Finding evidence for the impact of hilsa fishery management in Bangladesh

Combining theory-testing and remote sensing methods

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Bangladesh's hilsa fishery is a rare example of 'carrot-and-stick' management. This study uses a theory-based, mixed-methods approach to assess whether intended outcomes have occurred; and whether management is a cause. The evidence is mixed. Compensation appears to have improved livelihoods, but may not have incentivised compliance with regulations. Fishing bans may have helped increase hilsa abundance, but strong spatial variation in how fishers view the fishery and its regulations, combined with remote sensing data, suggest declining habitat suitability may be masking the benefits in some areas. We make four recommendations: that the compensation scheme is redesigned to better fit fishers' needs, then scaled up; that sanctuaries are reassessed for ecological suitability and long-term environmental M&E is put in place; that short-term fishing closures to protect spawning fish be implemented more widely; and that local communities should become involved in co-management. More broadly, we show that creative theory-based approaches can help assess conservation interventions when attributing cause and effect is difficult.

Contents

Summary

Hilsa (*Tenualosa ilisha*) fishery management in Bangladesh is a rare example of 'carrot-and-stick' management in developing world fisheries – so how well does this mix of regulations and incentives work? Impact evaluation traditionally relies on comparing what happens under management against what was expected without management (ie comparison with counterfactuals). But that needs baseline social and ecological data that is not available in the hilsa fishery. Therefore this study uses a theory-based, mixed-methods approach inspired by the principles of process tracing to collect and assess evidence that a) the intended outcomes of management have been realised; and b) management has contributed to these outcomes.

We based our study on a previously-published Theory of Change for the hilsa fishery and investigated evidence for three hypotheses:

- Hypothesis A (the 'hypothesised causal mechanism'): management actions have contributed to an increase in hilsa abundance and socioeconomic improvement
- Hypothesis B: the compensation scheme has not contributed to an increase in hilsa abundance
- Hypothesis C: hilsa abundance has been largely determined by environmental conditions.

The study set out expectations arising from the hypotheses and gathered evidence for these. We surveyed attitudes and perceptions among 601 fishing households in 21 villages across five districts (Barisal, Bhola, Patuakhali, Pirojpur and Jhalokathi).The study also gathered information on compliance with fishing bans (using radar), and on environmental conditions (as interpreted from Landsat remote sensing images).

Although the nature of the evidence meant that it could not be used to decisively infer causality, observing evidence for an expected outcome strengthened confidence in that part of the associated hypothesis, while not observing evidence weakened confidence. In other words, when rigorous counterfactual impact evaluations are not possible, creative mixed-method, theory-based approaches can still be used to identify the weaker and stronger components of an intervention, and thus to direct improvement.

The management components with the strongest evidence for a contribution were those aiming for socioeconomic improvement. It also seems likely that management actions have contributed to some compliance with regulations, particularly a reduction in sanctuary fishing during the ban period. Awareness-raising activities may have played a key part in influencing these changes.

However, the evidence did not rule out either of the alternative hypotheses. This weakens confidence in some key components of the hypothesised causal mechanism and highlights four main management actions that are needed for the hilsa fishery to improve.

Firstly, this study suggests the compensation scheme might not have contributed to an increase in hilsa abundance, even if fishers are better off. This may be because of fishers' poor access to assistance with debt, market power structures, or problems with allocating compensation effectively. We recommend the rice and AIGA compensation schemes should be redesigned with stakeholder consultation so that they better fit hilsa fishers' needs, and that their coverage should be increased in an equitable way. Compensation needs to help to lower the opportunity costs associated with complying with fishing bans but also to go further, and actually incentivise compliance.

Secondly, it is plausible that changing environmental conditions have undermined the impacts of management in some areas. At present there is no evidence to infer the relative contributions that management and environmental conditions have had on hilsa abundance. However, species with similar life cycles to hilsa tend to have strong population responses to environmental change. Overall, evidence that management actions have increased hilsa abundance is equivocal and spatially variable. Strong geographical variation in the trends fishers perceive, and their views on how regulations affect these trends, suggests that the sanctuary fishing bans may not have had the intended impact on hilsa abundance in some cases. This could be because adverse environmental change is masking or outweighing any benefits from management. The spatial variation in habitat suitability seen in the Landsat images supports this interpretation. Therefore,

it is important that a complete ecological reassessment of sanctuary zoning is conducted, and that a long-term ecological monitoring and evaluation programme is established.

Thirdly, since remote sensing indicates that habitat suitability is not concentrated in the sanctuary areas (and that small rivers outside them, such as the Kaliganga and Payra, are fishing hotspots), fishing bans should be implemented throughout the river system. This should also reduce the chance of blockages in fish migration routes undermining the benefits of temporary fishing closures.

Fourthly, hilsa fisheries management agencies should develop a system of co-management with local communities. There is clearly nowhere near 100 per cent compliance with fishery regulations. However, even if a small minority of fishers have changed their behaviour because of management interventions (as appears to be the case), that change could eventually affect the whole population through community encouragement and peer pressure. It would be unrealistic to expect substantial improvement in 'top-down' enforcement of regulations at this stage. Nevertheless, other studies have shown that local communities' participation in implementing, monitoring and enforcing regulations can lead to compliance through collective action and can work well in tandem with institutions like compensation schemes.

Overall, we conclude that the hilsa management package has contributed to socioeconomic improvement and, at the very least, has potential to help increase hilsa abundance, especially if further steps are taken. More broadly, this study demonstrates that creative theory-based approaches to evaluation offer potential for examining causality in conservation interventions when attribution is difficult.

1

Introduction

The Bangladesh hilsa fishery

Globally, fisheries provide about 7.3 billion people with 15–20 per cent of their animal protein and support the livelihoods of 10–12 per cent of the world's population (FAO 2014). The majority of these people are involved in small-scale and artisanal fisheries, which increasingly export their production and have great potential to contribute to poverty alleviation in developing countries (World Bank 2010; Garcia and Rosenberg 2010; Wilen 2013). Yet, effective implementation of sustainable management is limited by a lack of will and ability to bear the short-term costs, particularly in small-scale and artisanal developing world fisheries (Carbonetti et al. 2014; Brown et al. 2015; Ovando et al. 2016). When management interventions are implemented in these fisheries, individual or groups of fishers may perceive personal costs to exceed the benefits. This can lead to resistance and non-compliance, particularly when enforcement is weak (McClanahan et al. 2012; Wallace et al. 2015).

In line with the recent popularity of market-based approaches to resource management and conservation, a range of economic instruments are becoming available for fisheries management (Innes et al. 2015). Schemes such as Payments for Ecosystem Services, which attempt to realign the incentives faced by individuals with the objectives of management, have the potential to alleviate some of the short-term costs of fishery reform (Bladon et al. 2014). In some circumstances a 'carrot-and-stick' approach has been used to strengthen individual and collective motivations for compliance. The idea is to enable and incentivise poor communities to reduce their reliance on resources under protection while facilitating a more equitable distribution of the costs of better management (Wunder 2007; Clements et al. 2010). Yet, implementation of these incentive-based approaches is still relatively rare in fisheries (Lau 2012; Binet et al. 2013; Begossi 2014).

Hilsa (*Tenualosa ilisha*) fishery management in Bangladesh is one of the few examples of this carrot-and-stick approach in the developing world (Mohammed and Wahab 2013). Hilsa are migratory fish in the herring family, found throughout South and Southeast Asia in marine and freshwater (Bhaumik 2015). Not only are they a symbol of national, cultural and religious pride for Bangladesh, but up to 500,000 people directly depend upon the species for their livelihoods, particularly in coastal communities (Islam et al. 2016b). Yet, high demand from Bangladesh and India has reportedly led to a gradual decline in hilsa production since the 1970s, particularly inland.

In response to research concluding that protecting jatka (juvenile hilsa) should reverse this decline, in 2003 the Bangladesh Government's Department of Fisheries (DoF) established an action plan to sustainably manage and increase the production of hilsa (DoF 2002). The management actions that have been phased in so far combine regulations with incentives (Dewhurst-Richman et al. 2016). The regulations focus on controlling exploitation patterns rather than exploitation rates, and particularly on restricting the exploitation of jatka through: a seasonal ban on fishing in sanctuary areas, a seasonal ban on any jatka-related activities, restrictions on fishing gear, and some regulations for fishing vessels. There is also a seasonal ban on hilsa fishing to protect spawning hilsa.

In recognition of the socioeconomic cost imposed by the seasonal fishing bans on fishing communities, a compensation scheme – sometimes referred to as an example of 'payments for ecosystem services' – was established (Mohammed and Wahab 2013; Wahab et al. 2013; Islam et al. 2016b). This largely consists of distributing rice (40kg per household per month for four months of the year) to fishers in 15 districts, funded through a pre-existing Vulnerable Group Feeding programme. Some Alternative Income Generating Assistance (AIGA) is also provided to a smaller proportion of fishers, particularly those in and around the hilsa sanctuaries, along with awareness-raising activities. Following implementation of these interventions, officially reported hilsa landings began to rise, and there is anecdotal evidence to suggest that the compensation scheme may have had, or at least has potential to have, social and ecological benefits (Rahman et al. 2012; Bladon 2016). However, there has been no rigorous impact evaluation of either the management package as a whole or the compensation, scheme and so these observations cannot yet be causally linked to management.

Aim and objectives

Evaluating the impact of hilsa fishery management interventions is difficult due to the lack of pre-intervention social and ecological data. Studies of management success have therefore used fishers' knowledge and their perceptions of management impacts as indicators of management success (Islam et al. 2016a). Often overlooked in the pursuit of more scientific evidence, stakeholder perceptions can support rapid impact assessments when environments for evaluation are challenging (Sainsbury et al. 2015; Bennett 2016). Numerous studies have demonstrated the usefulness of fishers' knowledge and perceptions in decision-making when scientific knowledge is limited (Silvano and Valbo-Jørgensen 2008; Daw et al. 2011; Gaspare et al. 2015). Because they depend on local resources, small-scale artisanal fishing communities can be highly aware of their impacts on fish populations and can provide valuable insights into fish behaviour and ecology (Drew 2005; Silvano and Begossi 2009; Ramires et al. 2015).

However, perceptions alone can rarely determine causality (Bennett 2016). Bladon (2016) looked at hilsa management and assessed whether it might have impacts over and above what was expected without interventions (ie its scope for 'ecological additionality') using local perceptions, but used a complementary combination of statistical and contribution analyses – an approach that showed potential for further development and exploration.

This study aims to evaluate the impact of the current package of hilsa fishery management interventions using a theory-based, mixed-methods approach inspired by the principles of 'process tracing', a qualitative method used to evaluate theories in political science. The study collected and assessed evidence to investigate whether a) the intended outcomes have been realised; and b) management has contributed to these outcomes. Although we may not attribute outcomes to the management package with absolute certainty, this approach should reveal a realistic degree of confidence that will in turn inform decisions for developing, improving and scaling up hilsa fishery management interventions.

2

Impact evaluation

Conservation interventions should always have ecological additionality (Maron et al. 2013). Without additionality, an intervention cannot be cost-effective, and it can be difficult to generate and maintain financial support (Wunder et al. 2008; Narloch et al. 2011). Conservation science increasingly emphasises the importance of projecting what would have occurred in the absence of an intervention (i.e. providing 'counterfactuals') when demonstrating causality, and thus the importance of quasi-experimental evaluation (Ferraro and Pattanayak 2006). However, projecting counterfactuals requires extensive quantitative baseline data and the counterfactuals must be established and recorded early on in an intervention's design if specific actions or behaviours are to be attributed to the intervention (Pagiola and Rios 2013; Clements and Milner-Gulland 2014; et al. 2014; Gurney et al. 2014, 2015). In many real-world, data-poor circumstances, this is not possible, and so the evaluation community has begun to advocate for rigorous alternatives to traditional counterfactual evaluation (Stern 2015).

2.1 Theory-based evaluation

Theory-based approaches to evaluation rely on 'generative causality'; i.e., they identify a causal mechanism that explains a specific effect and, by doing so, demonstrate a causal relationship. Unlike counterfactual approaches, they go beyond statistical correlations to describe *how* and *why* an intervention led to an observed outcome.

Contribution analysis is one theory-based approach that is increasingly used to evaluate development initiatives (Anderson 2005; Vogel 2012, 2013). The approach involves mapping out a conceptual theory of change (ToC) for an intervention; in other words, the mechanism presumed to lead to the intended outcomes, its underlying assumptions and contextual conditions (Rogers and Weiss 2007). The ToC can then be validated by looking for empirical evidence to support or discredit each of its underlying assumptions, allowing some level of causality to be inferred. The approach reduces uncertainty about the contribution an intervention is making to observed outcomes, either confirming theorised mechanisms or highlighting those that do not reflect reality. Yet, the validation component of contribution analysis lacks methodological guidelines for data collection (Befani and Mayne 2014).

Process tracing is a probabilistic tool that was developed to analyse historical events and is arguably the most important tool of causal inference in qualitative social research (George and Bennett 2005; Bennett 2010; Mahoney 2012). Like contribution analysis, it looks for empirical evidence to test hypotheses at each stage of a theorised mechanism, including hypotheses representing alternative causal explanations. But process tracing breaks down the theorised mechanism into the smallest possible number of components that are each necessary for the next component in the sequence, and each of which should be empirically measurable (Punton and Welle 2015a). Thus, it is not the strength of a piece of evidence in isolation, but the combination or accumulation of evidence that increases or decreases confidence in a causal mechanism (Bennett 2010).

Four kinds of empirical process tracing tests have been developed to make assessing evidence systematic and transparent. Each is based on different combinations of two principles: uniqueness and certainty. The more confidently a theory predicts a piece of evidence (certainty), and the less likely it is that alternative hypotheses can explain the evidence (uniqueness), the more confidence can be had in that evidence. The different combinations of uniqueness and certainty dictate whether the tests are necessary and/or sufficient for affirming causal inference (Van Evera 1997; Box 1).

Process tracing has received much attention from the field of international development (Barnett and Munslow 2014; Punton and Welle 2015a, 2015b) but, to our knowledge, no impact evaluations have applied the protocols in full. In practice, challenges arise when an intervention's outcomes are not fully known, when highly complex interventions are being assessed, and when variables are missing. For example, an assessment of an intervention that aimed to help frame nutrition policy in Tanzania found the evidence to be so vast that only empirical evidence passing the hoop test was considered (Punton and Welle 2015b). Other evaluations have used the principles to assess whether evidence could explain alternative plausible causal sequences for outcomes, and have followed this by assessing the extent to which each causal sequence could have contributed to an observed change (Oxfam 2011).

Process tracing is nevertheless a robust tool for evaluating impacts and can strengthen evidence assessment when validating Theories of Change (Befani and Mayne 2014; Befani and Stedman-Bryce 2016). Although it has not been used in conservation, it offers potential for 'after the event' evaluations because it does not require baseline or counterfactual data, or controls. It should be particularly useful as part of a broader mixed-methods approach, as it is used here.

BOX 1. PROCESS TRACING TESTS FOR CAUSAL INFERENCE

Smoking gun (sufficient): if the evidence is observed, the hypothesis is confirmed. If the evidence is not observed, the hypothesis is not confirmed or eliminated.

