सत्यमेव जयते

Draft Report

09 Valuation of Planted Mangroves

THE ECONOMICS OF ECOSYSTEMS AND BIODIVERSITY-INDIA INITIATIVE

COASTAL AND MARINE ECOSYSTEMS

Ministry of Environment, Forest and Climate Change
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Indo-German Biodiversity Programme

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Valuation of Planted Mangroves

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Project Team

Research topic: Accounting for Regenerated Forests: Evaluating the flow of Ecosystem Services from regenerated mangroves compared to original mangrove forest.

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THE ECONOMICS OF ECOSYSTEMS AND BIODIVERSITY-INDIA INITIATIVE

The Economics of Ecosystems and Biodiversity – India Initiative (TII) aims at making the values of biodiversity and linked ecosystem services explicit for consideration and mainstreaming into developmental planning. TII targets action at the policy making levels, the business decision level and awareness of citizens. TII has prioritized its focus on three ecosystems - forests, inland wetlands, and coastal and marine ecosystems - to ensure that tangible outcomes can be integrated into policy and planning for these ecosystems based on recommendations emerging from TII.

In addition to the existing knowledge, TII envisions establishing new policy-relevant evidences for ecosystems values and their relation to human well-being through field-based primary case studies in each of the three ecosystems. In response to an open call for proposals for conducting field-based case studies in the context of relevant policy or management challenges for conservation and the sustainable use of biodiversity and ecosystem services, over 200 proposals were received. A Scientific and Technical Advisory Group (STAG), comprising eminent ecologists and economists, appraised the proposals and recommended 14 case studies for commissioning under TII.

These studies in forests deal with issues such as hidden ecosystem services of forests, conflicts between humans and wildlife, and the economic consequences of species decline. In wetlands, the studies draw lessons on water resources management, community stewardship and equity, and the economics of hydrological regime changes. In coastal and marine ecosystems, the studies explore the opportunities and economic efficiency of interventions such as eco-labelling, seasonal fishing bans, mangrove regeneration, and the challenge of bycatch in marine fisheries.

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KEY MESSAGES

Mangroves provide food, fuel, recreation, contribute to fisheries, protect during disasters, aid in climate control through carbon sequestration and lessen coastal erosion. Gujarat has more than doubled its mangrove cover through reforestation and regeneration over mudflats. Planted mangroves have contributed to fisheries, biodiversity, and other ecosystem services. Mangrove restoration is a long-term ecological investment.

FINDINGS

- Planted mangrove effect on Gujarat commercial fishery was around **51 tons** of demersal, **45 tons** of crustaceans and **11.5 tons** of mollusks annually.
- Compared to the average daily catch in creeks with minimum pollution, the catch is reduced by **3.0 kg** in creeks with medium level pollution and by **4.1 kg** in highly polluted creeks.
- Planted mangroves provide benefits worth **`95.5 million** (**US$ 1.6m**) annually through contribution to commercial fisheries and promoting soil accretion.
- When mangroves are planted using direct sowing methods, the benefits to fisheries and coastal accretion can cover plantation costs within **15 years**, even with **5% rate** of discount.

RECOMMENDATIONS

- In terms of cost recovery, mangroves are evergreen assets and continue to contribute to the economy. They should be looked at as long-term assets and not be evaluated just on the basis of short-term gains.
- There should be a mangrove tax on commercial fishery to share the cost of planting mangroves.
- There should be strict control on issues such as water pollution and increased effort by commercial fishers that may affect the daily catch of artisanal fishers.
- Preference should be given to less costly methods of mangrove plantation.

Photo: Ritesh Sharma

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EXECUTIVE SUMMARY

Valuation of Planted Mangroves

Ecological restoration of degraded and depleted mangrove habitats and planting of mangroves over coastal mud flats is a worldwide phenomenon, but there is less rigorous research evaluating the relative flow of Ecosystem Services (ES) from these regenerated ecosystems. This is needed for accounting of natural resources (i.e. whether one hectare of regenerated forest should be considered equivalent to one hectare of natural forest or not) and cost benefit analysis of public policy. Meta-analysis of studies that evaluated the performance of regenerated forests in different biomes indicates that the restored ecosystems improve the biodiversity and provision of ES by 44% and 25% respectively compared to natural forests. However, studies on flow of ES from regenerated mangroves compared to original forests present mixed findings and there are limitations, like, studies are based on limited data (one day sample, etc) that may be suffering from biases due to temporal fluctuations or spatial differences across study sites and this may result in inaccuracy if such findings are generalized. This study evaluates planted mangroves by using a data set that takes care of such biases.

In India, the state of Gujarat has planted thousands of hectares of mangroves over coastal mudflats and the mangrove cover of the state is approximately 1694 km^2 as assessed in 2013. This is nearly double the 854 km^2 of mangrove cover the state was endowed with historically in 1930s. Though this is a remarkable achievement for the state government, it was less clear as to what has been the contribution of this investment to the state economy or if it makes economic sense to replicate such a policy in other states having some scope to increase mangrove cover. Keeping such policy questions in the background, this study evaluated the flow of ecosystem services of regenerated mangroves of Gujarat. One of the most important services of mangroves is that they act as a "nursery ground for fish fry" and thus contribute significantly to the fishery sector. This study values this ecosystem service along with one regulating service i.e. protection from coastal erosion for these regenerated mangrove forests. There were evidences of some section of coastal population in Gujarat depending on mangroves for some provisional benefits like fodder and fuel, but these values could not be accounted for in the study due to lack of time and resources to do the valuation, though a thorough review of studies on these benefits have been presented in the study. Thus the present study does a partial valuation of the regenerated mangrove forests of Gujarat.

The study used satellite imagery to assess the mangrove cover and the Difference-in-Difference (DID) technique of program evaluation and panel regression technique to evaluate the regenerated forest's contribution to the fishery sector and coastline erosion control. Both primary survey and secondary data were used in the analysis. The results show the planted mangroves to have increased the inshore and offshore fish catch significantly and have helped in net accretion of coastal land in between 1990 and 2013.

A comparison of the contribution of planted

Compared to the average daily catch in creeks with minimum pollution, the catch is lower by 3.008 kg in medium polluted creeks and by 4.069 kg in highly polluted creeks. Thus in an area with highly polluted sea water, mangroves are highly beneficial for artisanal fishermen

mangroves vs. natural mangrove towards fish catch was possible for inshore fishery. It was observed that compared to the average daily catch of artisanal fishermen in creeks having no mangroves, the catch is 4.237 kg higher in creeks with natural mangroves, 3.962kg higher in creeks having enriched plantation and 0.948 kg higher in creeks having 6-7 year old mangroves planted in mudflats. These effects are over and above water pollution and other features that can affect the daily catch of fishermen. The adverse effect of pollution was found strong. Compared to the average daily catch in creeks with minimum pollution, the catch is lower by 3.008 kg in medium polluted creeks and by 4.069 kg in highly polluted creeks. Thus in an area with highly polluted sea water, presence of natural and planted mangroves is helping artisanal fishermen to a great extent. Analyzing 26 years of data on off shore commercial fishery of west coast states of India (Gujarat, Maharastra, Karnataka and Goa), it was also found that catch of mangrove dependant fishes like demersal, mollusks and crustaceans have gone up significantly in Gujarat compared to other states after 1995 when mangrove cover increased in Gujarat. In terms of fish catch, mangrove effect on Gujarat commercial fishery was measured to be around 51 thousand tons of demersal, 45 thousand tons of crustaceans and 11.5 thousand tons of mollusks annually.

On coastal protection, though blocks with increase in mangrove cover witnessed both erosion and accretion, the rate of accretion was much higher than the rate of erosion in these blocks and net increase in land area attributable to mangrove presence was calculated to be 2206 hectares between 1990 and 2013.

Putting a monetary value on these two benefits of mangrove, the annual contribution of planted mangroves of Gujarat comes around ₹9.55 crores per annum or ₹1200 per hectare per year to Gujarat's economy in spite of all the limiting features like single species, stunted, lack of fresh water etc.

