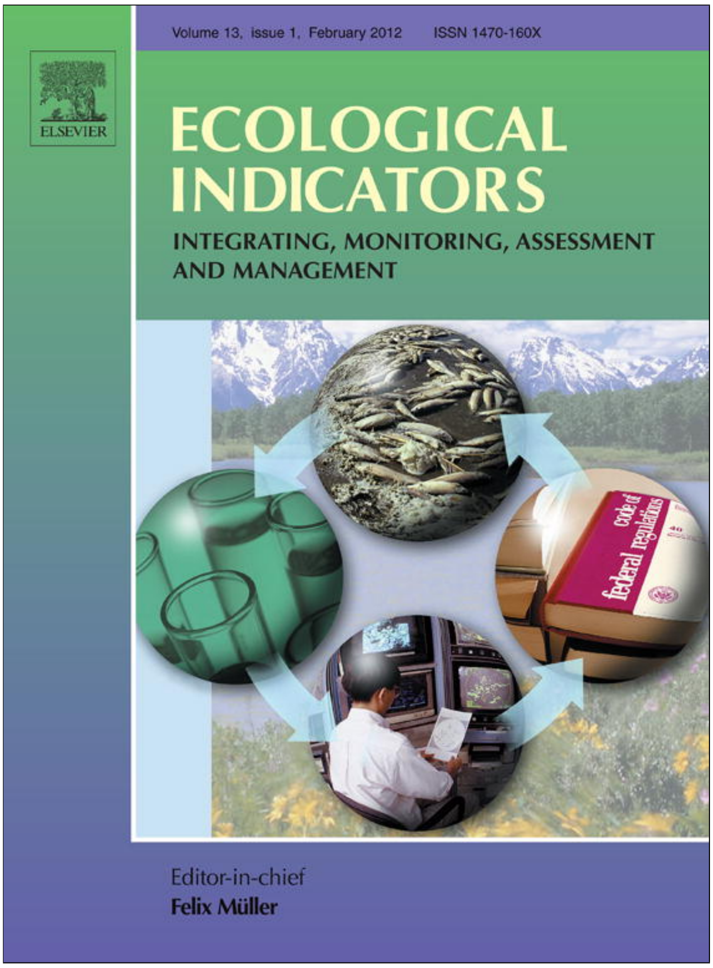
Volume 13, issue 1, February 2012 ISSN 1470-160X
ELSEVIER
ECOLOGICAL INDICATORS
INTEGRATING, MONITORING, ASSESSMENT AND MANAGEMENT
Editor-in-chief
Felix Müller

Ecological Indicators 23 (2012) 19–26

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

River dolphins as indicators of ecosystem degradation in large tropical rivers

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ARTICLE INFO

Article history:
Received 18 October 2011
Received in revised form 27 February 2012
Accepted 28 February 2012

Keywords:
River dolphins
Top predators
Amazon
Orinoco
Human stressors
Freshwater
Ecosystem degradation

ABSTRACT

Human stressors are currently impacting both the Amazon and Orinoco river basins and these are likely to increase. However, there is a lack of standardized monitoring programs to track these human stressors in most of the countries that overlap these basins, and no clear ecological indicators have been identified. In this study we investigated the relationships between measures of ecosystem degradation and river dolphins as potential ecological indicators. The presence of human stressors and their distance from the areas surveyed were used to provide an estimate of ecosystem degradation. We tested three ecological indicators of freshwater ecosystem degradation using river dolphins: (i) density of river dolphins, (ii) mean group size of dolphins, and (iii) dolphin sighting rates. We found a strong negative relationship between measures of habitat degradation and river dolphin density estimates in selected locations of the Amazon and Orinoco. Therefore, we suggest that river dolphins are good candidates as ecological indicators, flagship and sentinel species for monitoring the conservation status of large tropical rivers in South America. We suggest that further effort should be directed toward collecting reliable data on human stressors, creating collaborative networks for compiling existing data, and documenting and monitoring current trends in freshwater ecosystem degradation and indicator species in the Amazon and Orinoco basins with the goal of targeting areas for recovery or sustainable management.

1. Introduction

Human stressors can lead to ecosystem degradation (Alcamo et al., 2005; Foley et al., 2005). Currently, freshwater systems are at risk, with 65% of global river discharge being considered under moderate to high threat, and water security of 80% of the human population at high risk (Vörösmarty et al., 2010). In addition, biodiversity in freshwater ecosystems is in rapid decline and it is considered even more threatened compared to that of terrestrial and marine ecosystems (Revenga et al., 2000; Vörösmarty et al., 2010). Rivers are at risk due to the impact of multiple human stressors, including changes in water quantity and quality, habitat modification, exploitation of species, climate change, and introduced species (Table 1). The current impacts of these stressors are dramatically increasing and are unsustainable in the long term (Alcamo et al., 2005). In this context, it is critical to measure and monitor the status of freshwater ecosystems and the extent of their degradation (Revenga et al., 2000; UNEP, 2004). Obtaining this information is critical to prioritize areas for conservation, develop global conservation strategies, provide scientific knowledge to support policy and management actions, and to restore ecosystem services (e.g., Sanderson et al., 2002; Foley et al., 2005).

