Toward an ecosystem-based approach to fisheries: a risk analysis

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Fisheries management in the Galapagos Marine Reserve (GMR) has traditionally focused on the establishment of regulations for specific species, such as the sea cucumber and lobster. However, the white fish fishery targets nine species (Peñaherrera, 2007), with an additional 87 associated or incidental species (Murillo *et al.*, 2003). In fact, the white fish fishery encompasses three very separate sub-fisheries: (i) deep sea fishing, using SCUBA and hand lines with multiple hooks; (ii) fishing with trammel nets, and (iii) trawling for minor pelagic fishes (Peñaherrera, 2007). Due to the variety of techniques used, the intrinsic differences among the species, and lack of sufficient biological knowledge, it is not practical to have regulations for every single species.

The new Management Plan for the Galapagos National Park (GNP, 2005) presents an ecosystem approach that attempts to maintain the functionality of the insular and marine ecosystems through rational use of the resources. This focus also recognizes that human actions involving a single species may have direct and indirect consequences for other species within the ecosystem. For this reason, the Charles Darwin Foundation (CDF) is applying a new methodology, called "Ecological Risk Assessment for the Effects of Fishing" (ERAEF) to analyze the white fish fishery. This methodology was designed in Australia where it has been applied to various industrial and artisanal fisheries (Griffiths *et al.*, 2006; Hobday *et al.*, 2006; Smith *et al.*, 2007). Given the GNP's strong interest in ecosystem-based management, this is an important tool that supports the Park's management objectives.

The purpose of this article is to demonstrate the applicability of the ERAEF as a tool to evaluate and manage Galapagos fisheries and demonstrate its usefulness for future analyses within the GMR.

What is ERAEF?

The ERAEF is a multi-tiered analytical tool involving a preliminary literature review followed by three levels of analysis, with each level examining the previous one in greater detail (Hobday *et al.*, 2006) (Figure 1). The literature

review (Preliminary Level) identifies all of the possible activities and impacts associated with a particular fishery, such as engine emissions, fishing activities, onboard processing, and navigation, among others. If an activity or impact occurs in the fishery that is being analyzed, it is studied further in Level One; if not, it is eliminated from the analysis.