There are different estimates of cost of planting or regenerating mangroves in Gujarat and these vary from ₹12800 (seed sowing method) to ₹24400 (nursery method). Cost can go up to ₹66,240 per hectare if one considers soil testing, nursery development, plantation, scientific consultancy, maintenance and upkeep, etc. Estimating the sum of discounted benefits from mangroves over different years, it was found that cost recovery is possible from these two ecological services within 20 years (5 years gestation period and 15 years with benefits) even at 5% discount rate if seed sowing method is used for plantation. With nursery method, cost recovery is complete after 50 years at 5% discount rate and within 25 years at 3% discount rate. As lower discount rates are justified for biodiversity projects, assumption of cost recovery within 25 years of plantation is justifiable and the economy will be getting benefits afterwards in all future years, mangroves being permanent evergreen assets unless serious ecological interventions occur. Also these projects should be taken up as long term projects, not evaluated on basis of short term gain.

Thus results economically justify the coastal forestry department's attempt of mangrove restoration/ plantation. However, enriched plantation being more productive than plantation on open mudflats, the scope of doing such plantation should be explored and encouraged. The values also provide some basis to explore the scope of having a mangrove tax on commercial fishery, as they are found to be the maximum beneficiaries, to share the cost of replanting mangroves. The most important contribution of the study is for the research community which can use the data and results as a baseline for future research to generalize for other ecosystem services of regenerated mangroves or regenerated forests at other sites.

Key Words: Regenerated mangrove, Ecosystem service, Fishery, Coastal erosion, Accretion, Value of mangroves, Gujarat

1. Introduction

Mangrove forests provide many welfare and life saving ecosystem services like protection to life and property during coastal disasters, enhancement of fisheries, promotion of biodiversity which are habitats to numerous flora and fauna, climate control through carbon sequestration, and other important services like waste processing, food production, recreation etc. (Das and Vincent, 2009; Meyfroidt & Lambin 2009; Das and Crepin, 2013; Barbier et al., 2008; Ronnback 1999; Valiela, 2001; Aburto-Oropeza et al., 2008; Barbier et al., 2011; Blaber, 2007; MEA, 2005). The world has witnessed rapid mangrove loss due to various reasons like over harvesting, clearing for developmental uses or for other high yielding land uses like aquaculture, agriculture, etc. (FAO, 2008). The rate of mangrove loss has slowed down, with the latest estimate showing that the world has lost 192,000 hectares (474,000 acres) of mangroves in between 2001 and 2012.[1] This is much lower as compared to 3.09 million hectares lost in between 1980 and 2000 (FAO, 2008). Based on this data, the annual rate of mangroves loss is also seen to be declining steadily-- 1.04% during 1980-1990 to 0.72% during 1990-2000, and then from 0.66% during 2000-2005 to 0.13% in between 2001-2012. This is again a relatively low rate of loss compared to the rate of tropical deforestation which stands at a total of 4.9% from 2000 to 2012 (or 0.41percent annually).[2] The recent years, probably with spectacular increase in environmental knowledge and awareness about value of mangroves, are witnessing a revival of mangrove forests in many parts of the world either through ecological restoration of degraded mangrove areas or mangrove planting over non-mangrove areas like mud flats, salt marshes, or other degraded coastal lands, like rejected aquaculture ponds etc. (Field, 1998, Lewis 2001, 2009). Such policies are also partly instigated by global policy commitments such as the Convention on Biological Diversity.[3] These regenerated forests fall into four categories depending on the process followed to increase the forest cover---- natural regeneration, assisted natural regeneration, planting of native species of trees or planting of non-native species of trees (UN-REDD, 2010). The latter two categories constitute the maximum extended mangrove cover now, the natural mangrove land available for natural or assisted natural regeneration being exhausted by other land uses. Planting of mangroves in non-mangrove habitats, though a widely practiced phenomenon in many countries, is found to exhibit varying degree of success when the restoration success rate of planted mangroves was assessed either using remote sensing data for periods before and after restoration (Selvam et al. 2003), or by estimating mangrove survival rate (Hashim et al. 2010) or through societal perceptions (Iftekhar and Takama 2007; Ronnback et al. 2007). The success rate has been found to depend on factors like site or species selection (Elster 2000), socio -economic factors of nearby areas (Walters 2007), well designed tidal hydrology (Lewis and Gilmore 2007), community participation/involvement (Boromthanarat et al. 2006) etc. Depending on local conditions, people have been preferring natural recovery of mangrove stands compared to plantation (Kairo et al. 2002) and efforts at combining native mangrove species with exotic ones have also resulted in successful restorations compared to those planting only exotics (Ren et al. 2007). However, such natural recoveries are limited.

Mudflats have been the most widely used habitats for mangrove planting, but the success rate has never been impressive, especially with respect to bio-diversity of mangrove species. Plantations on the sea ward side have seen the lowest rate of success (Erftemeijer and Lewis, 1999). Bangladesh had the most ambitious mangrove plantation initiative in mudflats during the period of 1980-90, but only 2 out of 27 species (*Sonneratia Apetala around 29-52% and Avicennia Marina around 30-60%*) displayed promising survival rates after five years on mudflats. Insect, pest problems, burial of mangrove seedlings due to waves and high rate of sedimentation as well as sediment erosion contributed to severe drop in success rates in mudflats. Similarly, 1980's and 1990's respectively witnessed mangrove (*Avicennia Officinalis and Kandelia Candel*) replanting on Malaysian and Hong Kong mudflats followed by Thailand and Vietnam where many different species were tried. All these attempts at mangrove planting in mudflat regions of South East Asia were characterized by poor survival rates and high seedling mortality and only species of low economic value were found to survive (Erftemeijer and Lewis, 1999). The large scale mangrove plantation initiative of government of Gujarat, India on mud flats also finds *Avicennia Marina* as the only surviving species in almost all of the planted mangrove sites, as described later under section 2. Mud flats are proven productive ecosystems with high economic and ecological value (UNEP, 2005; Naber et al., 2008[4]; Erftemeijer and Lewis, 1999) and reclaiming mudflats and salt marshes for mangrove plantation is also against Ramsar convention and Wetland (Conservation and Management) Rules

2010. Moreover, reclaiming these habitats by planting mangroves for coast line stabilization or other benefits could also be a wrong resource allocation decision if the flows of ecosystem services from these planted mangroves are found to be inadequate or not accruing at all. Such dilemmas make evaluation of ecosystem services from planted mangroves an important area of research for efficient planning.

With low species diversity and low survival rate, the planted mangroves are usually sparse forest patches. This raises the question whether these ecosystems provide much of the ecosystem services that are available from natural mangroves and if they do, then how do the flow of such services compare to those of natural mangroves. Flow of ecosystem services from planted mangroves have been evaluated by studying and comparing various ecological parameters like: (i) the biodiversity richness like composition of microbes, fungi, plants, tropical guilds as well as invertebrates and vertebrates like mud crab populations (Walton et al. 2007; Ellison 2008), (ii) the composition of forest structure through vegetation cover and height, woody density, biomass, basal area or litter structure (McKee and Faulkner 2000; Macintosh 2002; Bosire et al. 2008; Kairo et al. 2008), (iii) ecological characteristics as well as biotic and abiotic features like the soil pH level, organic content or moisture content between planted and natural mangroves (Khayat and Jones 1999; Walters 2000) etc. Kaly and Jones (1998), Moberg and Ronnback (2003), Lamb et al. (2005), and Benayas et al. (2009) studied the revival of various ecosystem services due to site based ecological restoration for integrated landscapes and found that both revival and resilience of ecosystem services can't be achieved just by restoring only one ecosystem, it requires landscape based ecological restoration activities. Crona and Ronnback (2006), Ronnback et al. (2007), and Bullock et al. (2011) have examined exclusively the revival of one specific ecosystem service, the role/use of restored mangroves as nursery grounds for shrimps by studying the abundance of juveniles near the planted mangroves compared to areas near the natural mangrove strand. All above attempts at evaluating planted mangroves have been ecological evaluations, and thus, evaluation of planted mangroves from the point of view of societal benefits has been limited. This study attempts a socio-economic assessment of the planted mangroves of Gujarat by measuring the economic benefits being delivered to society.