Hoop (necessary): if the evidence is not observed, the hypothesis is eliminated. If the evidence is observed, the hypothesis is not confirmed, but it is not eliminated either.

Straw-in-the-wind (neither necessary nor sufficient): if the evidence is observed it is not sufficient to confirm the hypothesis, but it does affirm plausibility. If the evidence is not observed this is not sufficient to eliminate the hypothesis.

Doubly decisive (necessary and sufficient): if the evidence is observed, the hypothesis is confirmed. If the evidence is not observed the hypothesis is rejected.

Source: adapted from Befani and Stedman-Bryce (2016)

3 Methods

The theory-based evaluation approach in this study of hilsa management in Bangladesh loosely followed Beach and Pederson's (2013) process tracing protocol, as described by Punton and Welle (2015a) and set out below. Because we could not test each and every step of the causal mechanism, we were not able to confirm whether the intervention as a whole was responsible for the final outcome, but we were able to establish a degree of confidence in its contribution to key components of the mechanism.

3.1 Developing a hypothesised causal mechanism

Our hypothesised causal mechanism for change in the hilsa fishery was drawn from a reconstructed ToC by Bladon (2016). Bladon (2016) based this ToC on fishing regulations and associated management, as set out in the Hilsa Fisheries Management Action Plan (DoF 2002), and on discussions with fisheries managers and other key informants. The mechanism depicts the hypothesised causal pathways between management actions and outcomes, the assumptions that underpin them, associated risks and external influences.

The hilsa fishery management package aims to make hilsa production more sustainable and to improve fishers' socioeconomic situation (Fig. 1). The main intervention hypothesis (A) is therefore that the management actions have contributed to an increase in hilsa abundance and to socioeconomic improvement. For instance, fishing regulations are expected to protect *jatka* (juvenile hilsa) because the threat of their associated sanctions change fishers' behaviour; compensation is expected to make fishers better off and therefore more willing/able to comply with the regulations; and awareness-raising is expected to change fishers' attitudes to jatka fishing, so boosting compliance. Together, these actions are expected to have boosted abundance of hilsa. However, there are alternative (but not mutually exclusive) hypotheses. It is plausible that, while the management as a whole has helped boost hilsa abundance, the compensation scheme has not (hypothesis B); and that environmental conditions largely determine hilsa abundance (hypothesis C). Table 1 presents the evidence that would be expected under each of these hypotheses.

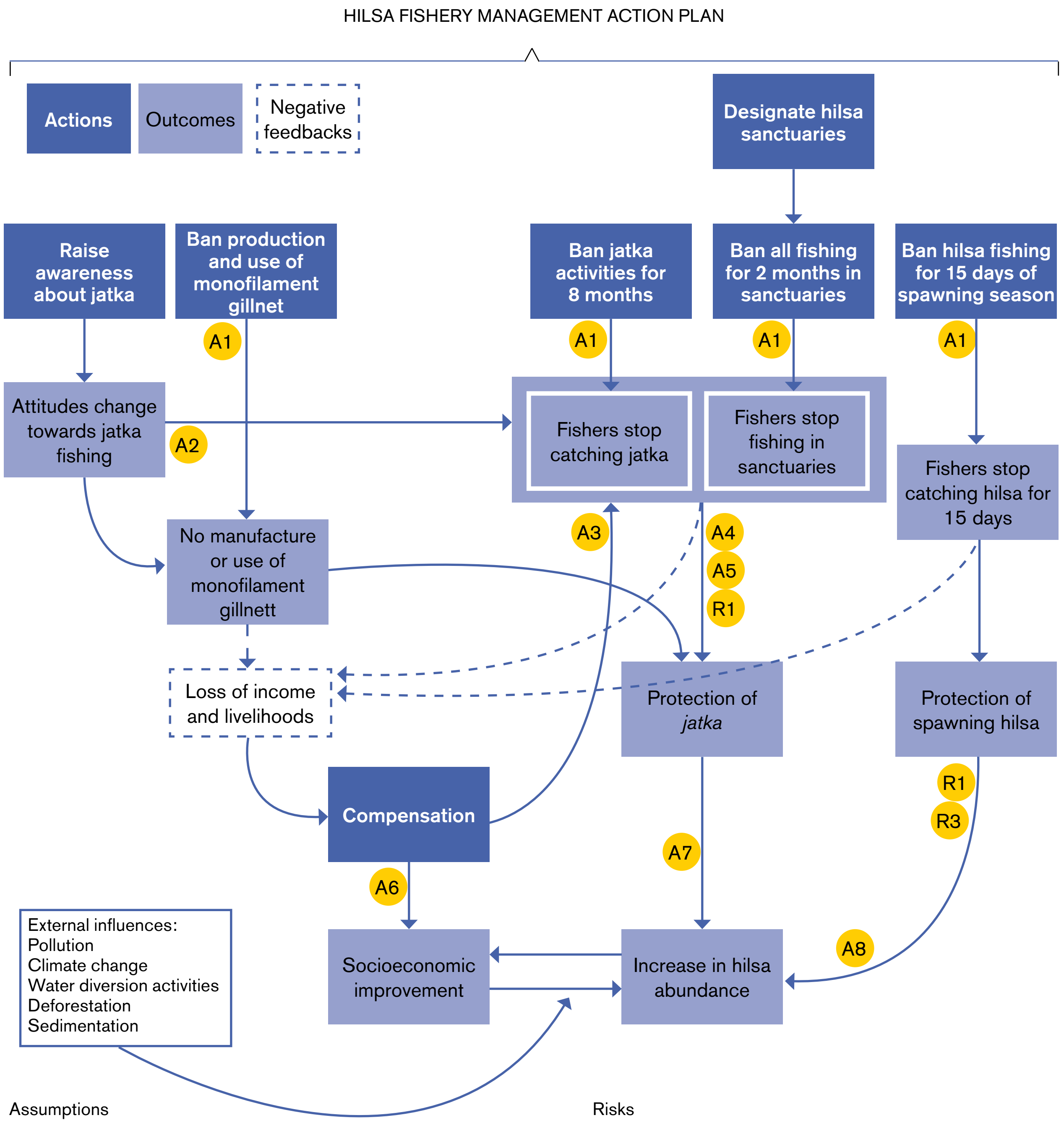
3.2 Operationalising the causal mechanism

The mechanism was prepared for testing by identifying expectations for causal links between its component parts, for which empirical evidence would be possible to collect. We also looked for plausible alternative explanations that might explain each component, and identified expectations for these. Due to the complexity of hilsa fishery management and the time and resource limitations, we did not collect evidence for each and every expectation, but only for those that could be evaluated using fishers' knowledge and perceptions and with remote sensing data (Table 1).

3.3 Collection of evidence

Empirical evidence was collected through a survey of fishing households in July and August 2016, which provided local knowledge and perceptions of hilsa fishery management, and a remote sensing study, which

Figure 1: Hypothesised causal mechanism for Bangladesh hilsa management



Assumptions

- **A1** Threat of sanctions leads to behavioural change
- **A2** Awareness of fishery states and regulations enhances compliance
- **A3** Compensation incentivises compliance
- **A4** Sanctuaries hold nursery grounds
- A5 Bans coincide with peak period of *jatka* presence
- **A6** Compensation is allocated to the right people
- A7 Protecting *jatka* leads to increase in hilsa abundance
- A8 Protecting spawners leads to increase in hilsa abundance

Risks

- R1 Focus on inland fisheries management is not sufficient
- R2 Single species management is not sustainable
- **R3** 15 day period does no longer fit the spawning season
- R4 15 day ban is no longer enforced in the right area

Source: Based on Bladon (2016). Assumptions and risks in bold indicate the components assessed in this study.

Table 1: Expectations for main intervention hypothesised causal mechanism and plausible alternatives

HYPOTHESIS A: THE MANAGEMENT ACTIONS HAVE CONTRIBUTED TO AN INCREASE IN HILSA ABUNDANCE AND SOCIOECONOMIC IMPROVEMENT	HYPOTHESIS B: THE COMPENSATION SCHEME HAS NOT CONTRIBUTED TO AN INCREASE IN HILSA ABUNDANCE	HYPOTHESIS C: HILSA ABUNDANCE HAS BEEN LARGELY DETERMINED BY ENVIRONMENTAL CONDITIONS
Expectations	Expectations	Expectations
• Most fishers comply with gear regulations • Most fishers catch fewer jatka and gravid hilsa than before management was put in place • Most fishers comply with sanctuary fishing bans • Most fishers acknowledge positive ecological trends over the last 5–10 years • Most fishers acknowledge positive social trends over the last 5–10 years • Most fishers acknowledge direct ecological/socioeconomic impacts of regulations • Fishers in sanctuary areas acknowledge more positive trends and impacts than those outside • Fishers in sanctuary areas have a higher awareness of regulations • Most fishers acknowledge that the 15-day ban is sufficient to protect spawning hilsa • Most fishers acknowledge benefit of compensation for communities • Compensation was provided to enough fishers • Compensation is received by the 'right' households • Compensation enhances compliance • Awareness of fishery regulations enhances compliance • Sanctuary fishing bans coincide with period of inland environmental conditions most suitable for hilsa	• Compensation was not provided to enough fishers • Compensation has not reached the 'right' households • Most fishers do not acknowledge benefit of compensation for communities • Fishers do not acknowledge positive social trends • Compensation does not enhance compliance	• Fishers in sanctuary areas do not acknowledge more positive trends and impacts than fishers outside • Most fishers acknowledge that the 15-day hilsa fishing ban needs to be increased • Habitat suitability is low in some sanctuary areas
Expectations not investigated for this study:		
• Hilsa can be managed sustainably as a single species • Focus on inland fisheries is sufficient • Protecting jatka maximises production • Protecting spawners maximises production • Spawner protection is enforced in right area		• Environmental conditions have become more or less suitable for hilsa in some areas and seasons

Note: Some causal pathways could not be investigated due to lack of data, but have been explored by Bladon (2016).

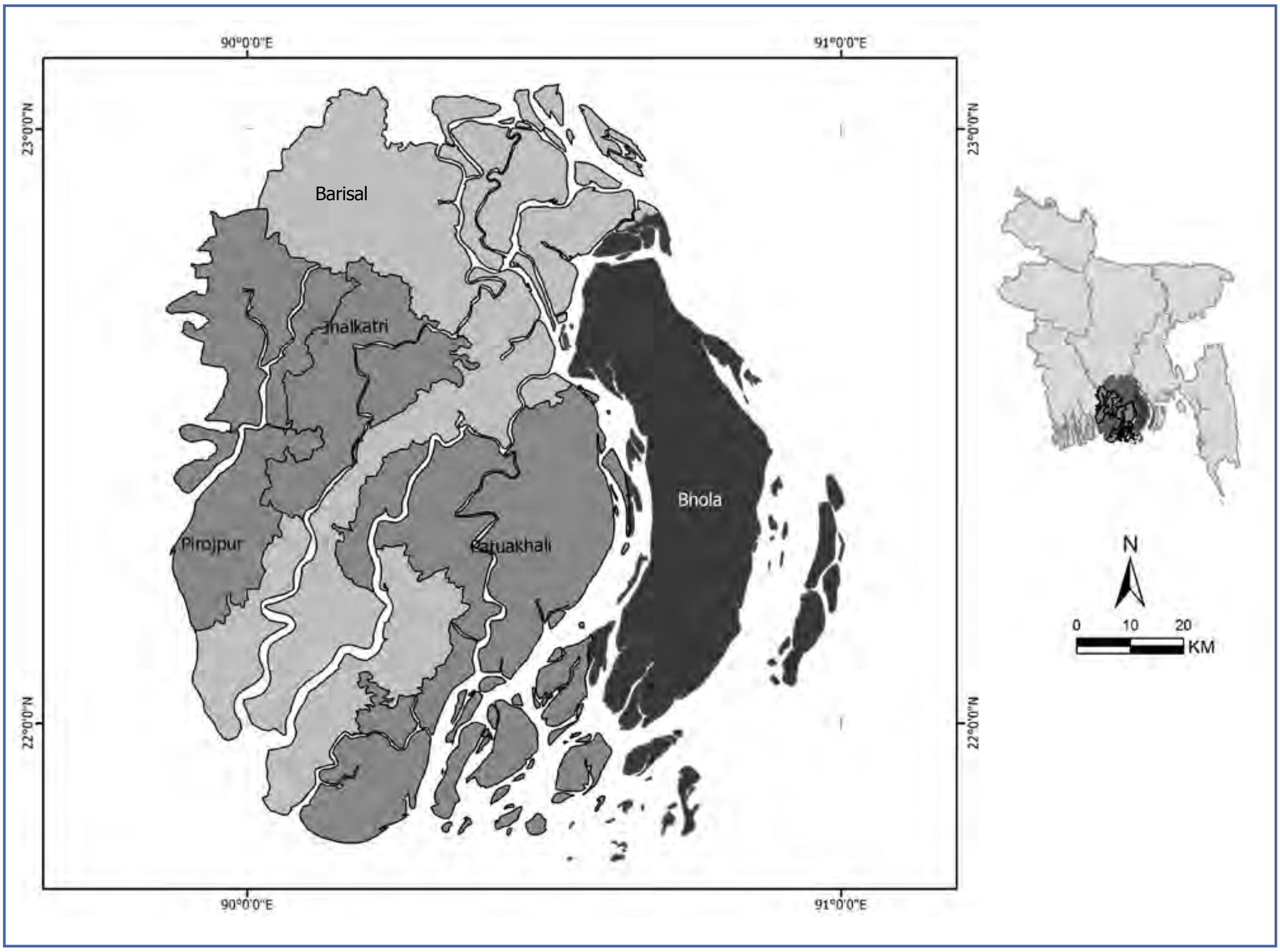
provided specific data on compliance with the seasonal fishing bans and on spatial and temporal variation in rivers' habitat suitability for hilsa.

3.3.1 Household survey

We surveyed 601 fishing households in 21 villages across five districts (Barisal, Bhola, Patuakhali, Pirojpur and Jhalokathi) within the hilsa fishery management area (Fig. 1; further details available on request). Households were selected through stratified systematic sampling (described below) and respondents were questioned in person through a semi-structured interview (available on request).

Villages within sanctuary areas (Bhola district and the Kalapara upazila of Patuakhali district) provided 179 surveyed households and the rest (417) came from outside sanctuary areas. Within each of the districts, two sub-districts (upazila) with high concentrations of fishers were identified through consultations with local fisheries officers. We employed the stratified systematic sampling method. We aimed to interview a large enough number of fishers in each district (120–121), so that any problems associated with small and non-random sampling were not likely to influence results. For each selected upazila, four to five villages with a high concentration of hilsa fishers, preferably located near the river, were then selected, based on the official list of fishers. Each district sample of 120 or 121 was then allocated proportionately to the selected villages, according to the total number of fishers in the village. All households in the selected village were serially numbered and every n^{th} household was selected for interview, where *n* is the total number of fishers in the village divided by the total district sample size. Within each household, enumerators interviewed the fisher, if available. If not, they chose a male household member over a female member, since men tend to be more involved in fishing activities. If the enumerators could not find anyone to speak to in the selected household, they selected the preceding or following fisher on the list.