The reliability of ecosystem degradation measurements depends on our ability to accurately understand and measure the number and intensity of human stressors and their effects on biodiversity and ecosystems. Ecosystem degradation often occurs gradually, making it difficult to recognize without repeated measures of reliable indicators (Dale and Beyeler, 2001). Freshwater ecosystem degradation is sometimes measured using a suite of ecological indicators, such as macro-invertebrates, fishes, macrophytes, and organisms that live between terrestrial and aquatic ecosystems, such as odonata (e.g., Moya et al., 2010). Good, carefully selected indicators can provide warning signals of significant but cryptic changes to ecosystems (Karr, 1999; Noss, 1999).

The collection of detailed data on ecological indicators may be costly, especially in developing countries where funding is limited and where large tropical rivers of exceptionally high biodiversity are located (Revenga et al., 2000). For example, there are at least 5600 identified species of freshwater fish in the Amazon River Basin and new species are being identified at a rapid rate (Albert and Reis, 2011). As an alternative, it has been proposed to collect data on population trends of specific indicator species (Revenga et al.,

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doi:10.1016/j.ecolind.2012.02.034

Table 1
Principal human stressors that are responsible for freshwater degradation and their impact on the ecosystems.

Human stressors	Impact of stressors on freshwater ecosystems
Water quantity	Water withdrawals by domestic, industrial and agricultural needs, reservoir storage capacity
Water quality	Source point and non-source point pollutants (e.g., organic pollutants, increased nutrients, heavy metals, microbial contamination, toxic organic compounds), suspended particles, temperature
Habitat modification	Roads, dams, reservoirs, land transformation, land use intensity, agriculture, vegetation cover, fragmentation
Exploitation of species	Fishing pressure, destructive fishing practices (e.g., blast fishing or fishing using poison or explosives), excessive by-catch and discards, aquaculture
Climate change	Increasing water temperature, decreasing precipitation, increasing acidification, changes in primary production
Introduced species	Increasing the rates of species introduced in freshwater systems and the success rate of those introduced

Alcamo et al. (2005), Hoekstra et al. (2011), Revenga et al. (2000), Alkemade et al. (2009), Moyle and Randall (1998), Alcamo et al. (2003), GIWA (2002), Milà i Canals et al. (2009), Falkenmark (1997), Bennett et al. (2004), Karr and Chu (1999), Vörösmarty et al. (2010), Vörösmarty et al. (2000).

2000; Noss, 1999). Top predators such as mammalian carnivores, sea birds and raptors are among the indicator species suggested (Furness and Camphuysen, 1997; Sergio et al., 2005, 2006, 2008; Piatt et al., 2007).

Top predators tend to be concentrated in important biodiversity hotspots (Worm et al., 2003; Sergio et al., 2005, 2006). The reduction or disappearance of top predators is related to significant ecosystem transformations, including impacts on several trophic levels and changes in energy flows, marine resources' removals from fisheries, and changes in the behavior of prey (Soulé et al., 2005; Heithaus et al., 2008; Baum and Worm, 2009). Moreover, their presence or absence can indicate the extent of the footprint of human pressures; those areas with low human population and/or strong conservation and regulations tend to have the highest sighting frequencies of top predators (Baum and Worm, 2009; Sandin et al., 2008; Ward-Paige et al., 2010).

River dolphins are top predators that inhabit some of the largest tropical river basins in Asia and South America, and may be ideal candidates to serve as ecological indicators. When comparing the level of freshwater habitat degradation of these river basins, the baiji dolphins (*Lipotes vexillifer*), now functionally extinct, were distributed in the most dramatically modified river basin, the Yangtze; the blind dolphins (*Platanista gangetica gangetica* and *P. g. minor*), which are currently endangered, are distributed in the second most modified basins, the Indus and Ganges; and the pink river dolphin (*Inia geoffrensis*) and tucuxi (*Sotalia fluviatilis*), vulnerable, are distributed in the least modified of these river basins, the Amazon and Orinoco (Smith and Reeves, in press). Hence, at a global river basin scale, freshwater dolphin species are distributed across a range of human stressor levels and their status informs the global level of freshwater ecosystem degradation (Smith and Reeves, in press).