The sections below discuss the mangroves of Gujarat, the research hypothesis, methodology, data used, findings, research gaps, policy implications etc. sequentially.

2. The Mangroves of Gujarat

The West Indian State of Gujarat having co-ordinates 23.2167° North latitude and 72.6833° East longitude has a long coastline of 1,650 km (over 21% of the Indian coastline) and holds 1103 sq.km of mangroves (24percent of Indian mangroves) (FSI, 2014). The mangroves here are devoid of dense mangroves as only 16% are found to be moderately dense, the rest being open mangroves. Of the twelve coastal districts of the state, Kachchh district holds almost 72% of the state's mangroves, the Kori Creek region on the north-western tip of the Gulf of Kutch accounting for about 66% and the southern Kutch area holding the rest 6%. This is followed by other districts like Jamnagar (15%), Bharuch (4%), Ahmedabad (3%), Surat (2%), and Anand, Bhavnagar and Navsari (1% each). Each of the other coastal districts like Amreli, Junagadh, Rajkot, Vadodara and Valsad hold less than 1% each of the total mangrove cover of the state. Gujarat mangroves are mostly stunted with an average height of 1 meter (except South Gujarat) and are less diverse unlike the mangroves of East coast of India and are dominated by the *Avicennia marina* species, especially in Gulf of Kutch region where it is the only species. The mangroves of South Gujarat are more diverse having nearly 16 different species present there (Pande and Pandey, 2009; GEC, 2008; Hirway and Goswami, 2007; Singh et al. 2012; Dasgupta and Shaw 2013). The state has achieved remarkable success in mangrove plantation and its mangrove cover has witnessed an increase of 676 km^2 in between 1987-2013, making it the second largest mangrove holding state in India after West Bengal (FSI, 2014). After this remarkable achievement, other potential areas to the extent of 810 sq km (Pande and Pandey, 2012) have been identified where mangroves can be planted in future. Based on Forest Survey of India's publication, Table 1 and Figure 1 show the remarkable success of Gujarat compared to other Indian states in increasing the mangrove cover.

Table 1 shows that all coastal states except Andhra Pradesh and Andaman and Nicober Islands have witnessed some increase in mangrove cover over the years. However, Gujarat state has witnessed the highest

[4] *https://www.cbd.int/marine/voluntary-reports/vr-mc-wb-en.pdf, accessed on 2nd April 2015*

increase to the tune of 631sq km whereas the increase is marginal for other states like 79 km^2 in West Bengal, 46 km^2 in Maharashtra, 23 km^2 in Odisha, 3 km^2 in Karnataka etc. Figure 1 brings out this disparity more clearly. Andhra Pradesh and Andaman and Nicober Islands show a net decrease in mangrove cover and the rest show a net increase, but the increase in every state is meagre compared to Gujarat. FSI data shows Gujarat to have lost 120 km^2 of mangroves in between 1999 and 2001, this is however reported to be partially due to change in scale of measurement of FSI data (Hirway and Goswami, 2007).

However, this assessment from Forest Survey of India seems to be an underestimate of the mangrove cover of Gujarat when the mangrove cover is measured after digitizing the satellite images of the coastal regions of the state. This study assessed the mangrove cover of Gujarat for three different periods, 1939, 1990 and 2013. The source for 1939 mangrove cover was "India and Pakistan AMS Topographic Maps, NF 45-14 Cuttack," Perry-Castañeda Library Map Collection, University of Texas, Austin[5], and for 1990 and 2013, Indian Satellite image – LANDSAT TM – 1990 and RESOURCE SAT – 2 – LISS-III – 2013 respectively, the last two being with a resolution of 23 meter. A sequence of complex methodologies like Geo-referencing, Mosaic of spatial data, Clipping of data from unused area, Image enhancement, Interpretation

Figure 1: Change in Mangrove cover of coastal Indian states between 1987 and 2011.

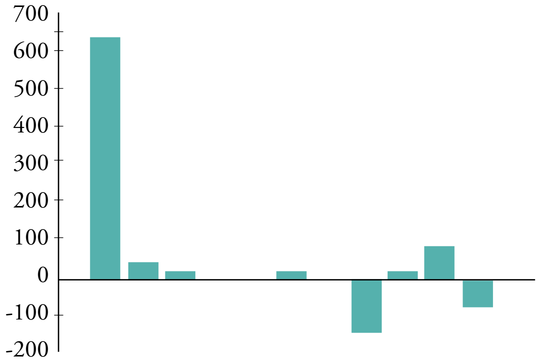

Table 1: Change in mangrove cover (in km^2) compared to previous estimate

Year/States	1989	1991	1993	1995	1997	1999	2001	2003	2005	2009	2011	Total change in mangrove cover
Gujarat	-15	-15	22	270	212	130	-120	5	75	55	12	631
Maharashtra	-26	-1	42	0	-31	-16	10	40	28	0	0	46
Goa	3	0	0	0	2	0	0	11	0	1	5	22
Karnataka	0	0	0	2	1	0	-1	1	0	0	0	3
Kerala	0	0	0	0	0	0	0	8	-3	0	1	6
Tamil Nadu	24	0	-26	0	0	0	2	12	1	3	0	16
Puducherry	0	0	0	0	0	0	0	1	0	0	0	1
Andhra Pradesh	-90	-6	-21	5	0	14	-64	-4	25	-1	-1	-143
Odisha	-7	3	0	0	16	4	4	-16	14	4	1	23
West Bengal	33	10	0	4	2	0	-44	39	16	16	3	79
Andaman and Nicobar Islands	287	-2	-5	0	0	0	-177	-131	-23	-20		-69
Daman and Diu	0	0	0	0	0	0	0	1	0	0	1	2
Total	209	-11	12	277	204	134	-389	-34	133	58	24	617

[5] *www.lib.utexas.edu/maps/ams/india/nf-45-14.jpg*

of satellite image, Generation of GIS layers from different spatial data, Superimposition, overlay, union and intersection of different data for both interpretation and analysis, calculation of area statistics, etc. were followed to measure the mangrove cover for these years. Table 2 shows the taluka level mangrove cover of the coastal districts of Gujarat for these years and Figure 2 shows the mangrove cover over three important areas of the state, the Kori Creek, Gulf of Kutch, and Gulf of Khambat.

Historically, as observed from Table 2 and Figure 2, the state had extensive mangrove covers to the extent of 854.93 km^2 which were mostly spread in the Gulf of Kutch region, mainly in Bharuch taluka of Kutch district and over the entire Jamnagar coast. This is also supported by the Gazetteers of the state – "*The South-Western Coastal Area Joined by the Little Rann of Kutch* endows swamps vegetated with mangrove forests on one hand and the sand flats and dunes-vegetated by grasses, etc., on the other terminating into the Little Rann of Kutch" (Gazetteer of Kutch, 1971). Surprisingly, the Kori Creek region that endows the largest mangrove cover of the state at present had no mangrove in 1939 (See Annex Figure 6).