Figure 2: Map showing five study site districts within the Lower Meghna region of Bangladesh



3.3.2 Statistical analysis

Univariate statistical tests were conducted. Where possible[1], linear mixed effects models (LMMs) and generalised linear mixed effects models (GLMMs) were used to test potential associations between knowledge/perceptions and contextual variables. A GLMM allows data to exhibit correlation and non-constant variance, and so accommodates a range of types of response and explanatory variables, as well as random effects (Zuur et al. 2009). Eight binary response variables were analysed with GLMMs (see Table 2). The GLMMs were fitted as random intercept models with district and village as grouping factors in the random effects and a logit link function. The best random effects structures were selected using likelihood ratio tests and validation plots (Bolker et al. 2009), and models were run with Laplace approximation using the package lme4 (Bates et al. 2015) in R version 3.2.3 (R Development Core Team 2016). Awareness of regulations, which was treated as a continuous variable, was modelling using LMMs in the same package (Table 2).

Table 2. Summary of response variables included in each statistical model with fixed effects and their expected influence

RESPONSE VARIABLE	FIXED EFFECTS	EXPECTED INFLUENCE
Model 1: Probability of reporting an improvement in livelihood status over the past 5–10 years (1 = improvement; 0 = decline or stable)	Sanctuary	+
	Compensation recipient	+
	AIGA recipient	+
	Debt	–
	Fishing experience	–/+
	Awareness score	+
	Schooling	+/–
	Female	+/–
	Income dependence	+/–
	Average catch	+/–
Model 2: Probability of reporting an increase in income from fishing over the past 5–10 years (1 = increase; 0 = decrease or stable)	Sanctuary	+
	Compensation recipient	+
	AIGA recipient	+
	Debt	–
	Fishing experience	–/+
	Awareness score	+
	Schooling	+/–
	Female	+/–
	Income dependence	+/–
	Average catch	+/–
Model 3: Probability of reporting fair distribution of compensation (1 = fair; 0 = unfair)	Sanctuary	+
	Compensation recipient	+
	Awareness score	+/–
	Debt	–
	Fishing experience	–/+
	Current net user	+/–
	Schooling	+/–
	Female	+/–
	Income dependence	–
Model 4: Probability of reporting a positive impact of fishing bans on income from fishing (1 = positive impact; 0 = no impact or do not know)	Sanctuary	+
	Compensation or AIGA recipient	+
	Current net user	–
	Fishing experience	–/+
	Awareness score	+
	Schooling	–/+
	Female	–/+
	Income dependence	–/+
	Debt	–
	Average catch	–/+

[1] Limited variation in some variables caused convergence issues that prevented the application of GLMMs.

RESPONSE VARIABLE	FIXED EFFECTS	EXPECTED INFLUENCE
Model 5: Probability of reporting an increase in hilsa abundance over the past 5–10 years (1 = increase; 0 = decrease or stable)	Sanctuary Compensation or AIGA recipient Fishing experience Awareness score Schooling Female Income dependence Current net user Order of questions Boat owner Average catch	+ + +/− + −/+ −/+ −/+ −/+ −/+ −/+ −/+
Model 6: Probability of reporting an increase in hilsa size over the past 5–10 years (1 = increase; 0 = decrease or stable)	Sanctuary Compensation or AIGA recipient Fishing experience Awareness score Schooling Female Income dependence Current net user Boat owner	+ + +/− + −/+ −/+ −/+ −/+ −/+ −/+
Model 7: Probability of reporting a change in fishing gear used over the past 5–10 years (1 = change; 0 = no change)	Sanctuary Compensation or AIGA recipient Current net user Awareness score Schooling Female Fishing experience Target jatka during ban Average catch	+ + − + −/+ −/+ −/+ − −/+
Model 8: Probability of reporting a positive impact of fishing bans on catch (1 = positive impact; 0 = no impact or do not know)[2]	Sanctuary Compensation or AIGA recipient Fishing experience Awareness score Average catch	+ + −/+ −/+ −/+
Model 9: Awareness of regulations (continuous)	Sanctuary Compensation or AIGA recipient Current net user Schooling Female Fishing experience Target jatka during ban Average catch Income dependence	+ + −/+ −/+ −/+ + − −/+ +

[2] This model was also run with schooling, female and income dependence instead of awareness score and average catch to check that including these variables did not significantly change final results.

Table 3. Description of explanatory variables used in statistical modelling.

VARIABLES	TYPE	DESCRIPTION
Fixed effects		
Sanctuary	Binary	Household lives within or adjacent to a sanctuary (1) or outside a sanctuary (0)
Current net user	Binary	Respondent uses a monofilament gill net (1) or not (0)
Compensation/AIGA recipient	Binary	Household receives rice compensation/AIGA (1) or not (0)
AIGA recipient	Binary	Household receives AIGA (1) or not (0)
Fishing experience	Continuous	Years of experience fishing
Boat owner	Binary	Respondent owns a boat (1) or not (0)
Awareness score	Continuous	Total score for answering true/false questions about fishing regulations correctly[3]
Income dependence	Continuous	Proportion of total annual income coming from fishing
Jatka fishing during ban	Binary	Respondent targets jatka during jatka ban (1) or not (0)
Average catch	Continuous	Average catch per fishing trip in peak fishing season (kg)[4]
Order[5]	Binary	Options for question about hilsa abundance were offered to half the respondents in one order (1) and to half in another order (0)
Debt	Binary	Respondent currently owes money (1) or not (0)
Female	Binary	Respondent is female (1) or male (0)
Schooling	Continuous	Years of education
Random effects		
District	Categorical	5 level factor
Village	Categorical	21 level factor

A summary and description of fixed effects can be found in Table 3. Continuous fixed effects were standardised by two standard deviations for direct comparison of coefficients following model averaging (Gelman 2008; Grueber et al. 2011). Some fixed effects were omitted from models where there was no rationale for including them, or where convergence issues were caused by small sample sizes in some categories (Table 2). Sanctuary area was included in all of the models because this is where hilsa management is focused, and thus the treatment site. Compensation and or AIGA were also included as fixed effects due to their expected livelihood impacts and potential influence on fisher perceptions. Years of fishing experience, which was significantly correlated with age, was expected to influence perceptions of trends due to shifting baselines (Pauly 1995). Gender and years of schooling were included as potentially confounding variables. Current net[6] user was included as a proxy for catching jatka, since it also includes not only respondents who said they target jatka but also those who did not, but probably catch it anyway by using current nets. Boat ownership was used as a proxy for investment in fishing, proportion of household income coming from fishing was used as a proxy for income dependence on fishing, and average catch volume was included as a proxy for fishing effort. Awareness of regulations was expected to influence perceptions about regulations and hilsa trends. Targeting jatka during the jatka ban was interpreted as evidence of non-compliance, and was expected to correlate negatively with changing fishing gear used over the past five to ten years and with

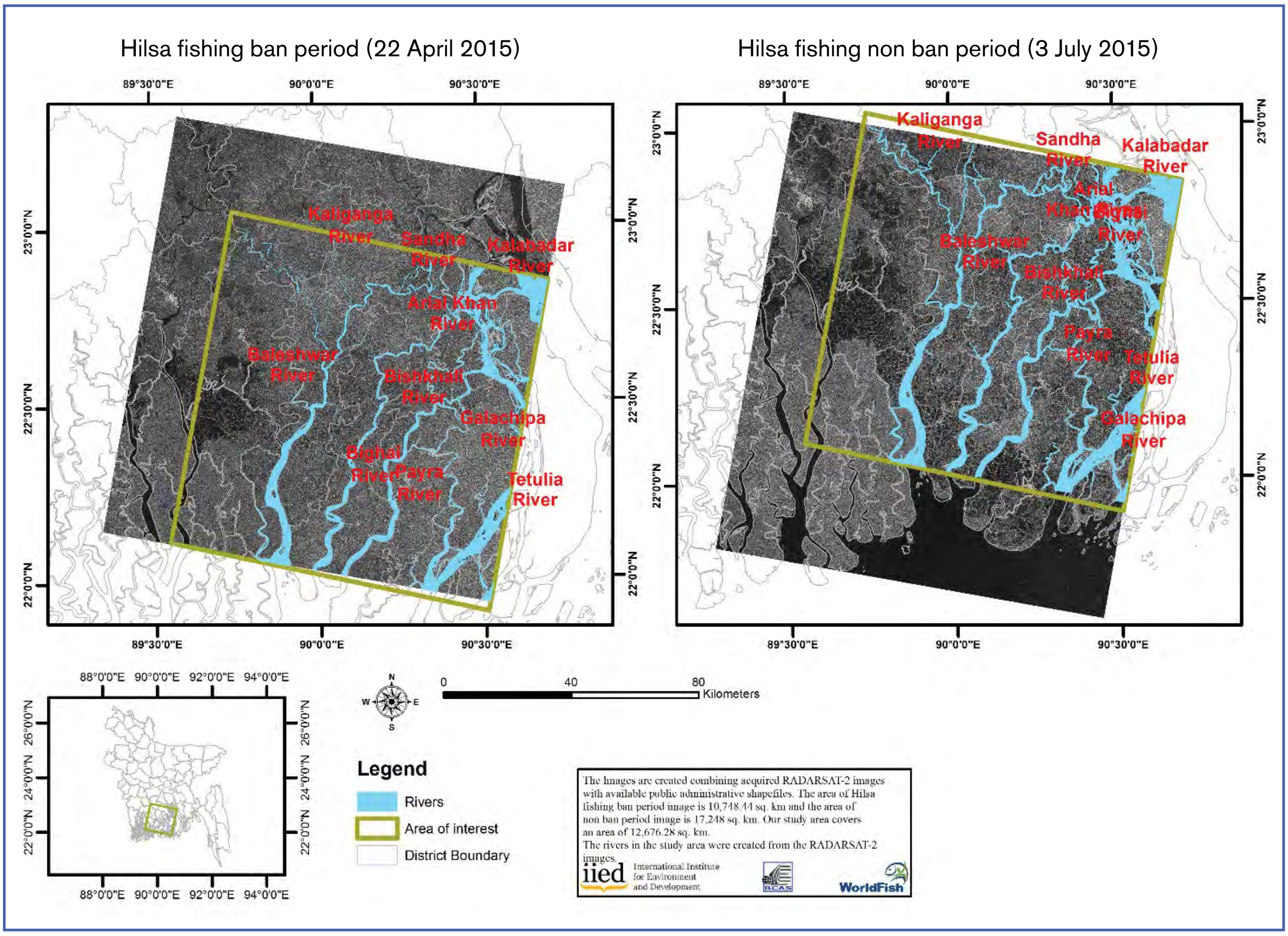
[3] Scored 1 for every correct answer and –1 for every incorrect answer.

[4] Significant positive correlation with average catch in lean season.

[5] (1) Increased, decreased or stayed stable; (0) Increased, stayed stable or decreased. This variable was only used in Model 5.

[6] Illegal monofilament gillnet often used to target jatka.

Figure 3: Study area chosen from Radarsat-2 images collected during hilsa fishing ban and non-ban periods



awareness. Debt was expected to influence perceptions about livelihood status and income.

Collinearity among fixed effects was explored using pairwise plots, chi-squared tests, and phi coefficients. None of the variables were significantly correlated ($p > 0.05$). Some were only weakly correlated ($-0.5 > \phi < 0.5$, $p < 0.05$). No models were clearly superior (weights of top models were < 0.9), so an information-theoretic approach to model selection was taken (Burnham and Anderson 2002; Bolker et al. 2009). All possible combinations of explanatory variables were fitted using Maximum Likelihood (ML) estimation procedures with the R package MuMIn (Barton 2016), and top candidate models with corrected Akaike Information Criterion (AICc) (< 4). These models were re-run using Restricted Maximum Likelihood (REML) estimation procedures for accurate parameter estimates, which were then averaged across these models, allowing Relative Variable Importance (RVI) to be determined. Coefficients were presented for the full average, rather than the subset or conditional average, which has a tendency of biasing the values away from zero (Barton 2016). Models were checked for residual normality, heteroscedasticity and correlations between fixed effects and the residuals. To analyse spatial effects on the response variables, we estimated Best Linear Unbiased Predictors (BLUPs) from the global models, which measured the residual effect associated with each random effect (district and village within district). BLUPs, or conditional modes, can be conceptualised as the equivalent of the linear coefficients found for the fixed effects (noting that they are not, strictly speaking, parameters).

Of the respondents, 85 per cent were household heads and 8 per cent were women, 0.5 per cent of whom were household heads. Five respondents were excluded from analysis because they said they do not catch hilsa or jatka.

3.3.3 Remote sensing

Radar satellite images were collected and analysed to compare the frequency, density (per 10 km^2) and clustering of small (4–7m x 1–2m) and large (10–20m x 4–10m) fishing boats during and outside the ban period. Under effective sanctuary management, we would expect to see fewer fishing boats in the sanctuary area during the ban when compared with a control area (outside sanctuary). Radarsat–2 Single Look Complex images (5m resolution) were collected from an area covering 16,434 km^2 at one time point during a night within the fishing ban period[7] (April 22nd 2015, 11:56:06 pm, GMT+6), and from an area covering 17,248 km^2 at one time point during a night outside the ban period (July 3rd 2015; 11:56:08 pm, GMT+6). Radar images were collected at night because this is often when people fish for hilsa during the ban period. To compare the two time periods a common overlap area of 12,676 km^2 was selected (Fig. 3). This area holds ten major rivers, one of which includes a sanctuary area (45 per cent of the Tentulia River). The rest are controls. Boat clusters were estimated through multi-distance spatial cluster analysis and interpreted as indicators of fish availability. More detail on Radar image pre-processing and post-processing are available on request.

Landsat-8 imagery was used to explore how the ecological suitability of hilsa habitat varied in space and time (a more detailed methodology is available on request). Landsat images were accessed from the U.S. Geological Survey's Landsat archives (http://earthexplorer.usgs.gov) and retrieved at four time points without cloud cover (November 6, 2013; January 25, 2014; March 14, 2014; and May 17, 2014). These time points corresponded with times when various ecological parameters for hilsa habitat suitability were monitored in a previous study within the same area (Hasan et al. 2015). We analysed the relationship between values of these ecological parameters and 21 Landsat-8 band values, band ratios and indices, at corresponding dates, using linear regression. Both the normalized difference vegetation index and normalized difference water index were used. Ten parameters with consistently high R^2 values (0.32–0.99; chlorophyll-a, dissolved oxygen, electrical conductivity, salinity, total dissolved solid (TDS), total suspended solid (TSS), water current velocity, water transparency, water temperature and pH) were then selected for mapping.

Cluster analysis suggested that the near and short-wave infrared Landsat-8 bands 5, 6, and 7 and the coastal/aerosol band 1, and their ratios, provided a good way to assess how ecological parameters that reflect habitat suitability vary in time and space.

3.4 Assessing the inferential weight of evidence

The principles of process tracing were used to assess the strength of each piece of evidence, taking into account contextual knowledge, general theory, the reliability of each source and their potential biases and limitations (Table 4). Due to the complexity of the fisheries management intervention and the types of evidence collected, strong hoop and smoking gun tests could not be applied (only the radar data provided evidence unique enough to be subjected to smoking-gun-type logic). Nevertheless, a hypothesis that passes multiple straw-in-the-wind tests can still generate high confidence in its validity (Mahoney 2012; Punton and Welle 2015b). Collectively, applying weaker tests still allowed a level of confidence in the validity of the hypothesised mechanism to be inferred. Where possible, evidence from independent sources was triangulated.

