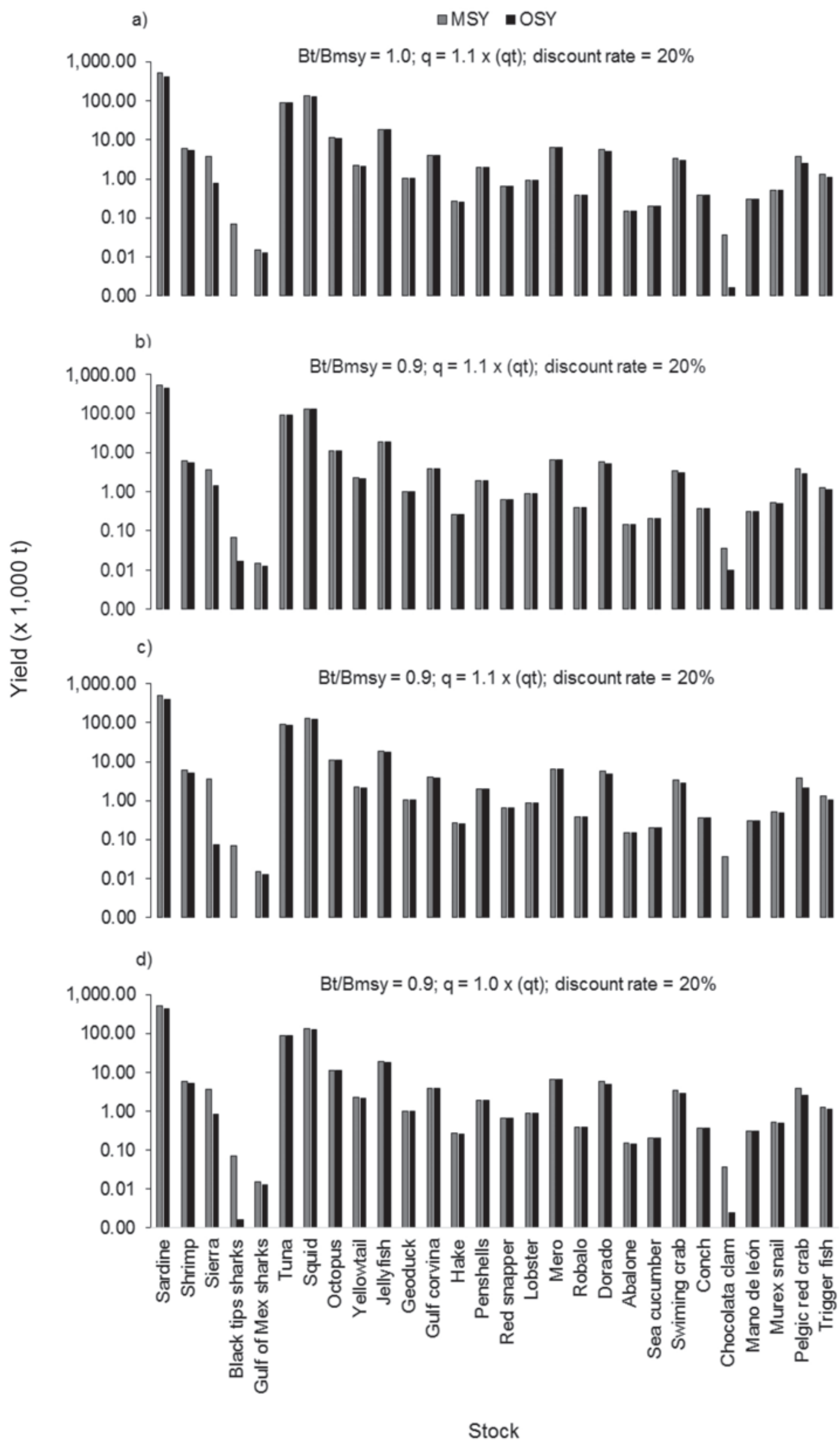


**Fig. 4.** Sensitivity analysis of MSY and OSY of 28 Mexican fisheries relative biomass size ($B_t/B_{msy}$) and catchability (q).

availability of targeted stocks and consequently low catch, nothing can be done by the firm to reduce or payoff investment costs. Some fixed costs might be palliated with a form of economic instrument such as loans or subsidized gear whereas operational costs are usually either absorbed by fishers, artificially reduced by fuel subsidies, or lowered by diversification of targeted stocks, landing of illegal stages of species such as juveniles or ripe females, either reporting or underreporting catches.

A reform in Mexican fisheries should account for illegal, unreported and unregulated catch (IUU). It is estimated that worldwide, IUU represents 30%-40% of reported catches (Nguyen 2012, Cisneros-Montemayor *et al*. 2013). Because of its magnitude and spread, IUU fishing may no longer be considered a phenomenon but a paradigm shift and as such one will have to deal with the agents of change (*sensu* Kuhn 1962). Understanding the nature of fisheries can explain why most fisheries worldwide experience OC, overexploitation (OE) and IUU fishing, and why there is a clear and rising risk of ecological degradation and social problems related to loss of natural capital. Notwithstanding wide acceptance of the previous tenet, it is not straightforward to come to agreement as to which are the most effective strategies to overcome such pressing challenges. The present study provides a basis to understand which Mexican fisheries will demand greater efforts to enforce a reform aimed at reducing IUU; fisheries with a lower relative degree of governance, as given by higher $\phi$ values, will require special attention in this regards.

The discount rate, which is intrinsic to fishers and firms, "determines how much the flow of future costs and benefits is discounted to obtain the net present value". High discount rates mean that fishers value current benefits more than in the future (Cheung & Sumalia 2015). High discount rates lead to high present fishing rates and therefore less sustainable natural resource use (Grafton *et al*. 2006, Anderson & Seijo 2010) and consequently difficulty to introduce reforms to increase or sustain stock size. As a result, under open access, fishers and firms press to maximize economic benefits leading to OE and decreasing returns, which cause even more effort increases (Anderson & Seijo 2010).

In the present study, the economic optimum for all fisheries implied increased yields and overexploitation, which is in agreement with economic theory, especially in open access situations (Clark 1976, Silvert 1977). In such situations, a careful design of reform will have to include tactical control of operation capabilities, fishing rates (fishing effort) and costs (via taxes). More strategic components of reform should include input controls such as quota or other rights-based regimes (Nasser 2012).

An overarching goal of an integral Mexican fishery reform should be to rebuild fished stocks because this will ultimately decrease the optimum yield for all fisheries. A reform should be designed to balance reductions of yield by implementing mechanisms to increase price (added value) of landed resources and promote technological improvements (increased $q$). A reform will need recognize that optimum yield for some stocks will have to be close to zero, depending on their biological rates of growth (Sumaila *et al*. 2012).

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