The area was covered with salt waste which, probably got washed off and mangroves started habituating the area (Figure 2). The other historical mangrove habitats were Bhavnagar and Bharuch districts in Gulf of Khambat and few pockets in Anjar and Abdasa talukas of Kutch district. Interestingly, in place of just 16 talukas that had mangroves in 1939, 42 talukas in 1990 and 32 talukas in 2013 are seen to have mangroves implying that mangroves were either planted in non-mangrove habitats, like mud flats or have come up naturally in some areas (as seen in case of Kori Creek islands). Forest Survey of India reports the mangrove

Figure 2: Mangrove cover in Gujarat 1939, 1990 and 2013

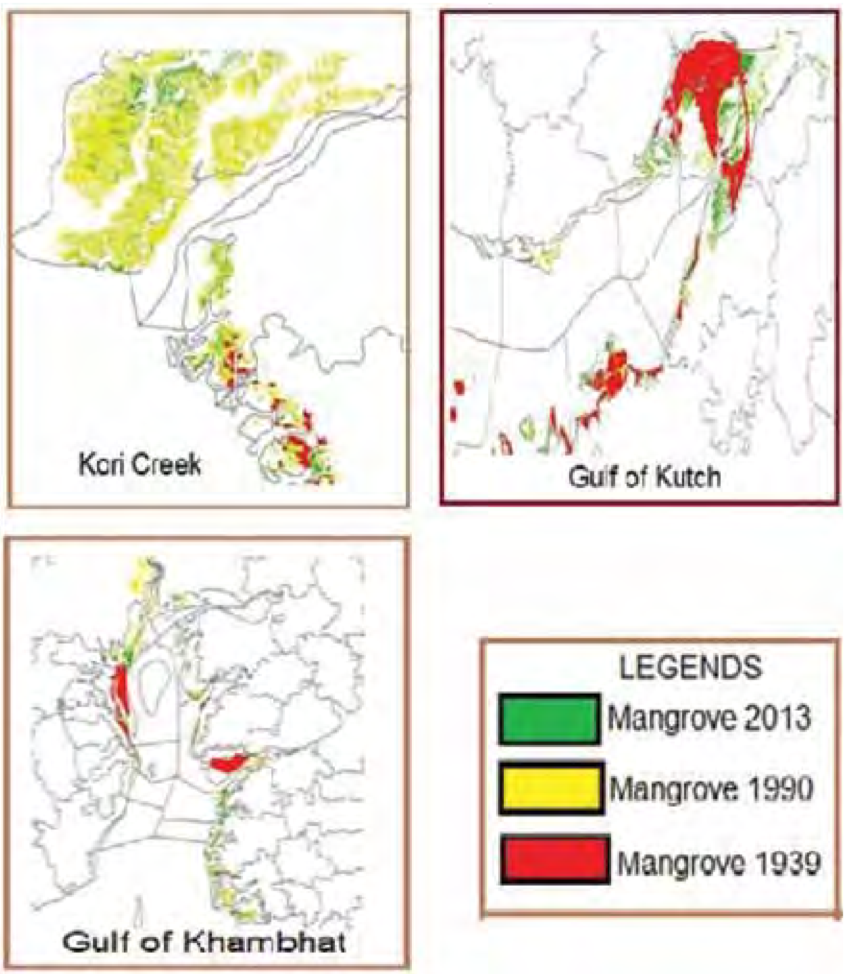

Table 2: Assessment of Mangrove cover (in km^2) of Gujarat from Satellite images

Taluk	District	MANGROVE_1939	MANGROVE_1990	MANGROVE_2013
Dhandhuka	Ahmedabad	3.18	68.98	33.93
Dholka	Ahmedabad	0	6.88	0
Jafarabad mahal	Amreli	0	0	0.75
Rajula	Amreli	0	0.49	1.92
Borsad	Anand	0	0.08	0
Khambhat	Anand	0	19.07	8.52
Amod	Bharuch	0	0	0
Ankleshwar	Bharuch	0	1.02	0
Bharuch	Bharuch	0	2.47	0
Hansot mahal	Bharuch	0	4.45	19.99
Jambusar	Bharuch	0	6.05	11.79
Vagra	Bharuch	80.87	21.98	23.76
Bhavnagar	Bhavnagar	104.58	11.72	20.3
Ghogha mahal	Bhavnagar	0.244	1.92	0.95
Mahuva	Bhavnagar	0	1.02	0.13
Talaja	Bhavnagar	0	4.26	2.46
Jamnagar	Jamnagar	105.48	44.57	107.91
Jodiya	Jamnagar	50.62	8.65	87.88
Kalyanpur	Jamnagar	19.92	7.26	20.95
Khambhaliya	Jamnagar	38.33	14.47	64.11
Lalpur	Jamnagar	7.87	0.85	9.72
Okhamandal	Jamnagar	6.89	2.74	9.54
Kodinar	Junagadh	0	0.14	1.5
Maliya hatina	Junagadh	0	0.08	6.46
Mangrol	Junagadh	0	0.09	0
Una	Junagadh	0	1.11	4.51
Veraval	Junagadh	0	0.09	0
Abdasa	Kachchh	21.658	31.44	81.4
Anjar	Kachchh	21.859	6.92	39.57
Bhachau	Kachchh	366.82	83.172	314.741
Kori creek	Kachchh	0	429.95	651.01
Lakhpat	Kachchh	8.85	36.56	89.34
Mandvi	Kachchh	0	0.26	0.91
Mundra	Kachchh	0	16.15	21.04
Gandevi	Navsari	0	0.14	3.99
Navsar i	Navsari	0	9.46	15.28
Porbandar	Porbandar	2.45	1.44	0

Contd...

Taluk	District	MANGROVE_1939	MANGROVE_1990	MANGROVE_2013
Maliya miyana	Rajkot	15.31	0.9	0
Chorasi	Surat	0	19.95	13.13
Olpad	Surat	0	6.58	22.64
Padre	Vadodara	0	2.06	0
Umargam	Valasad	0	0.51	1.25
Pardi	Valsad	0	0.24	0.82
Valsad	Valsad	0	0.19	1.68
Total mangrove cover		854.931	876.362	1693.881

cover of Gujarat to have been 397 km^2 in 1991, whereas my estimate based on satellite images shows it to be 876.36 km^2 after taking into account every little patch of mangroves found in different areas of the state. These estimates, however, match well with the estimates given by Gujarat Ecology Commission, 1024.03sq. km, for the year 2006 (GEC, 2009). Mangrove covers in 1990 and 2013 are much larger than what the state had endowed historically, though as per regular estimates from Forest Survey of India and studies on status of mangroves in Gujarat, there was rapid decline in mangrove cover in 1990s and possible reasons were industrial development, anthropogenic pressures due to over exploitation, natural disasters etc (Hirway and Goswami, 2007; Dasgupta and Shaw 2013). In spite of the pressures, the present spread of mangroves is much wider, nearly two times more in the state compared to the historical spread, and this increased spread has been possible because of sustained plantation initiatives of the state government. Probably, Gujarat is the only state in the world where the present day mangrove cover is much larger, nearly twice, than what it endowed historically in 1930s before the industrial development of the coastal regions of the state took place.

2.1. Mangrove Plantation in Gujarat

The policy decision to plant mangroves was initiated as early as 1948 in the state. *"The Forest Department (1948) of Kutch implemented a number of schemes for the state's development of forests. This included an initiative on the improvement of mangrove forests, which began from the First Five Year Plan. The basic idea behind the scheme was the protection of harbours and port areas from siltation through the process of mangrove plantation. During the three plan periods, around 1,498 hectares of area had been planted at a cost of 109, 558 Rupees" (Gazetteer, 1971, pp 210).* By 1989, creeks of Kutch had wide spread mangroves (Gazeetteer, 1998, pp 419). Thus, the wide spread mangroves areas that one finds today around the creeks of Gujarat are mostly planted and are the results of government initiative. This probably explains the lack of species diversity in these mangroves and their characteristic low height as they are mostly planted over mud flats with high levels of salinity and no fresh water.

The reported decline in mangrove cover from 1031 to 911 km^2 in between 1999 and 2001 in Forest Survey of India report alerted the state government and efforts for restoring degraded mangroves were intensified with the decision to not just plant in degraded mangrove areas but to plant mangroves in new areas also (GEC, 2008). Depending on the location, different mangrove plantation techniques have been used in the state, like (i) Poly Plot (PP) plantation in open sea shore areas, (ii) Enrichment Plantation (EP) in areas generally having sparse mangrove vegetation, (iii) Direct Seed Sowing (DSS) in blank areas devoid of mangroves, and (iv) Fish Bone Channel (FBC) method in areas with poor inundation.[6] Initially, all efforts at restoration were managed by the government and the active involvement of people of the community was completely neglected. However, the Gujarat Ecological Commission (GEC) later on pushed for participatory management of mangroves, as it was realized that the local people are among the principal stakeholders in mangrove forests and without their patronage, forest conservation will be difficult. The recent years are witnessing increasing participation of private sector in mangrove plantation under Private- Public-Partnership (PPP) arrangements (Viswanathan, 2011).