[7] March 1 to April 30 in 2015.

4

Assessment of the evidence

The household survey and remote sensing data both supported and raised doubts about the main intervention hypothesis (HA), indicating that some components of the hypothesised causal mechanism probably have been achieved, while others have not (Table 4).

Table 4. Expectations for Hypothesis A (HA) with primary evidence, inference and summary, including any implications for alternative hypotheses (HB and HC)

EXPECTATION	EVIDENCE	INFERENCE	SUMMARY
Most fishers comply with gear regulations	• 66% of respondents reported a change in gear types	• Management may have contributed to a change in gear types, but the change could just as well be a response to environmental conditions or technology available.	• Evidence supports the plausibility of HA, but gives no indication of whether the gear changes are desired or not and so it does not weaken alternative hypotheses.
	• 80% reported that mesh size has not increased	• Management may have contributed to an increase in mesh sizes used by a small proportion of fishers.	• Evidence raises doubts about HA, but does not rule it out.
	• 60% reported personally changing the type of gear used and the change was positively correlated with use of ‘current nets	• Management may have contributed to some changes, but a substantial proportion of these fishers appear to have started using a current net.	• Evidence raises doubts about HA, but does not rule it out.
	• 38% of respondents reported using a current net	• Management may have contributed to a reduction in current net use	• Evidence supports the plausibility of HA, but it may be subject to strategic bias.

EXPECTATION	EVIDENCE	INFERENCE	SUMMARY
Most fishers comply with gear regulations (cont.)	• 17% of respondents who vary their gear use throughout the year said they do it because of the regulations and another 24% to protect jatka	• Management may have affected gear use but it is driven more by which species are being targeted.	• Evidence raises doubts about HA, but does not rule it out.
Most fishers catch fewer jatka and gravid hilsa	• 36% of respondents reported targeting jatka during the jatka ban period	• Management may have contributed to the protection of jatka	• Evidence supports the plausibility of HA, but it may be subject to strategic bias.
	• Less than 20% reported the majority of their catch to be jatka in both seasons	• Management may have contributed to the protection of jatka	• Evidence supports the plausibility of HA, but it may be subject to strategic bias.
	• 57% said the proportion of jatka/fry in their catch has declined and 41% said the proportion of gravid hilsa in their catch has declined	• Management may have contributed to a reduction in jatka fishing, but this evidence could be a reflection of the jatka abundance, rather than of fishing behaviour. Actions could also have contributed to an increase in spawning, or fishers could still be targeting more gravid hilsa.	• Evidence supports the plausibility of HA, but it is ambiguous and may be subject to strategic bias.
Most fishers comply with the sanctuary fishing bans	• 23% reported personally changing their fishing location, largely due to challenging fishing conditions	• Fishers have rarely changed their fishing location, and management actions are unlikely to have motivated those who have.	• Evidence raises doubts about HA, but this evidence is not important because fishers in the study area tend to fish near their villages.
	• During the ban period, the density of small boats in the sanctuary area was half that found in the control area. The difference in small boat densities between the ban and non-ban periods was also much greater for the sanctuary area than control area	• Management may have contributed to compliance with the sanctuary fishing bans, but there is still a lot of illegal fishing in the sanctuaries.	• Evidence strengthens HA and is unlikely to have been observed by chance. However, there is some uncertainty in the detection of small boats using radar images.

EXPECTATION	EVIDENCE	INFERENCE	SUMMARY
Most fishers acknowledge positive ecological trends over the last 5–10 years	• 12% said their hilsa catch has increased and 46% said hilsa abundance has increased. Compensation recipients and respondents with high fishing dependence were most likely to report an increase in abundance, and there was a strong spatial effect.	• Management may have contributed to an increase in hilsa abundance in some areas, but the overall effect appears to be low. Trends could have been dampened by ongoing habitat damage.	• Evidence raises doubts about HA, but does not rule it out, and strengthens HC. It may also be subject to strategic bias.
	• 23% said there has been an increase in hilsa size. Current net users were less likely to report an increase, whereas high dependence on fishing, high awareness, boat ownership and gender correlated positively with reporting an increase. There was also a strong spatial effect.	• Management may have contributed to an increase in hilsa size in some areas. Trends could have been dampened by ongoing habitat damage.	• Evidence raises doubts about HA, but does not rule it out, and strengthens HC. It may also be subject to strategic bias.
Most of fishers acknowledge positive social trends over the last 5–10 years	• 40% said their livelihood status has improved. Perceiving an improvement was correlated negatively with debt and positively with fishing experience and awareness. There was also a strong spatial effect.	• Management may have contributed to improvements in livelihood status in some areas, through increased hilsa abundance or compensation, but debt could be limiting this contribution.	• Evidence raises doubts about HA, but does not rule it out, and strengthens HB. It may also be subject to strategic bias.
	• 40% said their household income from fishing has increased. Perceiving an increase was positively correlated with fishing dependence, and to a lesser extent average catch and awareness, and negatively correlated with debt and proximity to a sanctuary. There was also a strong spatial effect.	• Management may have contributed to an increase in income from fishing in some areas, but debt could be limiting this contribution.	• Evidence raises doubts about HA, but does not rule it out. It may also be subject to strategic bias.

EXPECTATION	EVIDENCE	INFERENCE	SUMMARY
Most fishers acknowledge direct ecological/ socioeconomic impacts of regulations	• 91% said regulations are having an impact on hilsa, and 69% said this impact has been positive. Reporting a positive impact was negatively correlated with catch and proximity to a sanctuary	• Management may have contributed to an increase in the abundance of hilsa, but sanctuary regulation enforcement and/or zoning may require improvement	• Evidence supports HA but may be subject to strategic bias and does not rule out HC.
	• 55% report that fishing bans increase income from fishing. Women, and those living near a sanctuary, reported less increase. Those with greater awareness, and fishers more dependent of the fishery reported more of an increase in incomes.	• Management may have contributed to an increase in the abundance of hilsa, but sanctuary regulation enforcement and/or zoning may require improvement.	• Evidence supports HA but may be subject to strategic bias and does not rule out HC.
Fishers in sanctuary areas acknowledge more positive trends and impacts than those outside	• Sanctuary respondents were significantly less likely to report an increase in hilsa abundance, improvement in livelihood status, increase in income from fishing, positive impact of fishing bans on income and catch.	• Sanctuary enforcement and/or zoning may require improvement. Community support may be low in some sanctuaries due to insufficient compensation/ awareness-building.	• Evidence raises doubts about HA, but does not rule it out, and strengthens HC. It may also be subject to strategic bias.
Fishers in sanctuary areas have a higher awareness of regulations	• The correlation between sanctuary and awareness was negative and received weak support for inclusion in top models .	• Awareness raising activities are not focused where they should be.	• Evidence raises doubts about HA, but does not rule it out.
Most fishers acknowledge that the 15-day ban is sufficient to protect spawning hilsa	• 60% of respondents said the ban is sufficient to protect spawning hilsa, but 31% said the ban needs to be increased.	• The 15-day hilsa fishing ban is appropriate for the protection of spawning hilsa, but could benefit from extension.	• Evidence supports HA but does not rule out HC.
Most fishers acknowledge benefit of compensation for communities	• 95% of fishers reported that compensation has benefitted communities. • No significant relationship between AIGA and alternative livelihoods.	• The compensation has contributed to socioeconomic improvement and therefore could have motivated compliance. • AIGA is not supporting alternative livelihoods.	• Evidence supports HA but does not rule out HB, and strategic bias may have influenced responses.
Compensation was provided to enough fishers	• 45–65% of affected fishing households are estimated to receive rice compensation, and a much smaller proportion receive AIGA.	• The rice compensation has contributed to widespread socioeconomic improvement and therefore could have motivated widespread compliance, but the AIGA has made a limited contribution.	• Evidence supports HA but does not rule out HB.

EXPECTATION	EVIDENCE	INFERENCE	SUMMARY
Compensation is received by the 'right' households	• Distribution of compensation is perceived to be fair by 69% of respondents, but perceived fairness is strongly positively correlated with receiving compensation. 33% of respondents perceived some form of elite capture.	• Perceptions of elite capture may have undermined potential for the compensation to incentivise compliance.	• Evidence raises doubts about HA and strengthens HB, but answers could be influenced by strategic bias and so this may not be a good indicator of community acceptance and thus impact on compliance.
Compensation enhances compliance	• Compensation was not significantly associated with use or non-use of current nets, catching jatka during the ban, or varying gear use due to regulations/to protect jatka	• Compensation does not incentivise compliance with regulations.	• Evidence raises doubts about HA and strengthens HB.
Awareness of fishery regulations enhances compliance	• Awareness correlates positively with change in gear use. • Illegal activities such as using current nets and catching jatka during the jatka ban correlated negatively with awareness, but were of limited importance in models. • 17% of respondents who vary their gear use throughout the year said they do it because of the regulations and another 24% to protect jatka/hilsa	• Awareness raising activities may have contributed to compliance with regulations.	• Evidence supports HA but it does not rule out alternative hypotheses.
Inland environmental conditions are most suitable for hilsa during the sanctuary fishing bans	• Landsat data show March has high suitability, particularly in terms of phytoplankton availability and salinity.	• Sanctuary fishing bans coincide with upstream hilsa migration, but there is no data for April or for marine habitat suitability.	• Evidence supports HA but it does not rule out alternative hypotheses.
Inland environmental conditions are most suitable during sanctuary fishing bans in the sanctuary areas	• Landsat data show the nutrition front to reach all rivers inland.	• Fishing bans for the protection of jatka should be implemented in all rivers.	• Evidence raises doubts about HA and strengthens HC.

4.1 Changes in fishing behaviour

4.1.1 Gear use

There was limited evidence to support the expectation that fishers acknowledge compliance with fishing regulations. Two thirds of respondents said there has been a change in gear types used over the last five to ten years. However, 47 per cent said that mesh size has decreased, 32 per cent said it has stayed the same, and only 20 per cent said that mesh size has increased. The majority perception that mesh sizes have not increased indicates that any changes are unlikely to be the ones managers intended.

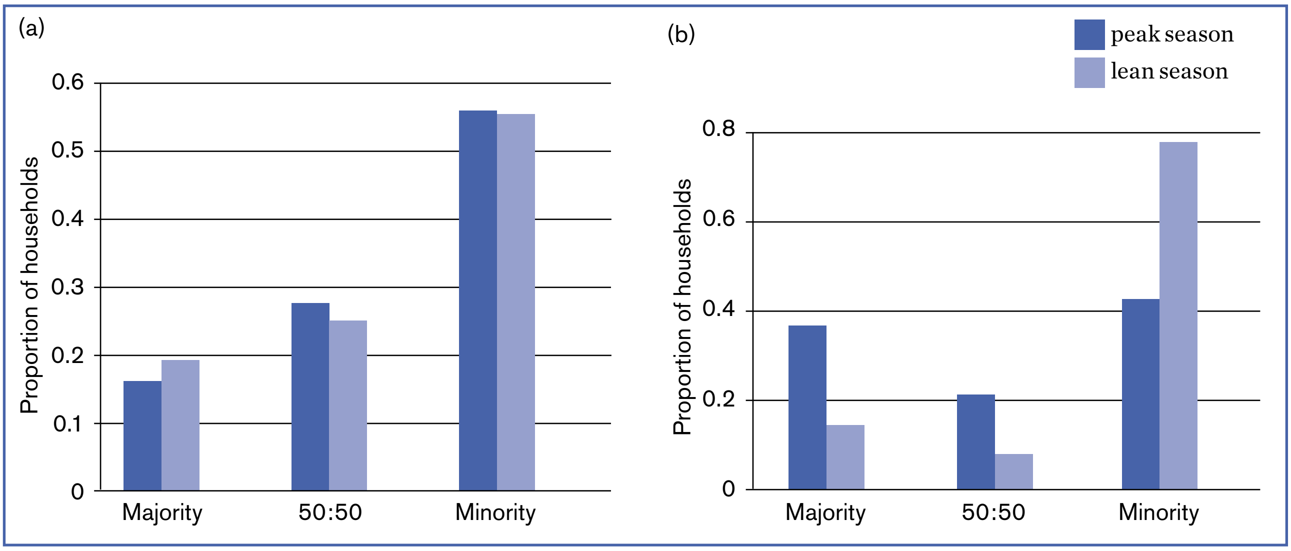
Thirty eight per cent of respondents reported using a current net. Over half (54 per cent) said they have used the same fishing gear over the past five to ten years. The most common reasons given for this were that catch is good, fish size has not changed, the government permits use of the current net, there is no need for change, and a lack of capital for change. The most common reasons given for changing fishing gears over time were that fish have got smaller, mesh size has got smaller, they catch more hilsa, they use bigger mesh net, or they have switched from using a current net to a chandi net[8]. Using a current net was an important positive correlate of reporting a change in gear use (Table 5: model 7, RVI = 1). Three quarters (75 per cent) of respondents said they use different gear at different times of year. Of this group, 54 per cent said they vary their use to target different species by season, 27 per cent said they are taking a conscious decision to protect jatka/hilsa and 19 per cent said changing fishing gear is due to regulations.

These results indicate that less than half of fishers change their use of fishing gear throughout the year in order to comply with fishing regulations. Although some of those who have changed their gear over the years may have done so because of regulations, those who have not changed their gear have limited ability to do so or do not feel pressured by regulations. The importance of current net in the models suggests that many of these fishers could have actually changed their gear use to better target jatka, despite management regulations.

4.1.2 Catch composition

Fifty seven per cent of respondents said that the proportion of jatka or fry in their catch has declined over the past 10 years, nine per cent said it has increased and the remainder said it has stayed the same or they do not know. Forty one per cent said that the proportion of gravid hilsa in their catch has declined over the past 10 years, 13 per cent said it has increased, and the remainder said it has stayed the same or they do not know. This could indicate a reduction in jatka fishing and fishing during the spawning season, but it could also be a reflection of jatka/spawner abundance and so this evidence is weak for Hypothesis A. Less than 20 per cent of respondents reported jatka being their main catch in either fishing season and the proportions were similar in both seasons (Fig. 4). Most respondents reported gravid hilsa made up a minor part of their catch in the lean season, but in peak season there was a significant shift towards catching more gravid hilsa ($\chi^2 = 152$, df = 2, $p < 0.001$; Fig. 4). These reports can be interpreted as evidence of some compliance, although they do not support the expectation that the majority of fishers comply with regulations.

Figure 4: Bar chart showing the proportion of households reporting catches of jatka (Fig.4 a) and gravid hilsa (Fig. 4b) as making up the major part, a minor part, or around half their catch over two seasons



[8] A type of set gillnet.