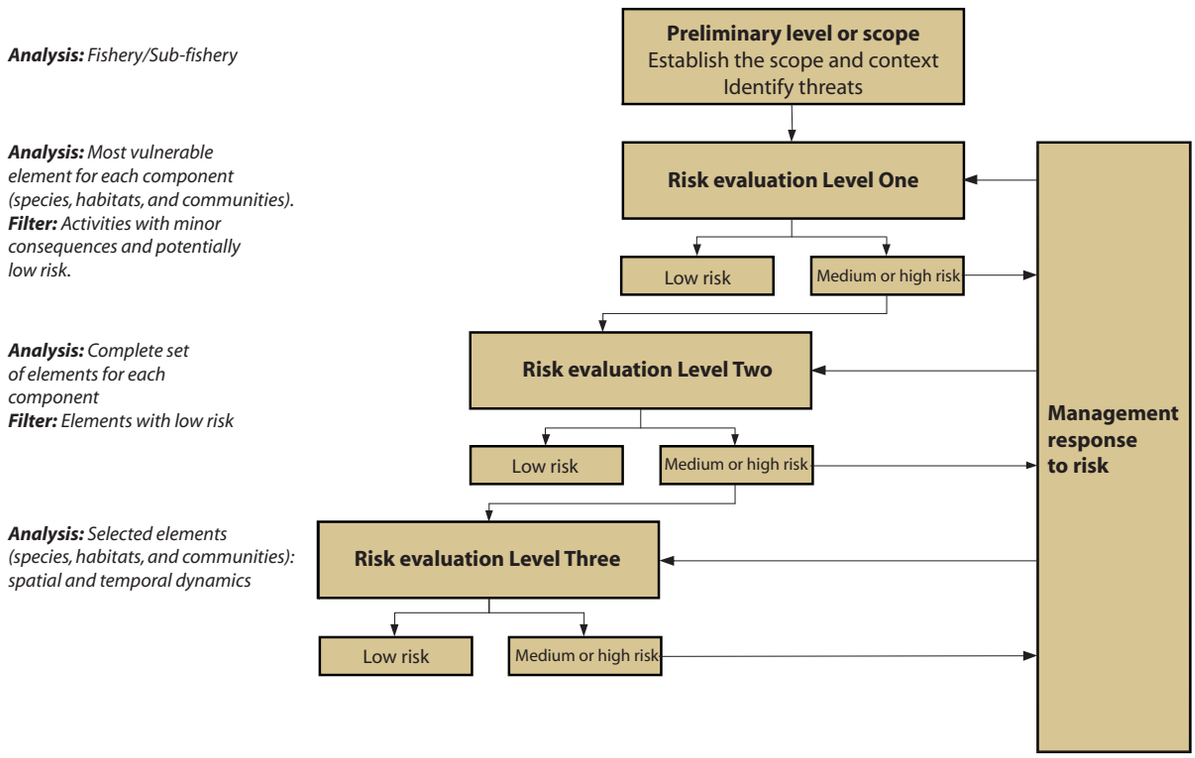

Figure 1. Organizational chart of the ERAEF evaluation system. Modified from Hobday *et al.* (2006).

Level One involves a qualitative analysis of the intensity of each activity and its impact on five ecosystem components: 1) target species; 2) associated species that accompany the target species or bycatch (those not kept by the fisherman); 3) protected, threatened, or endangered species (PTE); 4) habitats, and 5) communities. The results of Level One show the level of risk using a scale of "low-medium-high", with risk level assigned by the evaluators based on the consequences that an activity generates for each component of the ecosystem. If the level of risk of an activity on a specific component is low, no management measures are required. If the risk is medium or high, it requires management measures to reduce possible consequences or it is evaluated at the next level.

Level Two analyzes the risk to each species (target, associated, PTE) based on its biological productivity and its susceptibility to the fishery. Productivity is measured using available information on maximum age and size, age and size at sexual maturity, number of eggs, reproductive strategy, and its nutritional relationship with prey and predators (trophic level). Susceptibility categorizes the risk according to area and depth of the fishing activity in relation to the distributional depth of each species, the selectivity of the method of fishing in relation to size at sexual maturity, and post-catch mortality of the species.

In determining the risk for each species, susceptibility is more important than productivity. If a species has high productivity and low susceptibility, the risk is low. On the other hand, if the productivity is low and the susceptibility high, the risk is high. The results of this analysis indicate which of the species affected by the activity require management measures.

When the implementation of management plans does not diminish the level of risk for a particular species, the species

will be evaluated at Level Three. This level includes in-depth analyses such as the evaluation of population status, maximum sustainable catch levels, and reproduction and recruitment models.

The technical team implementing the ERAEF methodology in Galapagos includes scientists from various institutions involved in ecological and fisheries studies in the GMR, including the National Institute of Galapagos, the Spanish organization Instituto de Promoción y Ayuda al Desarrollo (IPADE), the University of Melbourne (Australia), Galapagos National Park, World Wildlife Fund, and the CDF. The results obtained thus far and summarized in this paper are those of the analysis of the deep sea sub-fishery.

Does the deep sea sub-fishery pose any threats? Are any species at risk?

The first step in the evaluation of the deep sea sub-fishery is to determine all of the units of analysis that form each ecological component. These analysis units serve as indicators of the effects of the activities evaluated at Level One and form the analytical base for Level Two. They include:

Ten target species (Table 1);

74 associated species, including fish and mollusks such as black jacks, conches, parrotfish, and moray eels;

73 PTE species, such as whales, dolphins, sharks, and marine birds;

16 habitat types (Table 2); and

15 types of marine communities (Table 3).

Table 1. Target species identified for the sub-fishery – deep sea fishing.