REMAG (Restoration of Mangroves in Gujarat) project was one of the first multi-stakeholder initiatives focusing on community-based approach to mangrove restoration programs in the state. It was a five year project

[6] *file:///C:/Users/IEG/Downloads/The_status_of_mangroves_in_Gujarat_CNPandey___R_Pandey%20(1).pdf, accessed on 12th April 2015.*

that started in 2002, was funded by the India-Canada Environment Facility (ICEF), New Delhi and involved the industry for the first time by asking them to invest in conservation and regeneration. By 2007, 4100 hectares of mangroves were planted under it. After the closure of REMAG, the government continued its efforts at restoring mangroves by extending the prevailing programmes based on the nexus of industry and local communities. Table 3 compiles mangrove plantation data from different sources for some years that show the scenario to be changing from pure government plantation to increasing involvement of private sector after the implementation of the REMAG project in 2002-03.

The primary goal of the public private partnership (PPP) model of the restoration initiative is "ecologically and socially responsible and sustainable management of mangroves" by building an alliance between the private sector, public agencies and the local communities (GEC, 2008). GEC works as a nodal agency and has selected many organizations as Project Implementation Partners (PIPs), namely Vikas Centre for Development (Ahmedabad), Gujarat Institute of Desert Ecology (Bhuj), Mahiti Gram Vikas Sanstha (Dholera), Shri Khambhat Taluka Anusuchitjati Sahkari Kheti Tahtha Utpadak Sangh and Manav Kalyan Trust (Khedbrahma) etc. These PIPs work as facilitators for community sensitization, formation and maintenance of Community Based Organizations (CBO's), micro-planning, project implementation, etc. All these initiatives have ultimately resulted in a remarkable increase in mangrove cover of the state and an ecologically sensitive coastal community and corporate sector.

3. Evaluation of the Ecosystem Services of Regenerated Mangroves of Gujarat

Assessment of ecosystem services provided by regenerated mangroves elsewhere concludes a successful mangrove restoration project, in terms of delivery of ecosystem services, to depend on multiple factors like slope and height of mud substratum, distribution of freshwater inputs, species composition, abundance and size structure of mangrove stands, density of detritivorous invertebrates, energy flows and other linkages within and extraneous to the ecosystem, the vertical zonation pattern of organisms etc. (Kaly and Jones, 1998). Most of the planted mangroves areas in Gujarat, in contrast, have no source of fresh water, are single species, mostly sparse and thus, do not possess most of the above features. Though regenerated mangroves in south Gujarat areas have perennial source of fresh water and are bio-diverse, the mangrove cover here is much limited, just 6% of the total mangrove cover of the state. As the remaining 94% of mangroves are found over mud flats or over islands with no fresh water, are sparse, constitute single species, and are stunted, the gain to the state from this massive investment is questionable and thus, forms an important research question for sustainability. With this

Table 3: Mangrove plantation in Gujarat by different agencies

Year	Hectares planted			
	Forest department, Government of Gujarat	Private sector (PPP model)	Indo Canada Environment Facility (ICEF)	Total
1983-84	7	……	……	7
1984-85	101	……	……	101
1985-86	104	……	……	104
1986-87	17	……	……	17
1987-88	400	……	……	400
1988-89	537	……	……	537
1989-90	402	……	……	402
1990-91	280	……	……	280
1991-92	796	……	……	796
1992-93	905	……	……	905
1993-94	1063	……	……	1063
1994-95	1204	……	……	1204
1995-96	709	……	……	709
1996-97	900	……	……	900
1997-98	1631	……	……	1631
1998-99	2803	……	……	2803
1999-00	3124	……	……	3124
2003-04	……	……	1250	1250
2004-05	……	……	560	560
2005-06	……	……	1101	1101
2006-07	……	360	1190	1550
2007-08	165	620	……	785
2008-09	285	560	……	845
2009-10	985	950	……	1935
Hectares planted by different agencies				23009

The study evaluates three different ecosystem services of planted mangroves: contribution to fishery (supporting/habitat service), contribution to coastal protection (regulating service) and contribution to livelihood (provisioning service) for the state of Gujarat

background, the present research tried to assess whether and to what extent the state is benefiting from some of the ecosystem benefits of the mangroves after these massive plantations took place. The objectives of the study were to seek answers to the following:

- How effective are regenerated mangroves as a habitat and nursery ground for fishery compared to natural mangroves?
- How does the mangrove-fishery linkage get modified by anthropogenic intervention, especially affluent discharge?[7]
- What are the contributions of planted mangroves to local livelihoods and which social strata are maximum beneficiaries of such investments?
- Has mangrove plantation provided any coastal protection in the form of reducing coastal erosion?

Thus the study evaluates three different ecosystem services of planted mangroves, contribution to fishery (supporting/habitat service), contribution to coastal protection (regulating service) and contribution to livelihood (provisioning service) for the state of Gujarat. The first two were evaluated with the help of primary and secondary data whereas the assessment of the third one is based on existing studies that have valued the provisioning services of planted mangroves of Gujarat.

3.1. Contribution of Planted Mangroves to Gujarat Fishery

Natural mangroves are proved to provide nursery and habitat to fish fry and juvenile fishes and thereby help to increase the fish growth and fish catch of the region and contribute to the economic welfare of people. Hutchison et al. (2014) provides a comprehensive account of the ecological processes through which mangroves contribute to fishery:

"Mangroves enhance fish production via two main mechanisms – the provision of food and of shelter. Their leaves and woody matter (detritus) form a key part of the marine food chains that supports fisheries. Decomposers of this detritus include micro-organisms such as bacteria and oomycetes, as well as some commercially important crab species. These decomposers process the leaves and woody matter into more palatable fragments for other consumers. .... Mangrove productivity is further enhanced by productivity of periphyton and phytoplankton occurring on mangrove trees, in their soils and in the water column, which typically have lower rates of productivity than the trees themselves, but are nutritionally more accessible to consumers. ... Mangrove roots and trunks provide a structure that species such as oysters can grow on. Their roots also trap fine particles, creating soft soils ideal for molluscs and crustaceans to burrow in. Mangroves also provide shelter for many species, enabling them to avoid predation and also invest more time in feeding (pp-6)".

Thus, mangrove existence is an important determinant of fish stock, the potential fishable biomass of a region and fish catch, though sustainability of fishery is more influenced by how the fishery is being managed. Though near coast fisheries like inshore mixed fisheries and inshore molluscs and crustacean fisheries are the most likely beneficiaries of mangroves' habitat services, commercial fisheries that operate many kilometres away from mangroves also benefit from mangroves' nursery habitat role or protection from predation service (Hutchison et al., 2014). There are many prominent studies (Lahmann et al., 1987; Freeman, 1991; Parks et al., 1994; Sathirathai, 1998; Barbier and Strand, 1998; Ronnbaek, 1999; Barbier, Strand and Sathirathai, 2002; Barbier et al., 2011) that have valued contribution of natural mangroves to increased fish growth in nearby areas and to the welfare of the fishing community. Mangrove deforestation of 320 km^2 in Thailand in between 1983-93 (32 km^2 annually) was shown to have resulted in annual welfare loss of US $408,000 to US $12,000 for the coastal fishermen community who practice artisanal as well as off shore fisheries (Barbier, Strand and Sathirathai,

[7] *The initial objective was to assess the effect of species biodiversity and rate of forest growth on mangrove fishery linkage, but later on the objectives were modified as these features are absent in mangrove areas of Gujarat.*

2002). The value of mangroves to different types of fisheries has been valued at various parts of the world and annual catch value of mangroves is seen to vary from US$0.14 million to US$6.1 million for off shore prawn fisheries and from just US$34 to US$2.7 million for inshore coastal fisheries (Christensen et al., 2008; Jansen and Padilla, 1999; Ruitenbek, 1999; Barbier and Strand, 1998). Based on other studies, Ronnbaek (1999) has quoted the dependency ratios of fishery on mangroves for different areas -- 80% for Florida, USA (Hamilton & Snedakar, 1984), 60% for Fiji (Hamilton & Snedakar, 1984) and India (Untawale, 1986), 67% for East Australia (Hamilton & Snedakar, 1984), 49% for Malacea Strait (Macintosh, D.J., 1982) and 30% for ASEAN countries (Singh et al., 1994). These numbers prove the critical role that mangrove plays for fishery of a region. The present study's contribution will be the evaluation of mangrove fishery linkage for planted mangroves and the use of a more sophisticated Difference-in-Difference (DID) technique to measure the planted mangroves' effect on fish catch.