In this study, we investigated whether river dolphins can indicate freshwater ecosystem degradation at a regional scale. We examined the potential for measures of river dolphin abundance to act as ecological indicators based on how well three abundance estimates (density, mean group size and sighting rate) correlated with the level of human stressors. To quantify and monitor the current and future level of human stressors, we first developed an index of freshwater ecosystem degradation integrating four major factors: (i) water quality degradation, (ii) habitat modification, and (iii) exploitation of species, as well as (iv) human population size in the area, as a proxy for multiple human stressors (see Ward-Paige et al., 2010).

2. Material and methods

2.1. Human stressors and index of freshwater ecosystem degradation

For each study area (Fig. 1), an index of the current freshwater ecosystem degradation was calculated. The degradation index was developed by listing 10 human stressors (Table 2) and by grouping them within four major categories: (I) water quality, (II) habitat modification, (III) species exploitation, and (IV) cities and human settlements. Each human stressor was coded according to four impact categories: (0) when disturbance is absent/no disturbance, (1) when disturbance is low, (2) medium and (3) high (Table 2). Score index of freshwater ecosystem degradation for each major category (water quality (I), habitat modification (II) and species exploitation (III), Table 2) were the average of those for the human stressors coded in that category, and an overall score index of freshwater habitat degradation was obtained by summing over these three major categories (Table 3), with overall value ranges from 0 to 8.5 (8.5 being the highest degradation). In addition, the information on human population size (cities and human settlements (IV), Table 2) for each river area surveyed was obtained using the databases of the population census for each country surveyed (Table 2, DANE, 2005; INE, 2001a,b; INEI, 2007; INEC, 2010). The future trend in freshwater habitat degradation was estimated for each human stressor based on current knowledge of, for example, water development projects planned (Table 3). Information used to provide current and future degradation index scores consisted of observations in the field, published and unpublished reports, and personal communications with researchers from each location surveyed (see also Gomez-Salazar et al., 2012).

2.2. River dolphin abundance estimates

Boat-based surveys were conducted between May 2006 and August 2007 in selected large rivers of the Amazon and Orinoco river basins (see details in Gomez-Salazar et al., 2012). From that study, we obtained abundance estimates for two species of river dolphins (*I. geoffrensis* and *S. fluviatilis*) in 9 areas, which comprise 12 rivers in 5 countries (Fig. 1). Abundance estimates were expressed as (1) river dolphin densities, or the number of dolphins per square kilometer surveyed (number km^{-2}), (2) mean group size of river dolphins, with group defined as a set of animals that are seen together within 250 m from the boat (see Gomez-Salazar et al., 2011), and (3) sighting rates of river dolphins, or the number of dolphins per km surveyed (number km^{-1}).

2.3. Correlation between river dolphin abundances and human stress

To evaluate whether river dolphin abundance estimates correlated with the indices of human stress, the non-parametric Spearman rank correlations were calculated, and tested against the null hypothesis of no correlation between dolphin abundance measure (density, group sizes, sighting rates) and each degradation score index (overall index of freshwater degradation, water quality degradation, exploitation of species) as well as the score index of human population size for the river areas surveyed (Table 5).