Family	Scientific name	Common name
Labridae	*Semicossyphus darwini*	Galapagos sheephead wrasse
Lutjanidae	*Lutjanus novemfasciatus*	Dog snapper
Malacanthidae	*Caulolatilus princeps*	Ocean whitefish
Scorpaenidae	*Pontinus clemensi*	Mottled scorpionfish
Serranidae	*Cratinus agassizii*	Grey threadfin bass
Serranidae	*Epinephelus mystacinus*	Misty grouper
Serranidae	*Mycteroperca olfax*	Galapagos sea bass (bacalao)
Serranidae	*Paralabrax albomaculatus*	White spotted sand bass
Carangidae	*Seriola rivoliana*	Jack

Source: Murillo *et al.* (2003) and Molina et al. (2004a and b).

Table 2. List of habitats in the GMR evaluated using ERAEF.

Location	Type of habitat	Cover	Depth (m)
Land	Coastline above sea level*	Not available	
Interior insular platforms (2 - 500 m)	Intertidal lagoons	Not available	0 - 2
	Coastal lagoons	Not available	1 - 2
	Sediment intertidal	Approximately 4,622,745 m^2	2 - 2
	Rocky intertidal	More than 80%	3 - 2
	Rock substrate	Not available	2 - 500
	Soft substrate	Not available	3 - 500
	Vertical walls	More than 50 walls considered important	4 - 500
	Hydrothermal crater	Not available	400 - 500
	Seamount	Not available	100 - 400
Exterior insular platforms (>500m)	Embankment or slope	No baseline	500 - 3 500
	Hydrothermal crater	Not available	> 2 000
	Deep rock substrate	No baseline	1000 - 3000
	Deep sediment substrate	No baseline	1000 - 3000
	Seamount	No baseline	400 - 1000
	Deep sea floor	No baseline	> 3000

* Includes all of the exposed areas of the islands above high tide.
Source: Based on Chadwick (2006), Banks (2007), and information from ecological monitoring by CDF (D. Ruiz, unpublished).

Table 3. List of communities under evaluation according to the biogeographical regions of the GMR.

Sub-biome	Vertical position	Name of community	Spatial location[1]				
			Elizabeth Bay	Far North	North	West	Southeast
Land	Supralittoral	Terrestrial organisms	x	X	x	x	x
Interior insular platforms - ~500 m)	Intertidal (0 - 2 m)	Mangroves or unsubmerged vegetation	x		x	x	x
		Intertidal meiofauna	x		x	x	x
		Rocky intertidal	x	X	x	x	x
	Subtidal (2 - 500 m)	Soft substrate benthos	x	X	x	x	x
		Rock substrate benthos	x	X	x	x	x
		Marcroalgae beds and kelps	f	F	f	x	f
		Hermatypic corals		X	f		f
		Filtering organisms		X	x	x	x
		Bentho-pelagic on seamounts					x
		Chemosynthetics				x	
Exterior insular platforms (>500 m)	Subtidal (~500 - 3 000 m)	Deep seafloor benthos	x	x	x	x	x
		Seamount bentho-pelagics		x	x		x
		Chemosynthetics		x			
	Abyss (> 3 000 m)	Deep sea benthos		x	x	x	x

1 The spatial location is coded as follows: x = present; f = fragmented; empty = absent.
Source: Based on Wellington (1975); Edgar et al. (2004); Chadwick (2007); and information from ecological monitoring by CDF (D. Ruiz, unpublished).

The Level One analysis indicates that this sub-fishery generates few impacts on habitats, but does impact target species and associated marine communities.

The activities assigned medium risk level are associated with weaknesses in or lack of attention to systems for quarantine, collection of organic and inorganic wastes, and fuel management and engine operation of fishing boats. The principal impacts of these activities are on the structure and functioning of habitats and species composition of communities. Bait collection is highlighted due to our lack of information related to the level of effort and its potential impacts. Since bait collection is highly connected with a second sub-fishery (fishing with nets), a study is needed to evaluate and manage the activity for both sub-fisheries.

Table 4. Summary of risk levels identified for direct and indirect activities in the deep sea sub-fishery, according to their ecological component.