Studies assessing the contribution of planted mangroves to fishery have followed simple techniques like comparing the fish abundance in planted mangroves to that in natural mangroves or in non-mangrove areas and have come up with different results. Some of these find replanted mangroves contributing similarly (or even better) compared to natural mangroves if planted mangrove strand has low elevation and is in good health, whereas poorly if denuded (*Crona and Ronnback, 2005; 2007*). Similar was the conclusion of Walton et al. (2006a and 2006b). The first two studies are based on Kenya and the second two, on Philippines. Studies on the Indian state of Gujarat where mangrove plantation has been wide spread also report increased fish catch after mangrove plantation (*Viswanath, 2011; Hirway and Goswami, 2007*).

There are studies that have come up with opposite observations. A study from Gazi Bay, Kenya and another from Pasir Ris in the eastern part of Singapore found fish catch from mangrove cleared sites, and sandy beaches to be more than the catches from reforested mangrove strands (Huxhan *et al., 2004; Jaafar et al., 2003*). These studies highlighted the need to control for temporal and site specific features that can affect fish growt h or fish catch while evaluating planted mangroves as nursery ground for fish. Single species mangrove plantation has been found to provide little ecosystem services, show lower capacity to regenerate and thus, to be unsustainable in the long run *(Rovai, et al., 2012)*. One interesting study from Kenya where the local community's perception is used to compare the ecosystem services from planted mangroves compared to natural mangroves clearly put s natural to be better than planted. Benefits from planted mangroves were reported to be nearly one third of similar services from natural strands in many cases *(Ronnback et al., 2007)*. Local communities observe the flow of ES over time and their opinion is less influenced by temporal or locational factors and thus, this assessment is more generic than the ones based on either one or two days sample. These studies also highlight the need to control for features like forest health, species diversity, site features, and temporal variations in order to make an unbiased assessment of planted mangroves compared to natural forests. As mentioned before, there exists little variation in health, diversity or site specific features of mangroves of Gujarat as 84% of sparse and dense mangroves are limited to few pockets, but there are areas with natural and planted mangroves, different types of plantation, and most specifically with different levels of water pollution from coastal industries and other developments. The research methodology of the study was developed to capture the effect of these features on the mangroves fishery linkage.

3.1.1. Research Methods

Though mangrove plantation is an old practice in Gujarat that started as early as 1950s during the first five year plan period (Gazetteer, 1971), there is no regular record publicly available to determine the net yearly addition to mangrove stock in these earlier periods. Regular estimates are available since 1987 with the publication of Forest Survey of India reports and these show mangrove cover to be increasing from 1993 onwards and declining before (see Table 1). The state witnessed a marginal increase of 22 km^2 in 1993, but a sharp increase of 270 km^2 in 1995 and afterwards. It may be that hectares planted were much less compared to hectares deforested before 1993. Table 3 shows that large scale plantation of mangroves happened only after 1991-92, when 800-900 hectares or more were planted every year. However, one doesn't have the survival rate of planted mangroves in Gujarat and is also not aware of the number of years these mangroves take to reach nearly one meter height after which they are likely to provide ecosystem services and act as nursery and habitat for fishes.[8]

As mangroves can be captured by satellite images if they are approximately one meter of height, I assume the increased mangrove cover as per the FSI report to be mature planted mangroves capable of providing

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ecosystem services including nursery ground and habitat for fishery. So I measure the effect of planted mangroves on Gujarat fishery from 1995 onwards using FSI data as the base. Keeping international literature in mind, mangrove effect was assessed for two different types of fishery, inshore artisanal fisheries and offshore commercial fisheries as both are beneficiaries of mangroves' nursery and habitat services.

3.2. Inshore Coastal Artisanal Fishery

3.2.1. Research Approach

Inshore fishery are usually mixed species fishery as the local fishermen, called *'Pagediya Fishermen'* in Gujarat, use simple nets for fishing and catch whatever species get into the net. They fish in different creeks near their houses and the creeks have different features, for example they may have natural mangroves or planted mangroves or no mangroves and the water of the creek could have different levels of pollution depending on the level of industrial activity on the coast on which the artisanal fishermen have no control. I exploit such diversity in creek features to measure the effect of planted and natural mangrove on inshore fishery and assess to what extent these effects get modified by pollution. Thus, the assessment of mangrove plantation on inshore fishery was in terms of total catch per day including all species per fisherman from different creeks. Multivariate regression analysis using a daily panel data, collected through *Pagediya* fishermen survey, was used to derive the results. The details of the survey and the results are presented in the results section below.

3.2.2. Data and Results

Pagediya fishermen in Gujarat are traditional artisanal fishermen who practice such fishing in nearby creeks. Almost all of them use a net as the main fishing instrument and spend nearly same number of hours in fishing. A pagediya fishermen survey was conducted simultaneously in 6 different fishermen's villages of Kutch district in the months of December-January, 2014 where the daily catch of each surveyed fisherman was recorded on every alternative day for nearly one and half month that gave on average 20 days of information on each fisherman. This survey was conducted simultaneously in all villages to neutralise the seasonal effect on catch and samples were collected for nearly 20 days from each fisherman, which also neutralised any day to day fluctuations in catch or in health of the fisherman or any outlier catch effect. In each village, 10 fishermen were randomly selected and their daily catch was recorded in the evening (with the help of women of the households) after they were back from fishing. On the first day, the demographic and socio-economic details of each fisherman were recorded along with fishing related details like name of the creek where fishing was done, time of departure and arrival, the fishing instrument used, and the fish catch (both number of species and weight) of the day. On subsequent visits, only fishing related details were recorded. The same interviewer repeatedly visited the fisherman's house each alternative day to record the information. This way the catch of each of these 60 pagediya fisherman was tracked for nearly 20 days each by maintaining a daily dairy of their catch. Villages were selected from different talukas like Anjar (Vandi), Mundra (Luni and Sekhdiya), Mandvi (Modhva), and Abdasa (Budiya, Lala and Rampar)[9] covering nearly 80% of the coastline of Kutch district to control for water pollution as well as different types of mangrove habitats. Both Anjar and Mundra are highly industrialised whereas Mandvi is less and Abdasa is least and similarly Anjar has creeks with natural and planted mangroves whereas Mundra has creeks with planted or no mangroves and both Mandvi and Abdasa have creeks with mostly no mangroves. Rather than selecting creeks and taking fish/juveniles samples from there as has been done in most of the previous studies (Crona and Ronback, 2005; Crona et al., 2006), this study tracked fishermen and compared their daily catch from different creeks and measured planted mangrove effect from these differences indirectly. This unique survey tracking 60 fishermen in 6 villages resulted in the daily fish catch information from 14 different creeks of Kutch district having very different features with respect to levels of pollution, mangrove cover etc. The names of these creeks along with their features are shown in appendix table 1. Creek features including extent of water pollution were collected from Prof. Thivakaran of research institute GUIDE (Gujarat Institute of Desert Ecology), the nodal agency of forest department of Government of Kutch for mangrove plantation. In total, 1029 days of daily fishing information was collected from the fishermen. Most fishermen (80%) were illiterate, had 16 years of fishing experience on an average, very few (20%) had subsidiary occupation and the average monthly expenditure was roughly ₹9000/

[8] Personal conversation with mangrove and marine biologist, Prof, A. Thivakaran (athivakaran028@gmail.com) on 12th November 2014.

[9] The name of the respective villages are in brackets.

per family. Fishermen of each village spent 9-10 hours on fishing per fishing day and all were unanimous on two things, (i) water pollution has decreased the fish catch and (ii) mangroves, wherever being planted are not helping fishery. Next the collected data was examined statistically at the level of the creeks.