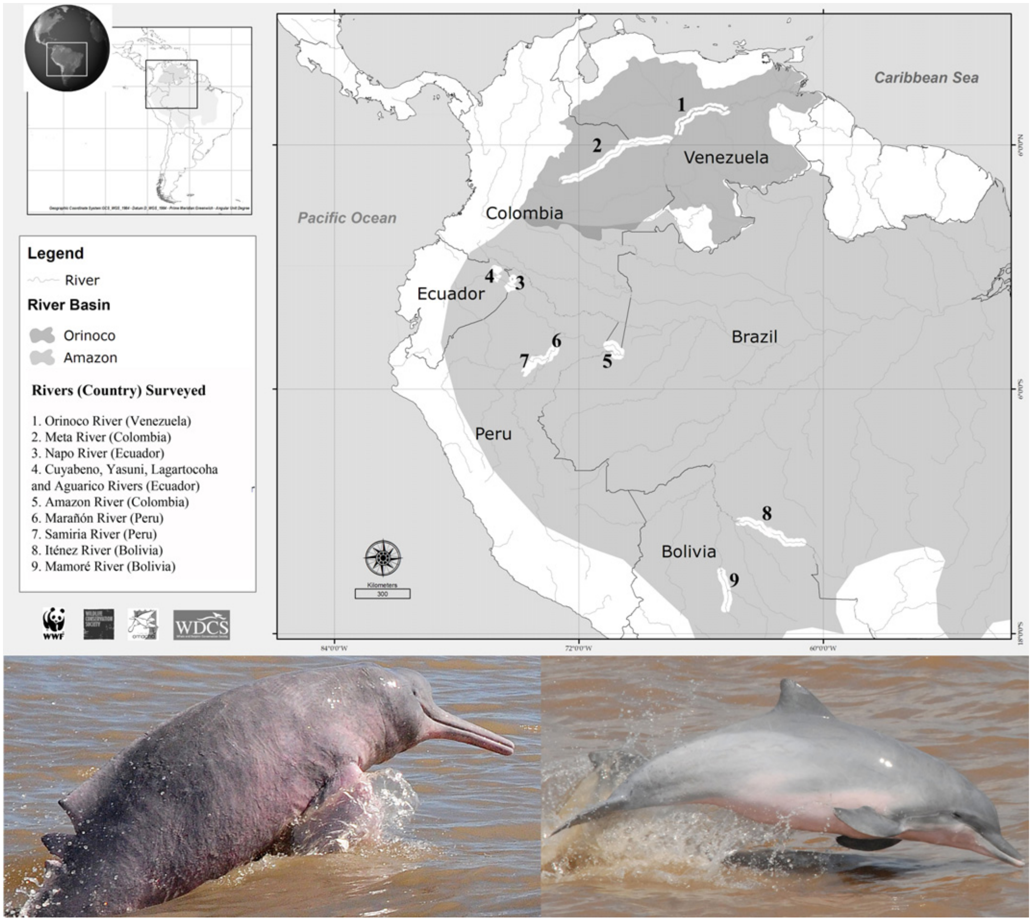

Fig. 1. Map of the nine study areas surveyed (modified from Gomez-Salazar et al., 2012) and the river dolphin species studied in the Amazon and Orinoco (left: pink river dolphin *Inia geoffrensis*, right: tucuxi *Sotalia fluviatilis*).

Table 2
Human stressors and definitions for each impact category. Codes for impact categories are (0) no disturbance reported, (1) low disturbance, (2) medium disturbance, (3) high disturbance. Some human stressors do not include high impact categories (–).

Human stressors		Impact categories [range distance from the study area]		
		Low (1)	Medium (2)	High (3)
I. Water quality				
1. Oil exploitation	Any size	100–200 km	50–100 km	Within 50 km
2. Tourism	Tourist resorts	50–100 km	Within 50 km	–
3. Ship traffic	Commercial, fishing, naval or transportation	Sporadic routes	Known shipping routes	–
4. Mining	Any	100–200 km	50–100 km	Within 50 km
II. Habitat modification				
5. Dams	Any size	500–1000 km downstream or 100–200 km upstream	200–500 km downstream or 50–100 km upstream	Within 200 km downstream and/or within 50 km upstream
6. Waterways	Any size	500–1000 km downstream or 100–200 km upstream	500–1000 km downstream or 100–200 km upstream	Within 200 km downstream and/or within 50 km upstream
III. Exploitation of species				
7. Entanglements/killing of dolphins to avoid competition for resources (fish)	Number of dead dolphins due to entanglements/or direct killing	Rare (recorded once or twice in the area)	Occasional (recorded once per year)	Frequent (recorded at least once per month)
8. Killing of river dolphins for bait	Number of dead dolphins killed for bait	Rare (recorded once or twice in the area)	Occasional (recorded once per year)	Frequent (e.g., mota fishery established in the area)
9. Fisheries		Subsistence	Commercial, main destination is cities within the river basin	Commercial, main destination is cities within and outside the river basin
IV. Cities and human settlements				
10. Human population size		Less than 100,000	Between 100,000 and 200,000	More than 200,000

Note: 200 km is the maximum distance surveyed of a 6 m boat with an outboard 25 hp engine (e.g., tourism boats). 100 km is the maximum distance surveyed per day on a boat/canoe (e.g., "peque-peque", mostly used by local communities) pushed by a home-made propeller or small engine. 5 km is the maximum distance surveyed in a canoe per day. Ships are larger than boats and have capacity for more than 10 people. Locations not defined under low (1), medium (2), or high (3) threat categories are ranked as not-known in the area (0).

Table 3
Overall score index for each impact category (high, medium and low, see Table 2) and risk trend levels of freshwater ecosystem degradation. The overall score index is the sum of the means over the four main categories of human stressors (water quality, habitat modification, exploitation of species, cities and human settlements, Table 2).

Overall score index		Summing over the different types of human stressors
High	Majority of human stressors are classified as high or medium, no stressors are classified as low	≥ 4
Medium	Majority of human stressors are classified as medium	≥ 3 and < 4
Low	Majority of human stressors are classified as low or no known, no stressors are classified as high	< 3
Risk trend (within the next 10 years)		
↑	Risk is expected to increase (e.g. construction of water development projects planned, increase number of oil stations, etc.)	
→	Risk is expected to remain similar, although some increase in human population size is expected.	
↓	Risk is expected to reduce given some conservation or management actions in the area.	
	Risk not recorded in the area, and not expected to appear in the next year.	