Type of impact	Fishery activity	Target species	Associated species	PTE	Habitat	Community
Direct with catch	Obtaining bait					
	Fishing					
	Incidental behavior					
Direct without catch	Obtaining bait					
	Loss of fishing equipment					
	Anchoring					
	Navigation					
Addition or movement of biological material	Transfer of species					
	Onboard processing					
	Supplies					
	Organic wastes					
Addition or movement of non-biological material	Garbage					
	Fuel spills					
	Chemical pollution					
	Smoke					
	Loss of fishing equipment					
	Navigation					
	Presence in the water					
Disturbance of physical processes	Anchoring					
	Navigation					
Impacts outside of the sub-fishery	Trawl nets, nets, illegal fishing					
	Coastal development					
	Illegal fishing - tourism, subsistence, research					
	Tourism					
	Patrol and vigilence, shipping & research					

Risk level: - low. - medium. - high.

NOTE: External impacts are not considered within Level One analyses.

Fishing is the only activity that represents a high risk to target species primarily due to the potential impacts on Galapagos sea bass (bacalao) and sea bass (el mero). Level One results also showed a medium risk for some other species. The olive grouper, the leather bass, some shark species, penguins, and sea lions were highlighted during the process as indicator species. However, species analyses at Level Two indicated low susceptibility to this sub-fishery for all species (target, associated, or PTE).

Of the target species, only the Galapagos sea bass and sea bass have high and medium risk levels, respectively (Figure 2a), while the associated species all showed a low risk level to this fishing activity (Figure 2b).

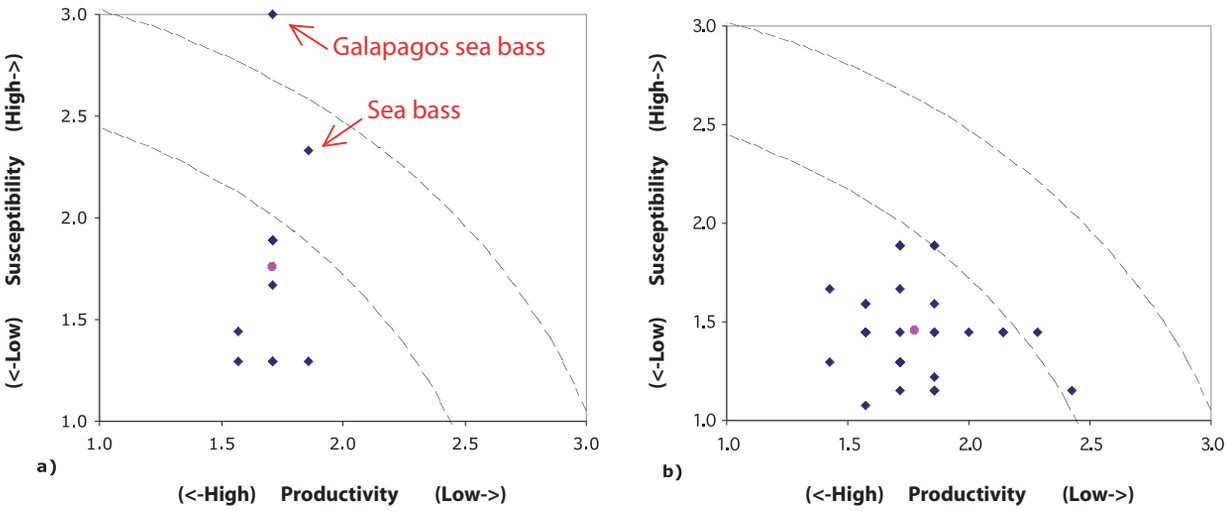

Figure 2. Results of the analysis of productivity and susceptibility for: a) target species, and b) associated species. The red point indicates the average value of productivity and susceptibility of each component analyzed. The broken lines indicate the limits of the risk zones: the lower line in each graph is the limit between low and medium risk and the upper line between medium and high.

Among bycatch species, species of eel, the coral reef cornetfish, and the yellow-tailed surgeonfish had a medium risk due to their productivity potential (Figure 3a). Of the PTE species, the majority were assigned a medium risk level, except flightless cormorants and torpedo rays, which were assigned high risk levels (Figure 3b). In spite of low productivity values, the susceptibility values of the bycatch and PTE species indicate that they are only slightly vulnerable to this fishery and thus of less concern for fisheries management.