Table 5: Results of GLMMs (Models 1–8) and LMMs (Model 9)

	MODEL 1: IMPROVEMENT IN LIVELIHOOD STATUS		MODEL 2: INCREASE IN INCOME FROM FISHING		MODEL 3: FAIR COMPENSATION DISTRIBUTION		MODEL 4: POSITIVE IMPACT OF FISHING BANS ON INCOME		MODEL 5: INCREASE IN HILSA ABUNDANCE		MODEL 6: INCREASE IN HILSA SIZE		MODEL 7: CHANGE IN FISHING GEAR USED		MODEL 8: POSITIVE IMPACT OF FISHING BANS ON CATCH		MODEL 9: AWARENESS OF REGULATIONS	
Fixed effects	*Effect (SE)*	*RVI*	*Effect (SE)*	*RVI*	*Effect (SE)*	*RVI*	*Effect (SE)*	*RVI*	*Effect (SE)*	*RVI*	*Effect (SE)*	*RVI*	*Effect (SE)*	*RVI*	*Effect (SE)*	*RVI*	*Effect (SE)*	*RVI*
Intercept	−0.45 (0.80)		−0.63 (0.88)		1.35 (0.51)		1.12 (1.98)		−0.38 (0.94)		−2.00 (0.84)		−1.98 (0.83)		12.06 (4.33)		1.78 (0.57)	
Debt	−0.78 (0.29)	1	−0.51 (0.34)	0.86	–	0.14	–	0.13										
Fishing experience	0.51 (0.22)	0.98	+	0.31	–	0.16			+	0.17	+	0.39	+	0.41	+	0.21	+	0.49
Sanctuary	−1.76 (0.96)	0.88	−1.58 (0.91)	0.89	–	0.34	−2.61 (0.70)	1.00	−2.29 (0.93)	0.98	–	0.18	–	0.23	−1.46 (1.27)	0.68	–	0.09
Awareness score	0.18 (0.24)	0.52	0.37 (0.28)	0.80	+	0.15	0.63 (0.33)	0.95	+	0.23	0.36 (0.32)	0.72	0.33 (0.29)	0.64	–	0.29		
Schooling	–	0.49	–	0.16	–	0.36	–	0.13	+	0.22	–	0.16	–	0.19			+	0.42
Average catch	+	0.43	0.28 (0.28)	0.67			–	0.33	–	0.47	+	0.34	+	0.43	−2.16 (1.14)	1.00	2.00 (0.05)	1.00
Compensation recipient	–	0.40	–	0.13	2.30 (0.32)	1												
Compensation or AIGA recipient							+	0.18	0.36 (0.35)	0.69	+	0.11	+	0.15	+	0.36	+	0.16
Female	–	0.31	+	0.17	–	0.22	−0.89 (0.45)	0.96	+	0.22	0.67 (0.47)	0.84	0.71 (0.46)	0.86			−0.71 (0.39)	0.74
AIGA recipient	–	0.19	+	0.16														
Income dependence	+	0.19	0.60 (0.24)	1	+	0.30	0.29 (0.33)	0.61	0.17 (0.24)	0.50	0.28 (0.28)	0.66					+	0.16
Current net user					+	0.21	+	0.26	–	0.15	−1.24 (0.32)	1.00	−1.18 (0.34)	1.00			–	0.28
Boat owner							+	0.17	+	0.16	0.46 (0.42)	0.72						
Order of question options									+	0.14								
Target jatka during the ban													–	0.18			–	0.17
# of models in candidate set	64		55		59		45		212		105		52		12		59	
# of households	592		592		592		590		593		594		580		592		590	
Random effects																		
Village	0.18 [0.43]		0.17 [0.42]		1.65 [1.29]		0.16 [0.40]		0.42 [0.65]		1.50 [1.22]		1.41 [1.19]		0.68 [0.83]		1.52 [1.23]	
District	3.51 [1.87]		4.09 [2.02]		0.19 [0.44]		18.46 [4.30]		4.31 [2.08]		4.00 [2.00]		4.11 [2.03]		173.99 [13.19]		0.78 [0.89]	

Table shows the full model-averaged coefficient estimates (standard error) and relative variable importance (RVI) from the candidate set of models where ΔAICc <4, based on households from 21 villages in 5 districts. Coefficient estimates are presented as contrasts from the intercept, standardised on 2 standard deviations following Gelman (2008). Where the RVI of a variable is < 0.5, only the direction of the effect is presented. Random effects estimates of variance [standard deviation] were taken from the global models.

4.1.3 Sanctuary fishing

Seventy seven per cent of respondents said their fishing location has not changed over the past five to ten years, mostly because they fish near their house or they have a small boat. Those who said they have changed their fishing location gave reasons of siltation, channel blockages, increased risk at sea, and less fish. The sanctuary bans do not appear to have caused changes in fishing locations. But, given that fishers in the study area did not report travelling long distances to fish, this evidence is not very important – fishers living inside sanctuary areas are more likely to stop fishing during the bans than travel long distances.

The analysis of radar data yielded the strongest evidence for at least some compliance with fishing bans, and perhaps the strongest evidence of impact found in this study (Table 6). The density of small boats in the sanctuary area (the number per unit of area) was estimated to be double the density in the control area during the non-ban period, and half the density in the control period during the ban period. The density of large boats was higher in the control areas (1 boat/10km^2) than in the sanctuary area (where no large boats were spotted in either radar images) and this did not change outside the ban period.

During the ban period, 'boat densities' decreased in the sanctuary (Tentulia River) while they increased in two of the control rivers (Bighai and Galachipa; Fig. 5). However, boat densities in the Tentulia River were much lower in both periods than they were in the control Kaliganga and Payra Rivers. The absolute change in the density of fishing boats between ban and non-ban periods was much higher in these control rivers than it was in the sanctuary. In proportional terms, the difference between ban and non-ban fishing densities is roughly similar in Tentulia (the sanctuary) and Kaliganga (control), but the change is proportionally greater in Payra (control) than in Tentulia when ban and non-ban periods are compared.

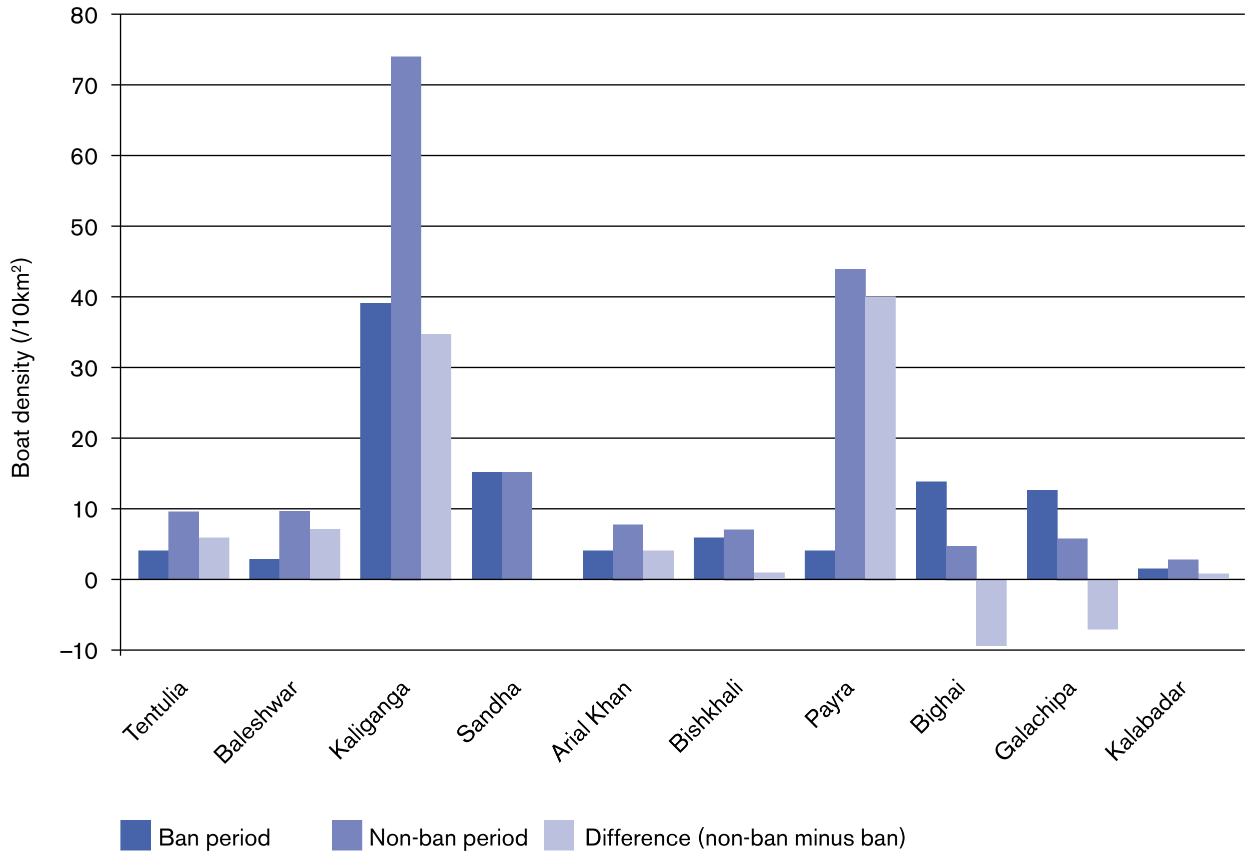
Cluster analysis also showed the Bighai River (control) to be a fishing hotspot during the ban period, whereas during the non-ban period portions of the Kalabadar and Tentulia Rivers (sanctuary) were hotspots (Fig. 6).

It is unlikely that such remarkable difference in fishing boat densities between ban period and non-ban period in sanctuary areas would be observed for any reason other than compliance with fishing regulations. On the other hand, these data also confirmed that some illegal fishing still goes on, which is not surprising, given the limited capacity for enforcement (Dewhurst-Richman et al. 2016; Islam et al. 2016a, 2016b). It should be noted, however, that there were uncertainties involved with the identification of small fishing boats at a spatial resolution of 5m, and in distinguishing them from other kinds of vessels. The differences between ban and non-ban periods could also have been confounded by the fact that the ban period falls in peak fishing season and the non-ban period in lean fishing season.

Table 6: Frequency and average density of small and large boats in control and sanctuary areas during and outside the ban period

	CONTROL AREA (818 KM^2)	SANCTUARY AREA (217 KM^2)
Ban period		
Small boat frequency	497	66
Small boats/10km^2	6	3
Large boat frequency	40	3
Large boats/10km^2	1	0
Non-ban period		
Small boat frequency	764	382
Small boats/10km^2	9	18
Large boat frequency	71	7
Large boats/10km^2	1	0

Figure 5: Number of all boats/10km² distributed across 10 rivers, as estimated from Radarsat-2 images. The sanctuary area is the Tentulia River and the rest are controls



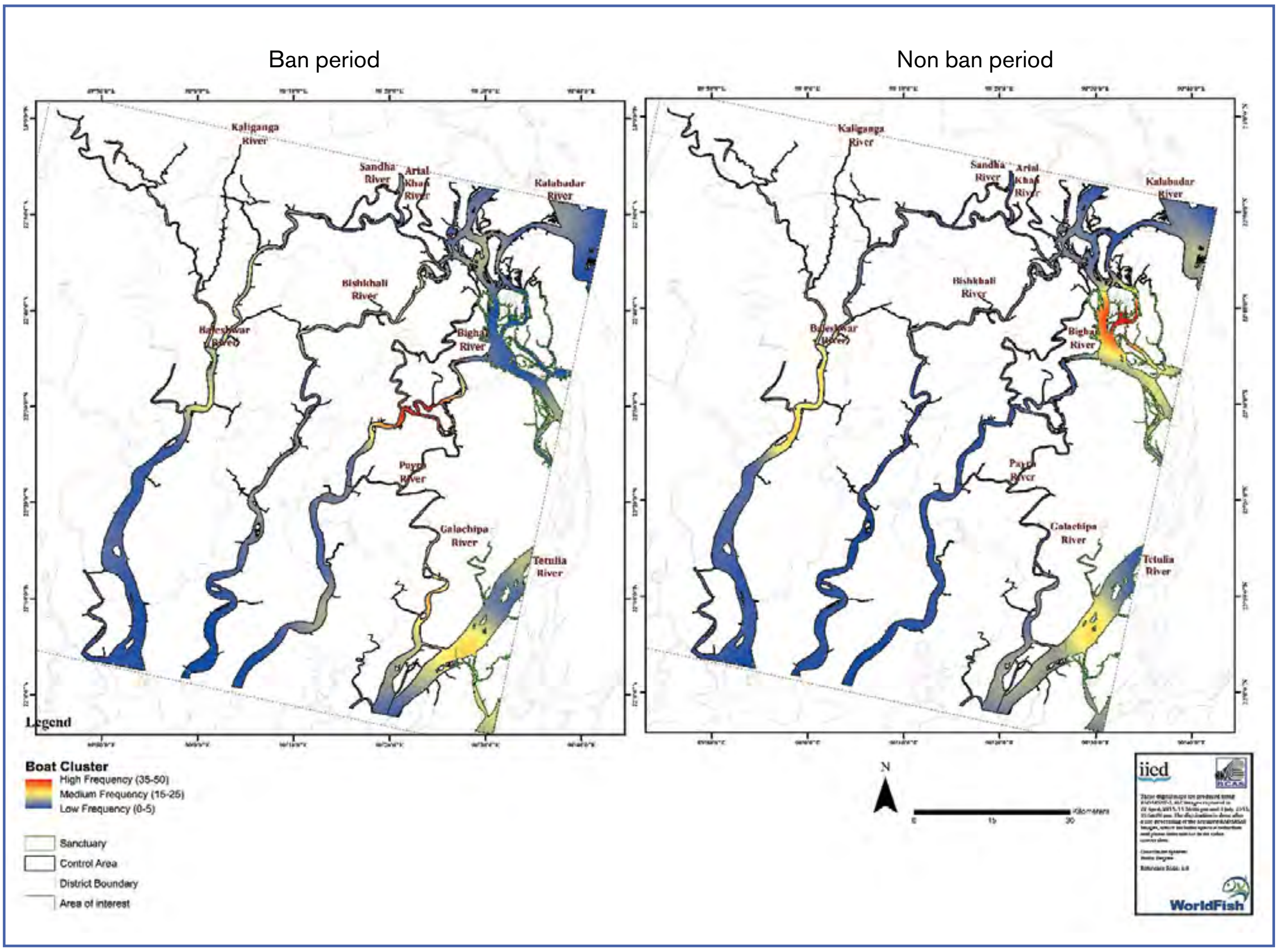
4.2 Impact of management on hilsa abundance

How far compliance with regulations has actually affected hilsa populations is unclear. When asked about the direct impacts of regulations, 91 per cent of respondents reported that regulations have had an impact on hilsa. The most commonly given effect was through the current net ban, the jatka fishing ban, and the 15-day hilsa fishing ban for brood fish. Sixty nine per cent said the fishing bans have had a positive impact on catch, 22 per cent said it has been negative and 9 per cent said they don't know.

Evidence for beneficial ecological trends over the last five to ten years was weaker; a minority of respondents reported such perceptions. When asked about catches, 74 per cent of respondents said their hilsa catch has decreased over the past five to ten years, 12 per cent said it has increased and 10 per cent said it has stayed the same. Fifty five per cent said hilsa have got smaller over the past five to ten years, 23 per cent said fish have got bigger and 20 per cent said it has stayed the same. At the same time, 46 per cent of respondents told us that hilsa abundance has increased over the past five to ten years, 44 per cent said it has decreased and 10 per cent said it has stayed the same. The large difference between the ten per cent of fishers who reported an increase in catch volume and the 46 per cent who reported an increase in hilsa abundance may be due to perceptions that fishing restrictions prevent them from catching their maximum potential. These findings contrast with an increase in officially reported landings estimates over the same time period, and some reports in the literature of an increase in hilsa abundance and size (BOBLME 2010; Rahman et al. 2012). However, these reports have rarely been substantiated with reliable data.