Table 4 shows the simple average daily catch from creeks based on the presence of mangroves. Column 2 shows the number of species caught daily and the highest numbers, 3.2 species on average, are caught from creeks with no mangroves. Number of species caught are 2.88 from creeks having natural mangroves, 3 from creeks having enriched plantation and the lowest, 2.5 from creeks with planted mangroves. Thus, number of species available seems to be lower in creeks with natural mangrove and lowest in planted mangroves compared to creeks with no mangrove. However, when the average weight of the species caught are compared, as shown in column 3, the conclusion changes. Weight of the catch is the highest, 6.97 kg, from creeks with enriched plantation followed by creeks with natural mangroves, 6.16 kg and then creeks with no mangrove (4.81kg) and last comes creeks with planted mangroves (3.69 kg). This simple comparison shows natural mangrove areas to have the healthiest fishes giving the highest catch to fishermen. Creeks with plain mudflats having no mangroves have high density of fish species, but they are unhealthy and low in weight. Creeks with planted mangroves had the lowest catch in terms of number of species and also have the lowest catch in terms of weight, indicating that mangrove plantation is not contributing to fishery either in fish density or in fish growth, at least in the short run. Mangroves have been planted in these creeks during 2006-09, so the creeks have young mangroves of six to nine years old and they do not seem to help fishery as per this data. Fishermen made observations similar to those reported in the survey. However, these findings are not conclusive as the results of Table 4 did not control for pollution which is reported to be the most damaging factor for fishery according to fishermen. Literature also reports discharge of heavy metals and effluents from the large number of industrial units at the coast, especially oil pollutants to have severely affected the ecological health of the state's mangroves and coast (Jagtap and Nagle 2007).

So these results were re-examined in a panel data model using controls for water pollution and some demographic and socio economic features of the fishermen. Creeks were put into three categories, i.e. low pollution, medium pollution and high pollution depending on the presence of industries or ports nearby. While the creeks of Abdasa taluka (Siyari creek) were marked low polluted as neither any industry or port is located here, the creeks of Mandvi, Mundra and Anjar talukas were marked either medium polluted or highly polluted depending on the presence of pollution sources nearby. Appendix table 1 shows the details. A multivariate panel regression model was estimated using fixed effects estimates. Fixed effect estimates controls for all those time non-varying features that could be affecting daily fish catch of fishermen. Table 5 shows these results.

Table 5 shows the multivariate regression results where the coefficients were estimated using the daily panel data of the survey. The dependant variable is the daily fish catch (weight)[10] of the 57 fishermen interviewed, each for 15 to 20 days, which is explained by a number of variables like creek features (type of mangrove present, water pollution level), education and experience of fishermen, family features, what they carry in boat when they go for fishing, etc. Water pollution of creeks was categorised as low, medium and high depending on the number and distance of the sources of

Table 4: Average daily fish catch of Pagediya fishermen from different types of creeks

Type of creeks	Average number of species caught	Average weight of species caught
Creeks with no mangrove	3.2 (0.63)	4.81 (1.62)
Creeks with natural mangroves	2.88 (0.70)	6.16 (1.86)
Creeks having enriched plantations (more mangrove plantation in places where sparse natural mangrove existed)	3 (0.00)	6.97 (1.67)
Creeks with few year old planted mangroves	2.5 (0.50)	3.69 (0.87)

Note: *Figures in parenthesis are the standard deviations*

[10] *Using Value of the daily catch as dependent variable also resulted in somewhat similar result, but such results are not presented as prices reflect market behavior whereas mangrove effect is physical in terms of health of fish which is better reflected in weight of the catch.*

Table 5: Regression result for inshore mixed fishery in Kutch district based on Pagediya fishermen survey (Dependant variable = Weight of the daily catch)

Independent variables	Estimated Coefficient	Independent variables	Estimated Coefficient
Natural mangrove creek	4.237*** (7.96)	Whether educated	-0.180* (1.77)
Enriched plantation creek	3.932*** (7.24)	Number of male members	0.079 (1.57)
Planted mangrove creef	0.948*** (2.71)	Number of female members	0.025 (0.48)
Medium polluted creek	-3.008*** (8.85)	Number of children	-0.070** (2.16)
Highly polluted creek	-4.069*** (7.25)	Has other subsidiary occupation	0.143 (1.42)
Fishing experience (years)	-0.009 (1.34)	Ancestors fishermen	-0.353 (0.88)
Carry bike in boat	-0.304 (0.74)	Carry food stock in boat	0.153 (0.90)
Carry blanket in boat	0.164 (0.36)	Carry ropes in boat	-0.129 (0.54)
Constant	6.087*** (8.85)		
Joint significance test of mangrove coefficients being different than zero			chi2(2) = 1322.89***
Number of observations			1029
Number of groups			57
Observations per group			15 to 20
Wald chi 2 (16)			1950.69 (P=0.00)

***, **,* *imply level of significance to be 1%, 5% and 10%.*

pollution near the creeks as explained above. There are three mangrove variables corresponding to natural, enriched plantation and planted mangroves and they are compared to no mangrove creeks. The results show that compared to the weight of daily fish catch in creeks with no mangrove, the weight of catch is 4.237 kg higher in creeks with natural mangrove, 3.962kg higher in creeks with enriched plantation and 0.948 kg higher in creeks with planted mangroves if we control for pollution level of the creeks and other demographic and socioeconomic features of the fishermen. All these results are highly significant and mangrove coefficients are different than zero as per the joint significance test and so are the pollution coefficients. Similarly, compared to no pollution creeks, daily fish catch is lower by 3.008 kg in medium polluted creeks and lower by 4.069 kg in highly polluted creeks. These results are also significant. Other significant variables indicate that compared to uneducated fishermen, educated ones are catching less and similarly fishermen with more children are also catching less compared to ones with no or few children.

These results refute the conclusion from table 4 and refute the hypothesis that mangrove plantation has no effect on fishery. Fishermen, who fish in creeks where mangroves were recently planted (within last 4-7 years), are catching 1 kg of fish more daily compared to fishermen who fish in creeks with no mangrove. However, this result is visible only after one controls for water pollution in creeks. As expected the catch is much higher in creeks with natural mangrove and having enriched plantation which are also natural mangrove areas.

3.3. Offshore Commercial Fishery

3.3.1. Research approach

Offshore commercial fishery, in contrast, is purposive and depends on the availability of the fish species as well as types of vessels acquired. Hutchison et al. (2014) provides the ecological basis of the possible links between mangrove cover and offshore commercial fishery (see section 3.1). As increased mangrove is likely to increase the growth of some species, mangrove effect on commercial fishery was assessed in terms of catch of mangrove dependant species. Species caught through commercial fishery were put into four categories, i.e. pelagic, demersal, molluscs or crustaceans and the trend in each of these categories post 1995 were analysed using a Difference-in-Difference (DID) approach. Pelagic species are not mangrove dependant whereas the other three, especially molluscs and crustaceans are mangrove dependant and increase in planted mangrove cover was hypothesised to increase the DID coefficient significantly for these species. Table 6 explains the DID procedure. In DID approach, data is put into a before (treatment), after (treatment), with (treatment) and without (treatment) set up and the difference in average (mean) of the dependent variable between the treatment and the control area before the treatment is compared to the same difference after the treatment. The difference of these differences is called the treatment effect.

Using this approach, the difference in mean catch of above categories of fish between Gujarat and other west coast states of India before 1995 were compared to such differences after 1995. Mangrove plantation was assumed to be the treatment, so years after 1995 were the treatment years and years before 1995 were the before treatment years. Gujarat was the treatment district, and other West coast states (Goa, Maharashtra and Karnataka) were taken as the without treatment districts as there is no such mangrove plantation drive in these states.

Fish catch data for the period 1985 to 2011 has been used in this analysis. The section below describes the data used, the source, and the variables in detail.