3. Results

3.1. Overall score indices as indicators of freshwater ecosystem degradation

Overall, we found that the Napo, Orinoco, and Meta rivers were currently the areas with the highest degradation index, the Amazon, Marañón and the Ecuadorian tributaries with medium values, and the Samiria, Iténez and Mamoré rivers with the lowest (Table 4). These indices were generally consistent across the four different categories of degradation (Table 4). In addition, human population size was significantly and positively correlated with overall degradation index and water quality (Table 5). This means that, as expected, those areas that are less populated have lower ecosystem degradation and better water quality. Density and sighting rates were significantly and positively correlated with each other (Table 5).

3.2. River dolphin abundance estimates and human stressors

Density and sighting were significantly and negatively correlated with the overall degradation index, water quality degradation and human population size (Table 5). Higher density estimates of river dolphins occur when rivers have a low index of overall freshwater degradation, when rivers have better water quality, and in areas that are less populated (Fig. 2). For instance, rivers with a high index of overall degradation had some of the lowest density/sighting rates of the pink river dolphin (0/0: Napo River in Ecuador; 0.57/0.11: Meta river in Colombia, respectively) and tucuxi (0/0: Napo River in Ecuador; 1.06/0.21: Orinoco River in Venezuela, respectively). A similar pattern was evident for density estimates and exploitation of species (Fig. 2), although the two indices were not significantly correlated (Table 5).

Group size did not appear to be closely related to the other two abundance estimates nor to any of the indices of human stress. In addition, neither group sizes nor sighting rates were significantly correlated with species exploitation (Table 5).

Finally, for the majority of human stressors the risk of freshwater ecosystem degradation was expected to increase and no stressors were expected to decrease (Table 4).

4. Discussion

4.1. River dolphins: indicator, sentinel and flagship species in large tropical freshwater ecosystems

Our study illustrates that both density estimates and sighting rates are good ecological indicators of overall freshwater ecosystem degradation, water quality degradation and human population size, and given that they are well correlated, obtaining only one of these estimates may be sufficient to use as indicator. Density, in addition, seems to respond more linearly to the levels of overall ecosystem degradation, water quality and human population size (Fig. 2). Also sighting rate will depend on the methodology of the survey, which may vary between studies, whereas density estimates correct for this. In summary, we recommend using density estimates of river dolphins as an indicator of freshwater ecosystem degradation. The results of this study are in line with previous studies that also found the density of top predators decreases with increasing human stressors (Sandin et al., 2008; Baum and Worm, 2009).

In contrast, there is no correlation between freshwater ecosystem degradation and the dolphins' group sizes. Group sizes vary according to habitat type and seasonality, responding to changes in the aquatic productivity and availability of resources (McGuire and Winemiller, 1998; Gomez-Salazar et al., 2011). Hence, group sizes may change mainly as a response to ecological factors, and for this reason group sizes may not to be good indicators of ecosystem degradation.

Using river dolphins as indicator species to develop monitoring programs and assessments of freshwater ecosystem degradation has multiple advantages, including the fact that (1) river dolphins are typically distributed in all habitat types of the Amazon and Orinoco river basins, with the exception of rapids and areas with very high ecosystem degradation (e.g., Napo River); (2) river dolphins are relatively easy to observe in an ecosystem where the majority of species occur under waters of high turbidity; (3) river dolphin surveys are relatively easy to conduct (see Gomez-Salazar et al., 2012) and require less sample processing compared with surveys of some other potential indicators such as invertebrates and algae; (4) river dolphins are long-lived and thus provide responses to long-term risks of ecosystem degradation; (5) potentially, river dolphins can act as sentinel species by providing early warnings about current or future increases in ecosystem degradation, such as bioaccumulation of heavy metals or other contaminants, as previously studied in other aquatic mammals (e.g., Wells et al., 2004; Bossart, 2011); and finally (6) river dolphins are a charismatic species, thus, can be used as flagship species to raise public awareness about conservation and management issues (Sergio et al., 2008). However, abundance estimates of other taxonomic groups, such as aquatic birds or fishes, might complement, and add to the value of, dolphin-based assessments of ecosystem degradation (Karr, 1999; Piatt et al., 2007; Navarro-Llácer et al., 2010). For example, the methodology and platforms used to conduct river dolphin surveys (Gomez-Salazar et al., 2012) could be used to survey other taxonomic groups such as aquatic birds and reptiles.

4.2. Current and future freshwater ecosystem degradation in the Amazon and Orinoco

Due to limitations on data availability, most of the score indexes used in this study are the result of presence and proximity of

Table 4
Score index and risk trends of freshwater ecosystem degradation, and human population size across the nine areas surveyed (Fig. 1). The direction of the arrows indicates whether the risk of degradation is expected to increase, decrease or remain the same (see Table 3). Overall score index is the sum of the means over the four main categories of human stressors (water quality, habitat modification, exploitation of species, cities and human settlements, Table 3).