Boat ownership and high income dependence on fishing were important positive correlates of reporting an increase in hilsa abundance and size, indicating that fishers who are more invested in fishing are more likely to perceive a positive change (Table 5: models 5 and 6). On the other hand, the probability of reporting a positive impact of regulations on catch was negatively correlated with average catch (Table 5: model 8),

Figure 6: Fishing boat cluster frequency in different river regions during and outside the ban period

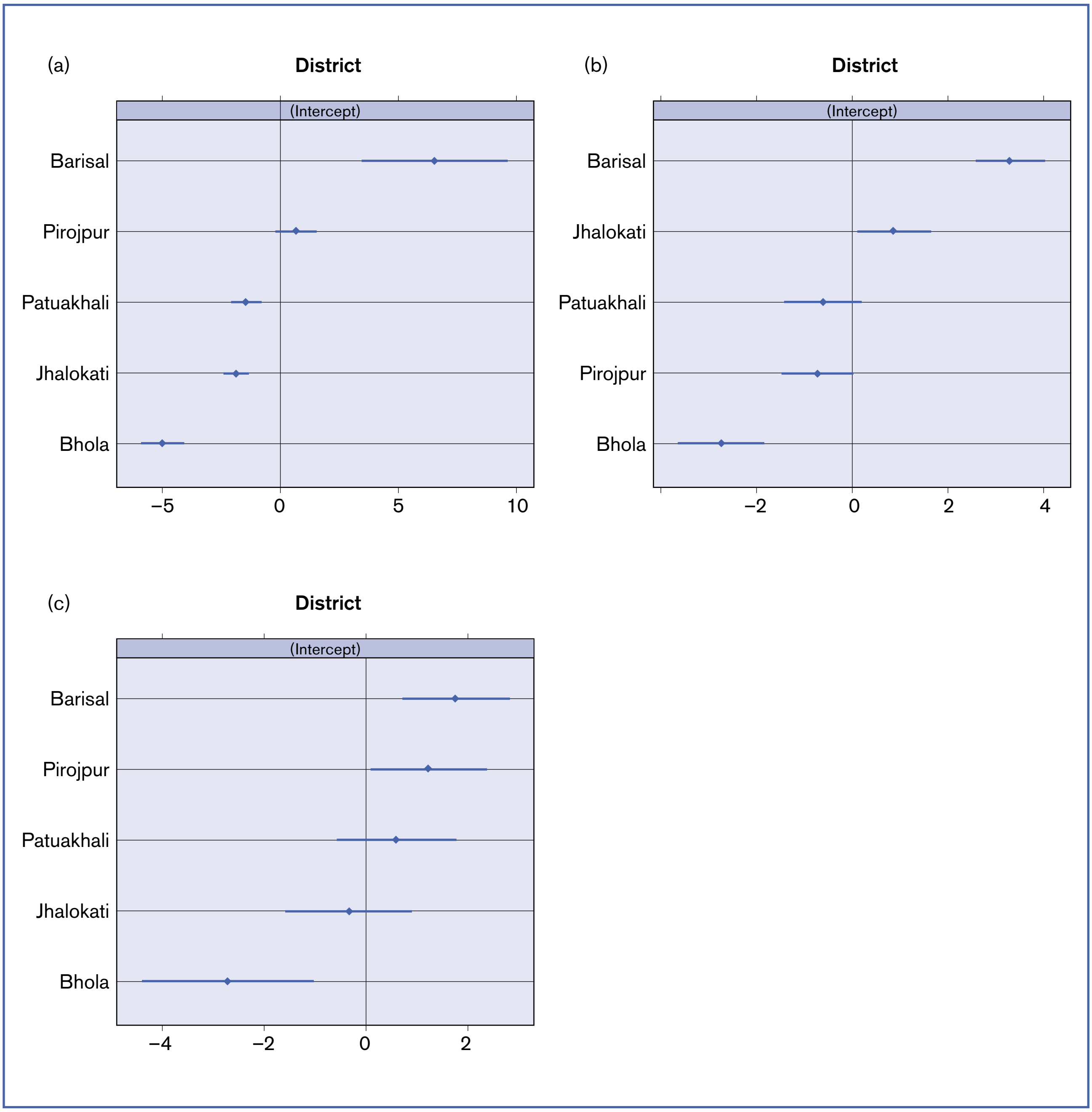


indicating that fishers who put in more effort are less likely to perceive a positive impact. Use of the illegal current net was an important negative correlate of reporting an increase in fish size, as would be expected (Table 5: model 6). Fishers living in a sanctuary area were significantly less likely to report an increase in hilsa abundance or a positive impact of fishing bans on catch (Table 5: models 5 and 8). Under effective sanctuary management, the impacts on hilsa populations were expected to be greatest inside and around sanctuary areas, where management is focused. However, because sanctuary respondents are subjected to the greatest restrictions on fishing, they may have been less inclined to report positive impacts than respondents living near sanctuaries, but without the same level of restrictions. In a similar survey, Islam et al. (2016a) found largely positive perceptions of the sanctuaries' conservation benefits, but respondents raised concerns that benefits are only experienced by those outside sanctuaries.

Nevertheless, the views of fishers living inside sanctuaries somewhat strengthens Hypothesis C. It is possible that the sanctuaries in this study area have declined in habitat suitability for hilsa and that important nursery grounds have shifted, or that some migratory channels are blocked. There is prior evidence of siltation blocking river channels, and in particular of water pollution in the Andharmanik River, which is a sanctuary site – although linkages to hilsa abundance are largely anecdotal (Hasan et al. 2015; Miah 2015; Bladon 2016). Nonetheless, this possibility is very important because if the sanctuaries do not have suitable habitat for jatka then they are unlikely to impact hilsa abundance even when management does succeed in achieving compliance with regulations.

For each of models 5, 6 and 8, the district random effect was more important than any of the fixed effects (Table 5). For instance, respondents in Barisal were consistently more likely to report a positive impact of regulations, an increase in abundance and an increase in size, whereas those in Bhola were least likely to (Fig. 7). This strong spatial variation suggests that impacts are being seen in some areas, but that environmental conditions such as pollution, climate change and siltation could be limiting the impacts of management, again supporting Hypothesis C.

Figure 7: Best Linear Unbiased Predictors for the district random effect in GLMMs for probability of reporting (a) a positive impact of fishing bans on income; (b) an increase in hilsa abundance; and (c) an increase in hilsa size. The x axes show the effect of living in a particular district in terms of the probability of reporting these perceptions. Error bars show the 95% confidence interval based on the conditional variance for each random effect.



The answers respondents gave for why they have shifted fishing locations (siltation, erosion and the formation of sand bars and submerged islands blocking river channel) are also consistent with this hypothesis.

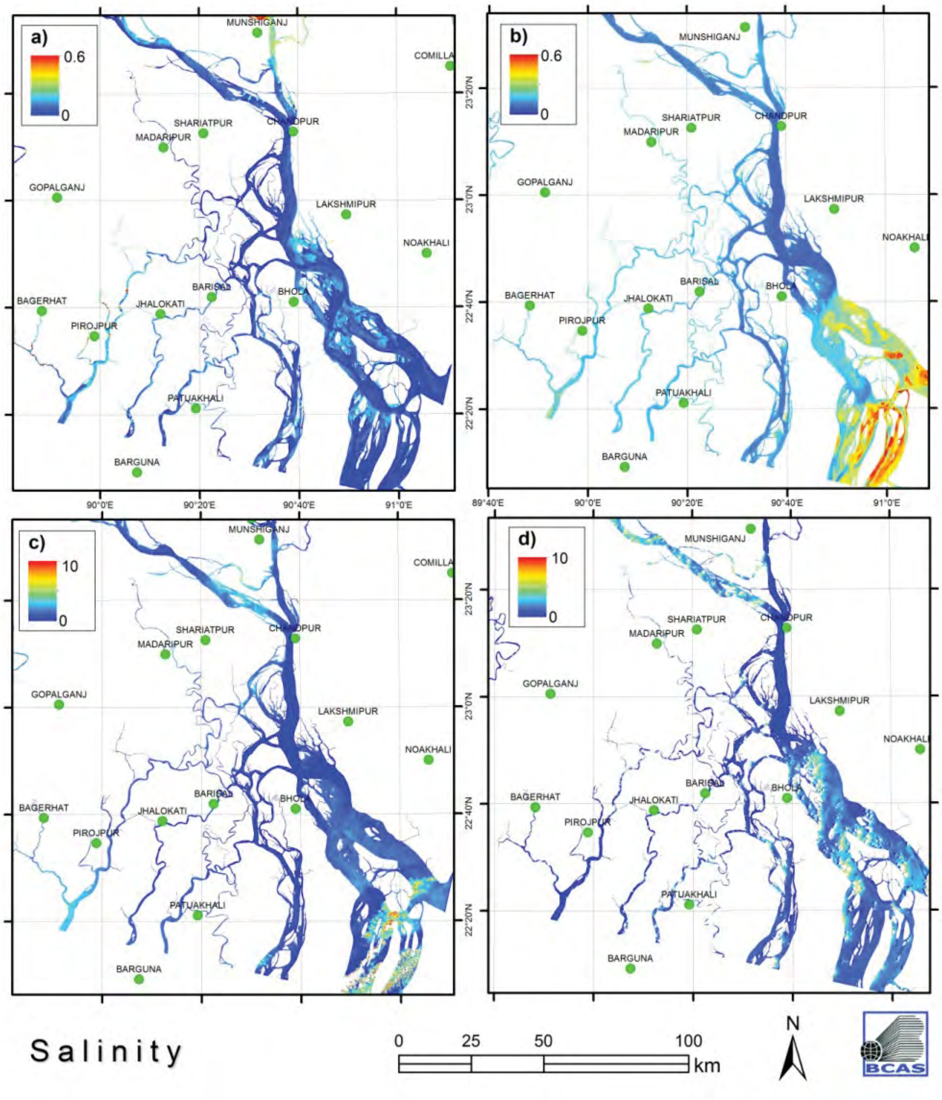
Spatio-temporal variations in hilsa habitat suitability support the timing of the sanctuary fishing bans around March, although no data were available for April (Table 7). For instance, water salinity is most suitable during November and March (Figure 8), and electrical conductivity (which indicates levels of impurities in the water) is most suitable in March (Figure. 9). Most importantly, the results show a 'nutrition front', i.e. a flow of chlorophyll-a and thus phytoplankton availability, moving inland during the dry season from November to May (Fig. 10). This supports the idea that hilsa abundance shifts from coastal to inland areas during this time. However, the nutrition front reaches all rivers inland, including the smallest one, indicating that fishing bans should be implemented not just in the sanctuary areas but in other major rivers. Blanket implementation could also be simpler from an enforcement perspective.

On the other hand, Total Suspended Solid (TSS) dynamics indicate high turbidity in the Shahbazpur Channel in November, January and March (Fig. 11) – more potential evidence of blocked migratory routes and support for Hypothesis C. Water pH was also found to be unsuitable in March throughout the study area, which could be an indication of pollution. Current velocity was not a useful indicator of habitat suitability as seasonal variability could not be evaluated from only four images. This type of analysis would produce more useful evidence if data were not limited to the dry season and coastal areas, and if available monthly over the long term.

Table 7: Suitability of ecological parameter values at four spawning times in the study area

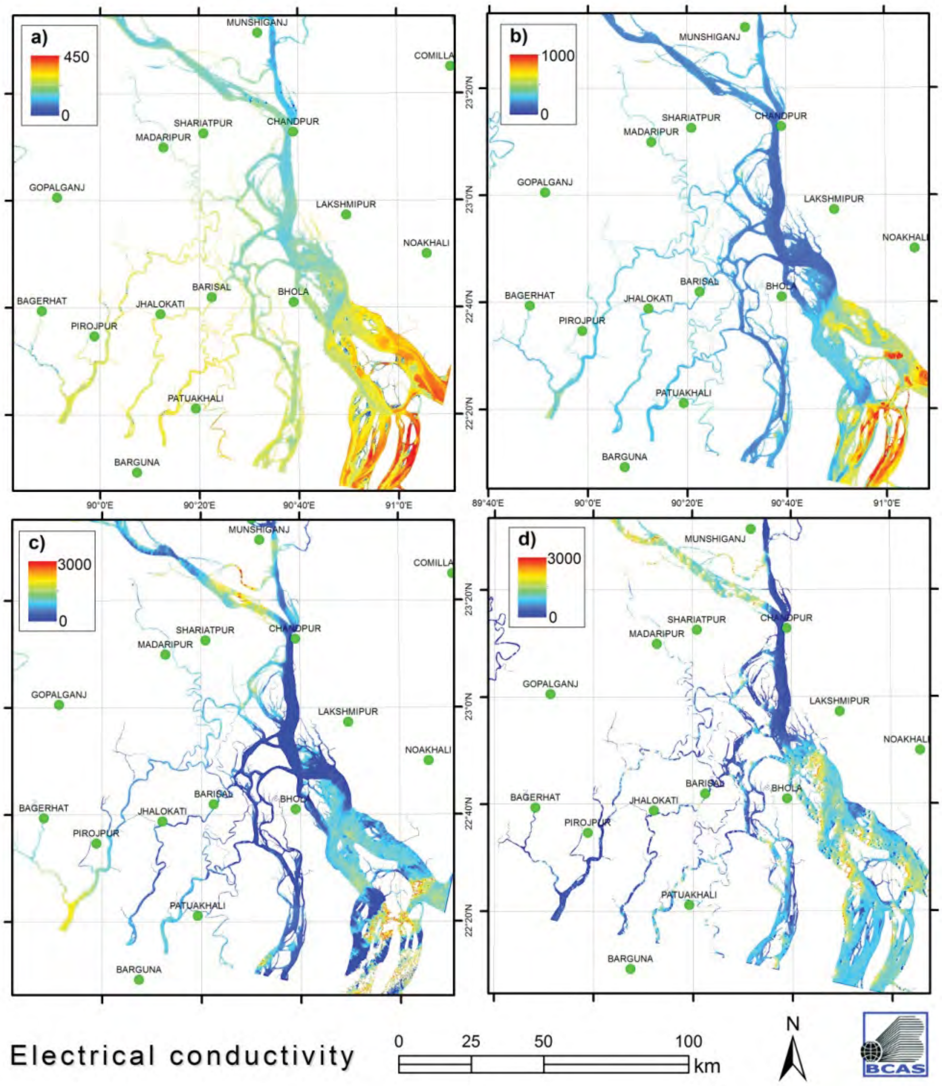
PARAMETER	NOVEMBER 2013	JANUARY 2014	MARCH 2014	MAY 2014
Chlorophyll-a	Moderate suitability in Shahbazpur Channel	Moderate suitability in most rivers	High suitability in Padma and Meghna rivers	Moderate suitability in Meghna River
Dissolved oxygen	High suitability in all the rivers	High suitability in Padma and Meghna rivers	High suitability in Padma and Meghna rivers	Moderate suitability
Salinity	High suitability	Low suitability	High suitability	Moderate suitability
Electrical conductivity	Low suitability	Low suitability	High suitability in Meghna and Tentulia rivers	High suitability in Meghna river
Total Dissolved Solid	High suitability	Moderate suitability	Moderate suitability	Moderate suitability
Total Suspended Solid	High suitability in Padma and Meghna rivers, low suitability in Shahbazpur Channel	Low suitability in Padma and Meghna rivers, unsuitable in Shahbazpur Channel	High suitability in Padma and Meghna rivers, low suitability in Shahbazpur Channel	Moderate suitability in Meghna river, low suitability in other rivers
Current velocity	High suitability	High suitability	High suitability	High suitability
Water transparency	High suitability	High suitability	High suitability	High suitability
Water temperature	High suitability	High suitability	Moderate suitability	Low suitability
Water pH	Moderate suitability	Low suitability in lower Meghna river	Low suitability	Moderate suitability