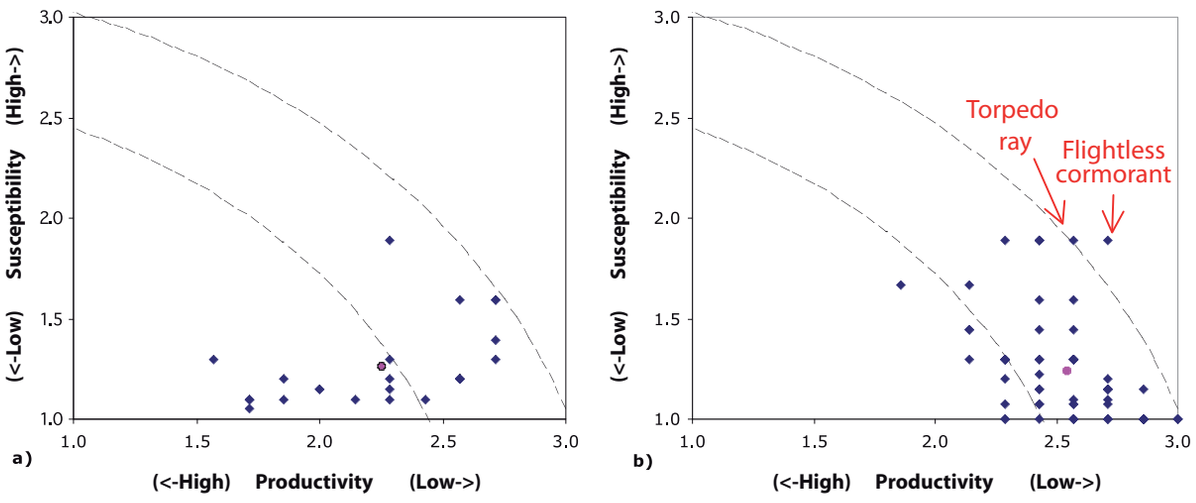

Figure 3. Results of the analysis of productivity and susceptibility for: a) discarded species, and b) PTE species. The red point indicates the average value of productivity and susceptibility of each component analyzed. The broken lines indicate the limits of the risk zones: the lower line in each graph is the limit between low and medium risk and the upper line between medium and high.

Photograph: Alex Hearn

What is the next step?

The EREAF process shows that the deep sea sub-fishery is very "clean" in comparison to other fisheries worldwide, such as longlining, dredges, and trawl nets (Morgan and Chenpadgee, 2003). However, on the basis of the results from Level One, we strongly recommend a revision of the quarantine process for ships to avoid the problems of introduction of rodents, insects, and plants (Calvopiña, 1991; Roque-Albelo et al., 2006; Coronel, 2007). We also recommend reinforcing and improving fuel management systems and general maintenance of ships and ship engines in order to reduce pollution from hydrocarbons and heavy metals from marine paints (Cubero et al., 2007). In the case of the Galapagos sea bass (bacalao) and sea bass (el mero), both analyzed at Level Two, additional studies (Level Three of EREAF) are necessary to evaluate the current status of these species and to develop appropriate management plans.

In addition, we recommend that more emphasis be placed on filling information gaps encountered during the analysis. Specifically, additional knowledge is needed regarding:

- Selectivity of catch size for fishing methods used in the GMR (important for establishing regulations regarding catch size);

- Impacts of the selective removal of the most exploited species within this fishery;

- Bycatch species and their post-catch mortality;

- Dynamics and distribution of bait collection;

- Level of contamination by metals of species that live nearest to populated areas; and

- Status of the marine environment vis-a-vis the introduction of invasive species.

The process of applying ERAEF has been underway for approximately one year. While the first step is completed, the evaluation of the minor pelagic sub-fishery and net sub-fishery still remain to be done. Complementary studies have highlighted illegal fishing and tourism as activities that pose potential threats to PTE species and marine communities. We recommend a broader application of this analytical tool to evaluate the impact of these activities and to focus management responses on areas with the greatest identified threats.