	Country (River)								
Human stressors	Venezuela (Orinoco)	Colombia (Meta)	Ecuador (Napo)	Ecuador(2) (Tributaries)	Colombia (Amazon)	Peru(3) (Marañon)	Peru(4) (Samiria)	Bolivia (Itenez)	Bolivia (Mamore)
Overall score risk	4.5	4.5	4.2	3.8	3.5	3.4	2.3	2.3	2.9
I.Water quality	**2.5**	**2.5**	**2.5**	**2.5**	**1.5**	**1.8**	**1.0**	**1.0**	**1.3**
1. Oil	3 ↑	3 ↑	3 ↑	3 ↑	0	2 ↑	0 ↑	0	0
2. Tourism	2 ↑	2 ↑	2 ↑	2 ↑	2 ↑	2 ↑	2 ↑	2 ↑	2 ↑
3. Ship traffic	2 ↑	2 ↑	2 ↑	2 ↑	2 ↑	2 ↑	1 ↑	1 ↑	2 ↑
4. Mining(1)	3 ↑	3 ↑	3 ↑	3 ↑	2 ↑	1 →	1 →	1 →	1 ↑
II. Habitat modification	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
5.Dams	0 ↑	0	0 ↑	0 ↑	0	0	0	0 ↑	0 ↑
6.Waterways	0	0 ↑	0 ↑	0 ↑	0	0	0	0 ↑	0 ↑
III. Species exploitation	**2.0**	**2.0**	**1.7**	**1.3**	**2.0**	**1.7**	**1.3**	**1.3**	**1.7**
7.Entanglements	2 →	2 →	2 →	2 →	2 →	2 →	2 →	2 →	2 →
8. Killing of river dolphins for bait	1 ↑	1 ↑	0 ↑	0 ↑	1 ↑	0 ↑	0 ↑	0 ↑	1 ↑
9. Fisheries	3 ↑	3 ↑	3 ↑	2 ↑	3 ↑	3 ↑	2 ↑	2 ↑	2 ↑
IV. Cities and human settlements 10. Human Population Size	432,409	181,276	264,695		117,125	437,665	92,000	94,210	195,844

(1) Particularly gold mining implies possible contamination by mercury residuals, (2) tributaries in Ecuador: Rivers Aguarico, Cuyabeno, Yasuni and Lagartococha, (3) River Amazon – named Marañon at the location surveyed, (4) freshwater protected area. Human population size: DANE (2005) (Colombia); INE (2001a) (Bolivia); INE (2001b) (Venezuela); INEI (2007) (Peru); INEC (2010) (Ecuador).

human activities rather than the proximate stressors that result from these activities. For instance, when considering gold mining, mercury used for the separation of gold particles is discharged into rivers and soils where it threatens biodiversity (Pfeiffer et al., 1993). However, there are no reliable statistics in our study areas on mercury release, so we use the presence and proximity of gold mining as part of the score index. Despite these limitations, the degradation index was correlated with human population size, which suggests the scores are providing effective measures of degradation.

The majority of the human stressors considered in this study are expected to increase due to growing human population numbers and to the growing interest in economically developing the Amazon and Orinoco basins (Laurance et al., 2005, Table 4). Areas with both high and low indices of freshwater degradation were within rivers that are planned to be dramatically altered by water development projects or oil exploration in the near future (Table 4). For example, waterways are being planned in the Meta, Napo, Iténez and Mamoré rivers.

4.2.1. Areas with highest overall score index of freshwater degradation

The Napo, Orinoco and Meta Rivers were identified as rivers with the highest degradation. This is the result of intense oil exploration and development in these areas, which in turn has caused multiple crude spills, increased road construction to facilitate accessibility in the area, increased ship traffic to transport people and machinery, increasing forest colonization, land speculation, commercial hunting and thus large socio-economic changes in the regions (Laurance et al., 2005; Portocarrero-Aya et al., 2010; Trujillo et al., 2010; Utreras et al., 2010). Industrial farming, deforestation, expansion of cattle ranching, the use of pesticides and chemical fertilizers, as well as fishing with chemicals and explosives have also been documented. There is growing interest in expanding industrial farming and oil exploration, and waterways are being planned (Trujillo et al., 2010). For instance, the commerce and navigability in the Napo is expected to increase as a result of the construction of the Manta-Manaus transportation corridor to connect the Pacific coast and the Brazilian central Amazon (Utreras et al., 2010; Utreras, 2011).

Table 5
Spearman's rank test correlation results between river dolphin (*Inia* and *Sotalia*) abundance estimates (sighting rates and density, Gomez-Salazar et al., 2012) and score indices of freshwater ecosystem degradation (overall score index of degradation, water quality degradation, species exploitation and human population size, Table 4 across the nine areas surveyed between 2006 and 2007 (Fig. 1).