Figure 8: Spatio-temporal variation of salinity in g/l (ppt) in coastal rivers of Bangladesh



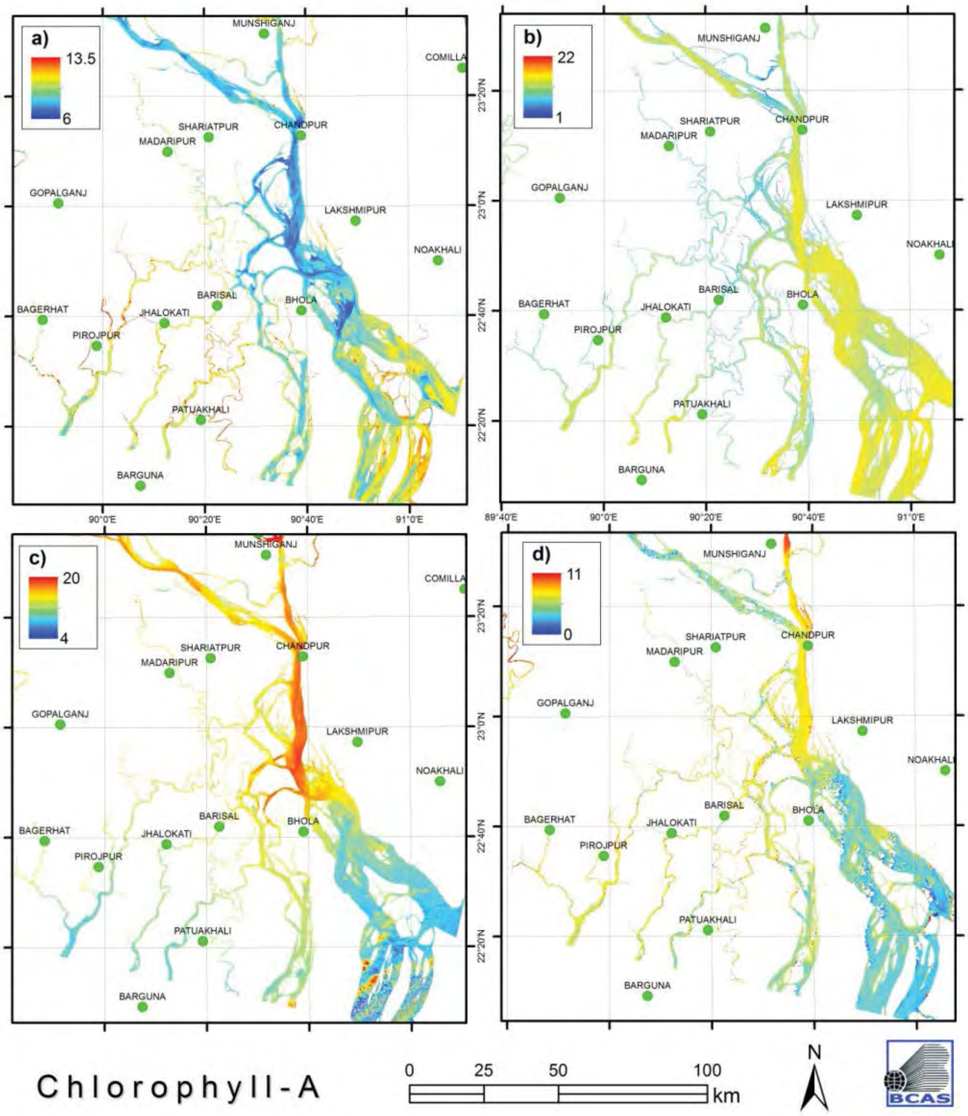
a) November 6, 2013
b) January 22, 2014
c) March 14, 2014
d) May 17, 2014

Figure 9: Spatio-temporal variation of electrical conductivity in µs/cm in coastal rivers of Bangladesh



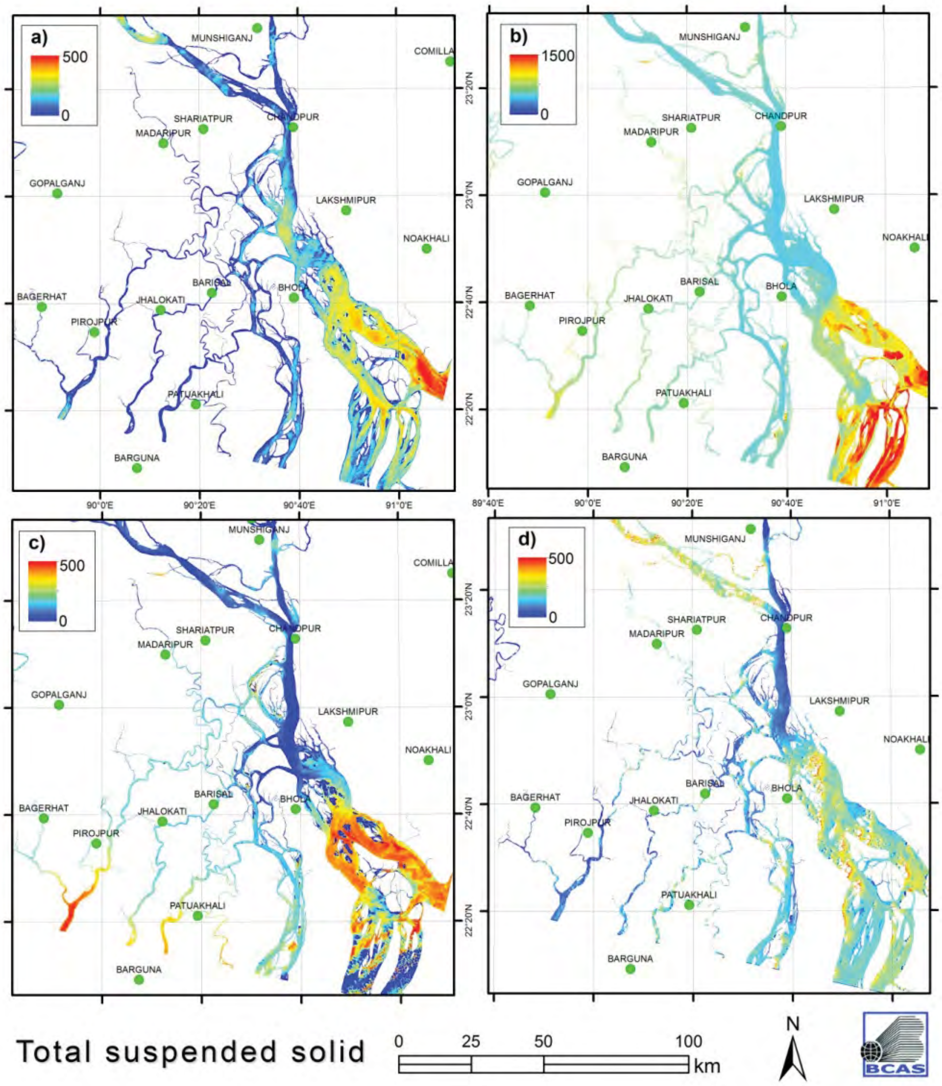
a) November 6, 2013
b) January 22, 2014
c) March 14, 2014
d) May 17, 2014

Figure 10: Spatio-temporal variation of chlorophyll-a in mg/l (ppm) in coastal rivers of Bangladesh:



a) November 6, 2013
b) January 22, 2014
c) March 14, 2014
d) May 17, 2014

Figure 11: Spatio-temporal variation of total suspended solid (TSS) in mg/l (ppm) in coastal rivers of Bangladesh



a) November 6, 2013
b) January 22, 2014
c) March 14, 2014
d) May 17, 2014

Spawning seasonality is partially determined by ecological parameters. When asked about the 15-day ban is sufficient to protect spawning hilsa, 60 per cent of respondents said it was sufficient, 31 per cent said it needs to be increased and only 8 per cent that it needs to be reduced. The majority support provides some evidence that the ban is appropriately timed. The variation in answers could reflect spatial variation in spawning seasonality or even a temporal shift: and that would somewhat strengthen Hypothesis C, that hilsa abundance is largely determined by environmental variability. Climate change, for example, could have driven a temporal shift in peak spawning period, limiting the impact of the fishing ban (Ahsan et al. 2014; Miah 2015). Previous ecological studies have recommended extending the ban (Hasan et al. 2015) and in 2016 a 22-day ban was implemented. Given the large proportion of respondents recognising the ban's importance, this extension has potential to receive community acceptance. It seems from this study results that respondents are more satisfied with the hilsa fishing bans for gravid hilsa than with the sanctuary management, a conclusion that is not surprising given the longer length of sanctuary fishing bans.

4.3 Impact of management on socioeconomics

Successful management is expected to have improved livelihood status through increased hilsa abundance and thus income from fishing, and through the compensation scheme. This improvement in livelihood status is necessary for compliance with regulations (Islam et al. 2016a). Fifty five per cent of respondents said the regulations improved their income from fishing, while 30 per cent said they reduced income and 14 per cent said they didn't know. Forty per cent of respondents said their livelihoods had improved in the past five to ten years, 36 per cent said their livelihoods have declined and 22 per cent said livelihoods had stayed the same. Similarly, 40 per cent said their household income from fishing has increased over the past five to ten years, 44 per cent said it has decreased and 19 per cent said it has stayed the same. Reporting an income benefit from the bans was significantly positively associated with reporting rising income ($\chi^2 = 65.3$; df = 2; $p < 0.001$), which increases the reliability of these perceptions.

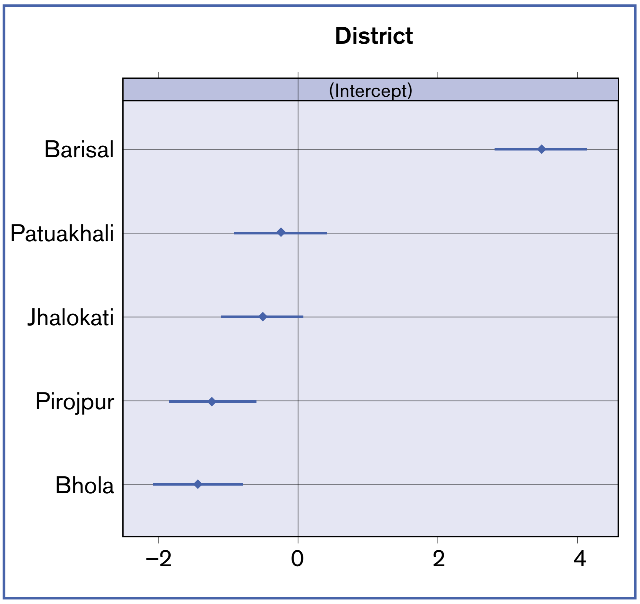
However, GLMMs revealed 'sanctuary' to be an important negative correlate of the probability of reporting fishing income benefits from the bans, and to a lesser extent of reporting an improvement in livelihood status (Table 5: models 4 and 1). This is not surprising, since sanctuary respondents experience more fishing regulations that impose costs, or are perceived to impose costs (Islam et al. 2016a).

Debt was an important fixed effect for the probability of reporting both an improvement in livelihood and an increase in income from fishing; respondents who owed money were less likely to report improvements (Table 5: models 1 and 2). Eighty four per cent of respondents reported being in debt and 86 per cent reported selling their catch via middlemen, who lock fishers into cycles of debt (Dewhurst-Richman et al. 2016). This indebtedness could have limited the impacts of management. Those fishers who have not observed an increase in income from fishing may also have been unable to reap the benefits of improved hilsa fishing because current power structures often limit the ability of fishers to get a fair price on their catch (Ali et al. 2010).

Years of fishing experience was also an important fixed effect for improvement in livelihood status (Table 5: model 1); less experienced fishers were less likely to report an improvement, which indicates that livelihoods were less good in the past than they are now. The most important fixed effect for the probability of reporting an increase in income from fishing was the proportion of household income that comes from fishing (Table 5: model 2); households with a greater income dependency on fishing were more likely to report an increase in income from fishing. Average catch was also an important positive correlate (RVI = 0.67), although the standard error was large. These results are perhaps to be expected: the more engaged in and dependent on fishing a respondent is, the more likely they might be to notice improvements.

As with the ecological perceptions, the district random effect was stronger than any of the fixed effects in models 1, 2 and 4 (Table 5). The pattern was also similar; respondents in Barisal were significantly more likely to report positive improvements, and those in Bhola significantly less likely (e.g. Fig. 12). This variation cannot be attributed to the distribution of compensation, as this variable was already taken into account. Instead, it can likely be explained by the political and economic differences between Bhola and Barisal. Barisal is economically better off and politically more influential than the coastal district of Bhola, with better transport infrastructure and markets, and so respondents here are likely to be getting a better price for their catch and thus more likely to experience improvements in livelihood status.