	Sighting rate	Density	Species	Overall degradation index	Water quality degradation	Species exploitation	Human population size
Group size	0.49	0.42	0.23	−0.10	−0.18	0.34	−0.17
Sighting rate	–	**0.86***	0.09	**−0.70***	**−0.81***	−0.21	**−0.48***
Density		–	0.05	**−0.81***	**−0.83***	−0.45	**−0.64***
Species			–	0.11	0.13	0.06	0.17
Overall degradation index				–	0.91	0.72	**0.73***
Water quality degradation					–	0.49	**0.81***
Species exploitation						–	0.33

Emboldened*: correlation is significant at the 0.01 level.

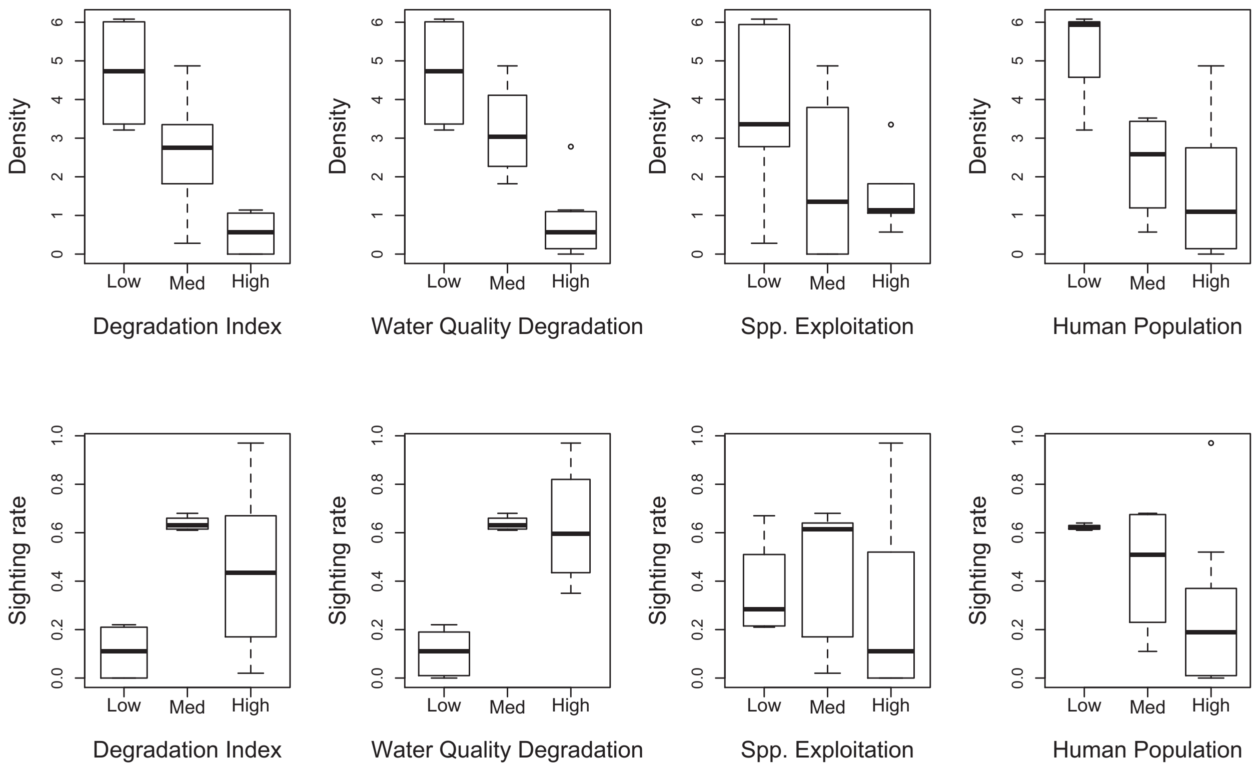

Fig. 2. River dolphin abundance estimates (density: number km^{-2} and sighting rates: number km^{-1}, from Gomez-Salazar et al., 2012) according to score indices of freshwater ecosystem degradation (overall score index of degradation, water quality degradation, species exploitation and human population size, Table 4) for the nine areas surveyed between 2006 and 2007 (Fig. 1). Box plot includes median, lower and upper quartile, sample minimum and sample maximum.

4.2.2. *Areas with lowest overall score index of freshwater degradation*

Samiria, Iténez and Mamoré Rivers were identified as rivers with lowest degradation. In fact, these areas have relatively low human stressors when compared with the other areas surveyed (McGuire and Aliaga-Rossel, 2010; Tavera et al., 2010; Gomez-Salazar et al., 2012). The Samiria River is located within the Pacaya-Samiria National Reserve, which is a well-managed freshwater protected area. However, waterways to improve navigability are planned in the Itenéz, Mamoré, and Madeira Rivers, and a hydroelectric dam is planned in the Madeira River (Tavera et al., 2010).

4.2.3. *Additional human stressors*

There are major human stressors that were not considered in our risk score assessment and that might have an impact on river dolphin populations, such as land-use changes, climate change, chemical pollution and aquatic noise. Major land-use changes, for instance, have a direct effect on the aquatic ecosystems by, for example, altering the flooding pattern and causing erosion and sedimentation (Laurance, 1998). Climate change will alter the biosphere on a larger scale and is expected to accelerate but its consequences in the Amazon and Orinoco have not been extensively investigated (Alcamo et al., 2005; Laurance et al., 2005). In addition, aquatic noise has been documented to affect large parts of marine ecosystems, including marine mammals, fishes and invertebrates (Weilgart, 2007) and its effects on freshwater ecosystems are unknown.

Finally, the capture of dolphins for use as bait is one of the most serious human stressors that might increase in the near future. For instance, in the central Brazilian Amazon, approximately 600 pink river dolphins are killed each year for bait (Loch et al., 2009), and if this activity spreads from Brazil to our study areas, the population sizes and densities of dolphins will likely decline within a few years (Gomez-Salazar et al., 2012).

5. Recommendations

Indices of human stress are currently the best way to provide an estimate of ecosystem degradation in large tropical rivers and adding information on population trends of indicator species, such as river dolphins, broadens the picture.

The value of river dolphins as indicators should be tested further at a river basin scale. To do this, we recommend directing research to areas where previous surveys already exist to facilitate the development of monitoring programs. Research should also focus on additional *key* locations in the Amazon and Orinoco. To make comparisons between areas as valid as possible, future effort in these *key* locations should carefully select the time of the year to conduct surveys and the size of the areas surveyed. Priority of additional *key* locations should be based on the following criteria:

5.1. *Potential hot spots and areas of concern*

By using the ecosystem degradation index developed in this study, areas with low risk of ecosystem degradation (potential hot spots) and areas of high risk of ecosystem degradation (areas of concern) can be identified. Subsequently, surveys could be conducted in these selected areas to continue evaluating the role of dolphins as indicators, and fundamentally to continue monitoring *key* areas of the Amazon and Orinoco.

5.2. *Representative sub-basins*

This study used information from less that 1% of the entire Amazon and Orinoco river basins, and only included information on river dolphin populations that inhabit 3 out of the 14 sub-basins described for the Amazon (Gomez-Salazar et al., 2012; UNEP, 2004). Further studies should prioritize *key* areas located in sub-basins that have not yet been studied to obtain a more representative picture of the conservation status of these freshwater ecosystems.

5.3. Upcoming water development projects

Surveys in areas where water development projects are proposed, or are at early stages of construction, are particularly important because of the future changes that those drainage areas will face due to the construction of dams and water ways. Dams, for instance, are built for flood control, irrigation and hydroelectric power, but the final outcome often does not meet the expected economic benefits and instead generates major environmental, social, and health impacts (WCD, 2000). In terms of biodiversity and ecological processes, the construction of dams can fragment populations, reduce river flow, affect river pulses, change the water quality, and ultimately contribute to the extinction of many species (WCD, 2000), including perhaps river dolphins. Hence, further studies should survey areas of the Amazon and Orinoco basin river basins before and after the construction of water development projects to investigate their effects on top predators and on the river system itself. Such studies will ultimately raise awareness about the potential impacts of additional dams in these regions.

Acknowledgements

We thank Fernando Trujillo, Sarah Wong, Marcela Portocarrero-Aya, Fundación Omacha and the Whitehead Lab for their support and helpful comments on the ideas of this manuscript. We thank Robert Scheibling, Heike Lotze, Marty Leonard, Bill Freedman and Cindy Staicer, for contributing with the ideas of this manuscript. Many thanks to anonymous reviewers for their detailed and helpful comments on the manuscript. This work was supported by the Whale and Dolphin Conservation Society (WDCS), Whitley Fund for Nature, Wildlife Conservation Society (WCS), World Wildlife Fund (WWF), Russell E. Train program (WWF), Organization of American States (OAS) Scholarship, National Geographic Society (NGS), Society for Marine Mammalogy Small Grant in Aid of Research, Cetacean Society International (CSI), Humboldt Institute (Colombia), Programa Crédito Beca de Colfuturo, and Dr. Patrick Lett Fund. We thank Victor Utreras (Ecuador), Jaime Bolaños (Venezuela), Freddy Arevalo, Lourdes Ruck (Peru), Saulo Usma and Enzo Aliaga-Rossel (Bolivia) for their support and insight about the areas surveyed. We thank Tiffany Steel, Nathan Ward, Ramon Filgueira and Krista Patriquin for their detailed and helpful comments on the manuscript.

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