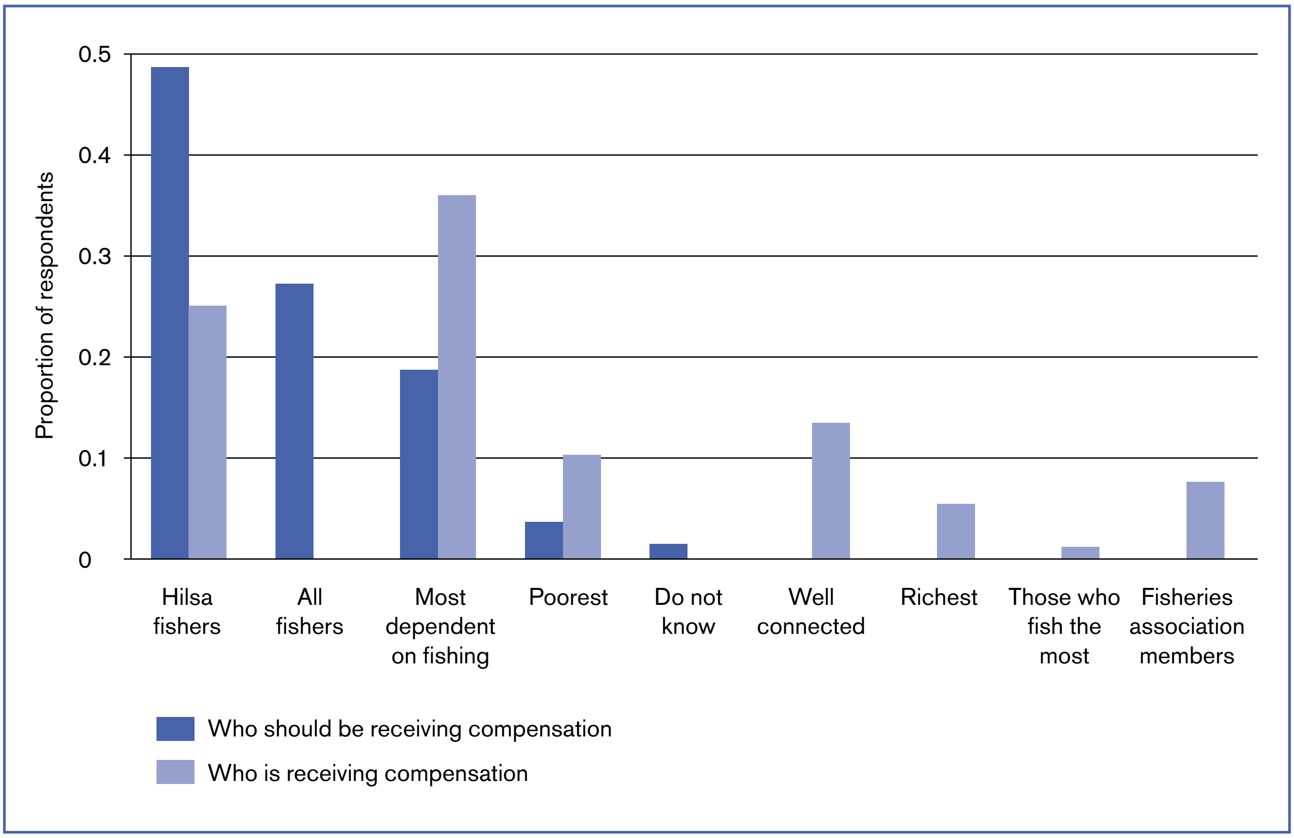
Figure 12: Best Linear Unbiased Predictors for the district random effect in GLMMs of probability of reporting an improvement in livelihood status. The x axes show the effect of living in a particular district in terms of the probability of reporting an improvement. Error bars show the 95% confidence interval based on the conditional variance for each random effect.



4.4 Impact of compensation

Ninety five per cent of respondents said compensation is benefiting communities and 69 per cent of respondents said the distribution of compensation is fair. Modelling showed these perceptions of fairness to be strongly positive correlated with receiving compensation, as would be expected (Table 5: model 3). There was also strong variation in perceptions between villages within a district, which indicates that the system of compensation allocation within villages is much more acceptable in some than others. A third (33 per cent) of people perceived some 'elite capture' in compensation distribution, and there was some disparity between the groups of people respondents said are receiving compensation and should be receiving compensation (Figure 13). Perceptions of fairness are usually good indicators of community acceptance and therefore compliance (Sutinen and Kuperan 1999; Sommerville et al. 2010; Harrison et al. 2015), and so these results largely support the main hypothesis, under which compensation should have contributed to socioeconomic improvement and thus incentivised compliance with regulations.

Figure 13: Graph showing the groups of people that the respondents said are receiving compensation and those who should be



However, there was no significant association: between compensation and varying gear due to regulations or to protect hilsa; between compensation and current net use; or between compensation and catching jatka during the ban ($\chi^2 > 0.05$). Moreover, receiving compensation was not an important correlate of reporting an improvement in livelihood status (Table 5: model 1). AIGA recipients did have a significantly lower proportion of their income coming from fishing (Wilcoxon signed rank test $W = 19696$; $p < 0.05$), but there was no significant relationship between receiving AIGA and reporting an alternative livelihood ($\chi^2 = 0.77$; $df = 1$; $p = 0.38$).

As suggested in previous studies (Mohammed et al. 2014; Bladon 2016), a major issue for the rice compensation scheme is that fishers are still required to repay the interest on their debts during the fishing bans. The weak association between compensation and compliance could be due to the small sample size of non-recipients (17 per cent), or it could be because their debts and lack of access to appropriate financial products (e.g. conditional cash transfers or microcredit with a freeze on interest repayments during the fishing bans) means that fishers are compelled to continue fishing during the bans. Indebtedness has previously been linked to illegal fishing (Rahman et al. 2014). AIGA is often viewed as having a greater potential to help fishers generate income for repayments during this time (Siddique 2009), and the above results partially support the expectation that AIGA improves livelihood diversity. However, it is not provided to enough households: only 11 per cent of respondents said they receive AIGA in comparison with the 83 per cent of respondents receiving rice compensation.

This evidence does not, therefore, rule out the plausibility of Hypothesis B: that the compensation has not contributed to an increase in hilsa abundance, even if it has contributed to socioeconomic improvement. It should also be noted that the high proportion of compensation recipients (83 per cent) in the sample could have influenced the perceptions of fairness. Of households affected by fishing regulations, 45–65 per cent received compensation in 2014 (Bladon 2016), which is much lower than the proportion of survey respondents compensated. Given the strong correlation found between perceptions of fairness and receiving compensation, perceptions of fairness might have been different in a more representative sample of respondents.

4.5 Impact of awareness-raising activities

The mean score for awareness of regulations was 2.7, with a range of -4 to 8 out of a possible -8 (highly unaware) to 8 (highly aware). LMMs (Table 5: model 9) showed a positive correlation of awareness with average catch volume and a negative correlation with female respondents (women are rarely involved in catching hilsa); respondents with higher fishing effort tend to have a higher awareness. The village random effect was also large; awareness was higher in some villages than others within a district, but variation between districts was not large. Awareness of regulations was lower amongst those who reported participating in illegal activities (current net use and targeting jatka during the ban) than those who did not, although these variables had limited support for inclusion in top models. Awareness of regulations also increased the probability of reporting a change in gear use in the past five to ten years, although the estimate had a fairly large standard error (Table 5: Model 7).

This evidence all suggests that awareness-raising activities have contributed to compliance with regulations. The positive correlations that can be seen between high awareness and the likelihood of reporting an improvement in livelihood status, an increase in fishing income and a positive impact of fishing bans on income (Table 5: models 1, 2, 4 and 6) also indicate that awareness-raising activities have contributed to community acceptance, which in turn may have influenced compliance. However, awareness was not higher inside sanctuary areas, as might be expected given that management is focused in these areas.

4.6 Caveats

A limitation to these findings is that they predominantly use perceptions as evidence. This means strong process tracing tests could not be performed, largely due to the risk of biased answers. People rarely give completely honest answers to questions about sensitive behaviours such as illegal resource use (Nuno and St John 2015), and so evidence regarding compliance with regulations cannot be interpreted with certainty. Furthermore, perceptions of ecological trends and impacts could have been influenced by respondents' satisfaction with management and socioeconomic situation. The positive correlation between receiving compensation and reporting an increase in hilsa abundance also highlights the risk that some respondents may have been tempted to provide biased answers in the hope of starting to or continuing to receive compensation.

However, even when perceptions of management impacts are coloured by support or dissatisfaction, findings based on perceptions can be valuable, since management effectiveness ultimately depends on community acceptance (Bennett 2016). Nonetheless, theory-testing process tracing requires outcomes to be known, and so the inference of causality in this study was complicated by these uncertainties. Furthermore, the tests were fairly subjective. And since the study did not find evidence for each and every component of the causal mechanism, it made key assumptions (for example that a focus on inland fisheries is sufficient) that limited our ability to infer overall impact.

Establishing control and treatment groups of respondents was also difficult when exploring the impacts of sanctuary management and compensation distribution. Since most households in the region receive some kind of food assistance as part of the Vulnerable Group Feeding programme, the 'non-recipient' group may have received compensation irrespective of the hilsa management intervention. Given the migratory nature of hilsa and the mobility of fishers, the sanctuary variable was also difficult to define, and might have been improved by grouping those fishers living near enough to sanctuaries to fish there with fishers living inside the boundaries.

5 Conclusions and recommendations

This research demonstrates that when rigorous counterfactual impact evaluations are not possible, creative mixed-method, theory-based approaches can still be used to identify the weaker and stronger components of an intervention, and thus to direct improvement. Although the nature of the evidence collected for this study meant that it could not be used to decisively infer causality, observing evidence strengthened confidence in a contribution claim, and conversely not observing evidence weakened confidence.

The management components with the strongest evidence for a contribution were those aiming for socioeconomic improvement. It also seems likely that management actions have contributed to some compliance with regulations, particularly a reduction in sanctuary fishing during the ban period. Awareness-raising activities may have played a key part in influencing these changes.

It is therefore reasonable to conclude that the hilsa management package has contributed to socioeconomic improvement and, at the very least, has potential to help increase hilsa abundance.

However, the evidence did not rule out either of the alternative hypotheses: (HA) that the compensation scheme has not contributed to an increase in hilsa abundance (HB); and that hilsa abundance is largely determined by environmental conditions (HC), which weakens some key components of the hypothesised causal mechanism. These alternative explanations highlight management actions that are still needed for the hilsa fishery to improve.

Firstly, the study suggests the compensation scheme might not have contributed to an increase in hilsa abundance, even if fishers are better off. The extent to which compensation has actually incentivised compliance with regulations is probably limited by a lack of access to help in managing debt, by market power structures and by the numerous issues with allocating compensation (Islam et al. 2016b). The detailed changes required to address this are documented by Bladon (2016), Dewhurst-Richman et al. (2016) and Islam et al. (2016b). But most importantly, the rice and AIGA compensation schemes should be redesigned to better fit the needs of hilsa fishers, with appropriate stakeholder consultation, and their coverage should be increased in an equitable way. A conditional cash transfer, or loan with repayments tailored to the timing of the fishing bans, could help to lower opportunity costs associated with complying with the ban and allow compensation to not only compensate but also incentivise (Mohammed et al. 2014; Porras et al. 2016). These changes could be sustainably financed through a Conservation Trust Fund for hilsa (Bladon 2016). This is currently being considered to be implemented by the Department of Fisheries.

Secondly, it is plausible that changing environmental conditions have undermined the potential impacts of management in some areas. At present there is no evidence to infer the relative contributions that management and environmental conditions have had on hilsa abundance. However, species with similar life cycles to hilsa tend to have strong population responses to environmental change. Overall, evidence that management actions have increased hilsa abundance is equivocal and spatially variable. The strong geographical variation in the trends fishers perceive, and their views on how regulations affect these trends, suggests that the sanctuary fishing bans may not have had the intended impact on hilsa abundance in some cases. The spatial variation in habitat suitability seen in the Landsat images supports this interpretation. For example, it is possible that some fishers have not perceived benefits from management regulations because migratory channels en route to sanctuaries have become blocked, or because water quality is poor, and this is outweighing any benefit from regulations.

Therefore, it is important that a complete ecological reassessment of sanctuary zoning is conducted in order to maximise the potential for the management package to achieve its aims, and that a long-term ecological monitoring and evaluation programme is established. A more comprehensive comparison of habitat suitability over time, assessed using Landsat images, would be useful in understanding this issue.

Thirdly, since remote sensing indicates that habitat suitability is not concentrated in the sanctuary areas (and that small rivers like the Kaliganga and Payra are fishing hotspots), fishing bans should be implemented throughout the river system. This should also reduce the chance of blockages in migratory routes undermining the impact of fishing bans.

An important question to arise from this study is: what level of compliance is required in order to achieve impact? There is clearly nowhere near 100 per cent compliance within the hilsa fishery. However, even if a small minority of fishers have changed their behaviour because of management interventions (as appears to be the case), that change could eventually affect the whole population through community encouragement and peer pressure. It would be unrealistic to expect substantial improvement in 'top-down' enforcement of regulations at this stage. Nevertheless, local communities' participation in implementing, monitoring and enforcing regulations can lead to compliance through collective action and can work well in tandem with institutions like the compensation scheme (Kerr et al. 2014; Begossi 2014; Sarkki and Karjalainen 2015). Therefore, our fourth recommendation echoes Islam et al. (2016a) in suggesting hilsa fisheries management should develop a system of co-management with local communities.

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Glossary terms

Contribution analysis: is an approach for assessing causal questions and inferring causality. It offers a step-by-step approach designed to help managers, researchers, and policymakers arrive at conclusions about the contribution their program has made (or is currently making) to observed outcomes. The essential value of contribution analysis is that it offers an approach designed to reduce uncertainty about the contribution the intervention is making to the observed results through an increased understanding of why the observed results have or have not occurred, the roles played by the intervention, and other internal and external factors.

Counterfactuals: projected scenarios estimating what would have occurred in the absence of an intervention

Ecological additionality: a measurable ecological impact over and above what would have happened without an intervention

Elite capture: situation where a minority of already relatively-privileged people gain most from interventions designed to help everyone

Generative causality: a causal mechanism explains a specific effect and, by doing so, demonstrates a causal relationship

Payments for Ecosystem Services: a tool aiming to improve the provision of Ecosystem Services by resource users to beneficiaries, by offering conditional positive incentives for behavioural change.

Process tracing: A probabilistic tool developed to analyse historical events. Process tracing breaks down the theorised mechanism into the smallest possible number of necessary component steps, each of which should be empirically measurable. Thus, it is the combination or accumulation of evidence that increases confidence in a causal mechanism, rather than any one piece of evidence in isolation.

Theory of Change (ToC): the mechanism presumed to lead to the intended outcomes, including underlying assumptions and contextual conditions

Upazila: an administrative sub-district in Bangladesh

Abbreviations

AICc	Corrected Akaike Information Criterion
AIGA	Alternative Income Generating Assistance
BLUPs	Best Linear Unbiased Predictors
DoF	Department of Fisheries, Bangladesh government
GLMMs	Generalised Linear Mixed effects Models
LMMs	Linear Mixed effects Models
REML	Restricted Maximum Likelihood
RVI	Relative Variable Importance
TDS	Total Dissolved Solid
ToC	Theory of change
TSS	Total Suspended Solid

Related reading

Mohammed EY, Ahmed CS, Ali ML (2014) Mitigating unintended local economic impacts of the compensation scheme for hilsa management. IIED, London. http://pubs.iied.org/17282IIED/

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Bangladesh's hilsa fishery is a rare example of 'carrot-and-stick' management. This study uses a theory-based, mixed-methods approach to assess whether intended outcomes have occurred; and whether management is a cause. The evidence is mixed. Compensation appears to have improved livelihoods, but may not have incentivised compliance with regulations. Fishing bans may have helped increase hilsa abundance, but strong spatial variation in how fishers view the fishery and its regulations, combined with remote sensing data, suggest declining habitat suitability may be masking the benefits in some areas. We make four recommendations: that the compensation scheme is redesigned to better fit fishers' needs, then scaled up; that sanctuaries are reassessed for ecological suitability and long-term environmental M&E is put in place; that short-term fishing closures to protect spawning fish be implemented more widely; and that local communities should become involved in co-management. More broadly, we show that creative theory-based approaches can help assess conservation interventions when attributing cause and effect is difficult.

IIED is a policy and action research organisation. We promote sustainable development to improve livelihoods and protect the environments on which these livelihoods are built. We specialise in linking local priorities to global challenges. IIED is based in London and works in Africa, Asia, Latin America, the Middle East and the Pacific, with some of the world's most vulnerable people. We work with them to strengthen their voice in the decision-making arenas that affect them – from village councils to international conventions.

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