3.3.2. Data and Results

Offshore commercial fishery is targeted and vessels are acquired to carry out targeted fishing on pelagic, demersal, or mollusc etc. It is thus natural that vessels acquisition, which are privately owned, will be guided by species availability and previous experiences. The state of Gujarat having 1640 km of coastline and 164000 km^2 of continental shelf, of which around 40% has a depth range of 0-50 m that enables both traditional and mechanized vessels to exploit fish resources, has a dynamic maritime sector. It was one of the earliest states to introduce mechanised vessels, is the leading marine fishery state in West coast of India (Figure 3) and by far has been the largest contributor of marine catch in India in many years. In 2013, Gujarat contributed 0.72 million tons (19%) out of the 3.78 million tons of fish landing of the country (CMFRI, 2014).

Table 6: Difference-in-Difference (DID) Method of explaining the change in average fish catch of areas having mangrove plantation

	Average catch With plantation (treatment)	Average catch without plantation	With without Difference
Average catch bfore plantation (treatment)	α1	β1	α1 - β1
Average catch after plantation	α2	β2	α2 - β2
Before after Difference	α1 - α2	β1 - β2	Difference-in-difference (DID) = {α1 - β1} – {α2 - β2} = {α1 - α2} – {β1 - β2}

Figure 3 shows the state of Maharashtra as the leading west coast state in fish landing till about 1990 after which Gujarat has taken the lead by increasing its landing significantly compared to other states, and has been able to retain its lead till now. The year 1988 witnessed minimum landing in Gujarat after which there seems to be a regime shift in the marine sector of the state and the landings have shown a steady increase except few years in early 2000s. The state of Karnataka is also witnessing increasing trend in marine catch, but it has happened only in the recent few years after 2004-05. Table 7 shows the overall growth rate of the species wise landing of west coast states during 1985-2013 and it shows landings of all species to have grown significantly in Gujarat, whereas Karnataka has witnessed significant increase in pelagic, demersal and mollusks, Goa in only pelagic and Maharashtra in only mollusks catches. Growth rates are higher in Karnataka in all cases except crustaceans, but these are mainly due to the recent achievements of the state.

However, growth is more striking in crustaceans and mollusks catch as the size of these fisheries was limited before 1990 and have leapt after that. Pelagic fishery has also grown in Karnataka and Goa, but the yearly landings are more consistent in Gujarat compared to these states as evident from Figure 4. The

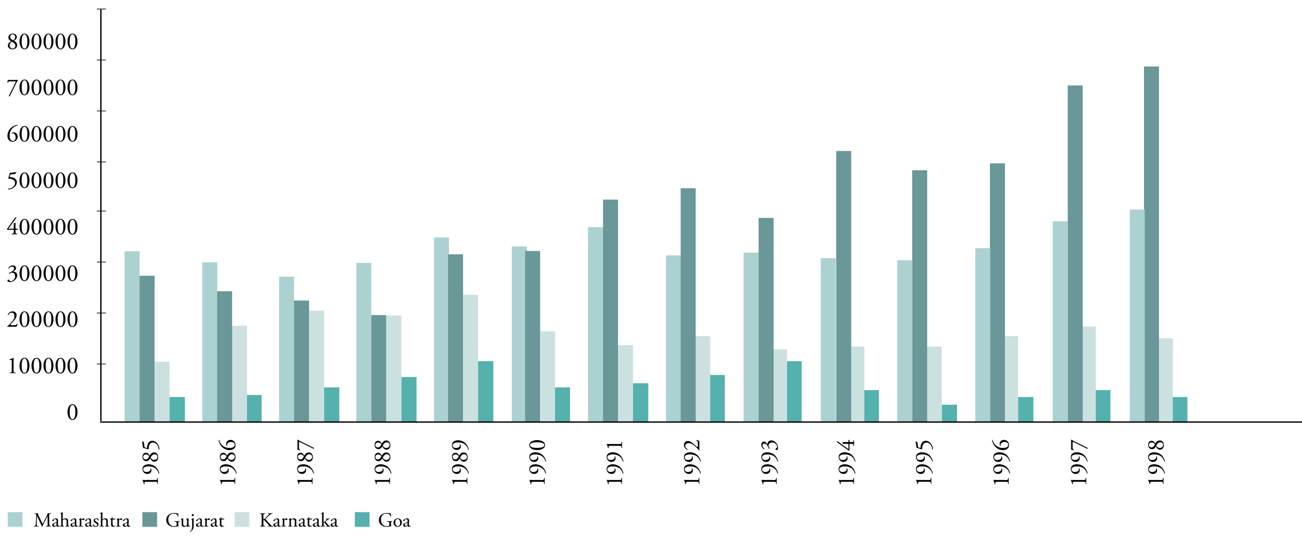
Table 7: Compound growth rate of species wise fish landings of west coast states during 1985-2013.

States	Pelagic	Demersal	Crusta-ceans	Mollusks
Maharastra	-0.05	-0.18	-0.46	1.07*
Gujarat	1.8***	2.93***	4.52***	8.81***
Karnatataka	2.75***	4.96***	0.38	11.37***
Goa	2.76***	0.59	-7.45***	1.11

*******and * are significant at 1% and 10% level of significance respectively.*

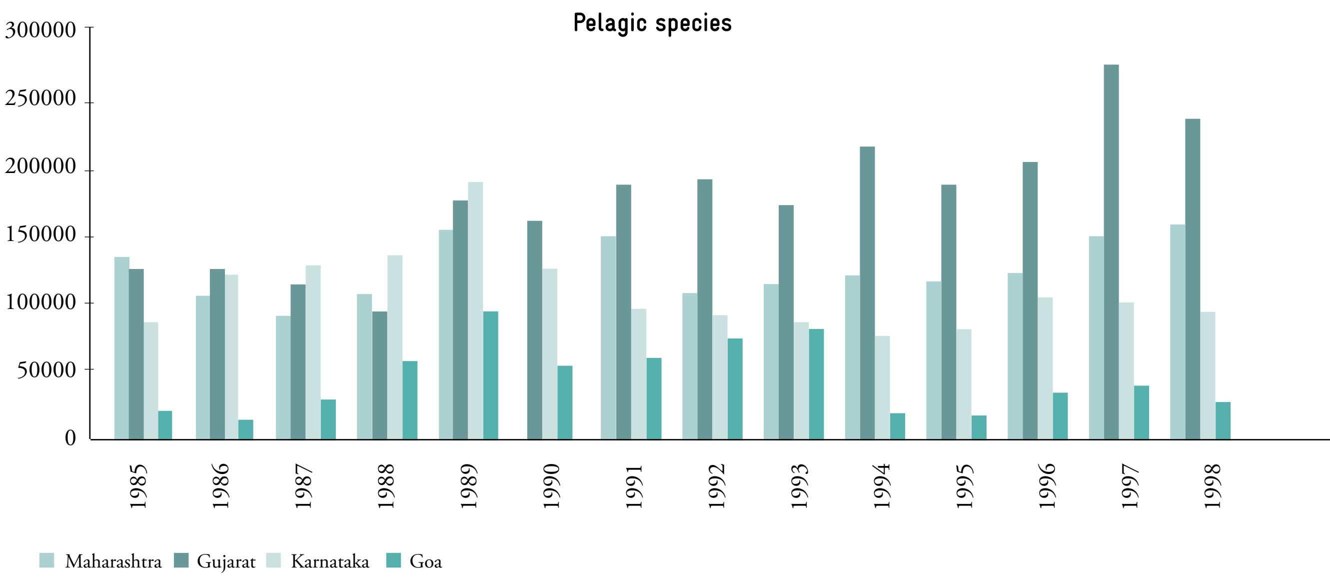
significant increase in pelagic landing in Karnataka and Goa are only in recent years. Though fishery policy of the states is the most important reasons for this turnaround of the fishery sector, mangrove plantation could also be playing a role. Demersal, crustaceans and mollusks are primarily mangrove dependant species and the growths in catch of these species are much higher compared to pelagic in Gujarat. Mangrove cover in Gujarat was always much larger compared to other west coast states and the state has planted thousands of hectares more, which has further increased the mangrove cover as well as the habitat and food for these species. Commercial fishery is not bounded by any interstate restriction of deep sea water and vessels of any state can fish anywhere. If mangroves increase the stock of demersal, crustaceans and mollusks in Gujarat coast (of course the fishes could be swimming to other areas and to deep sea, but

Figure 3: Total marine catch of West Coast states of India



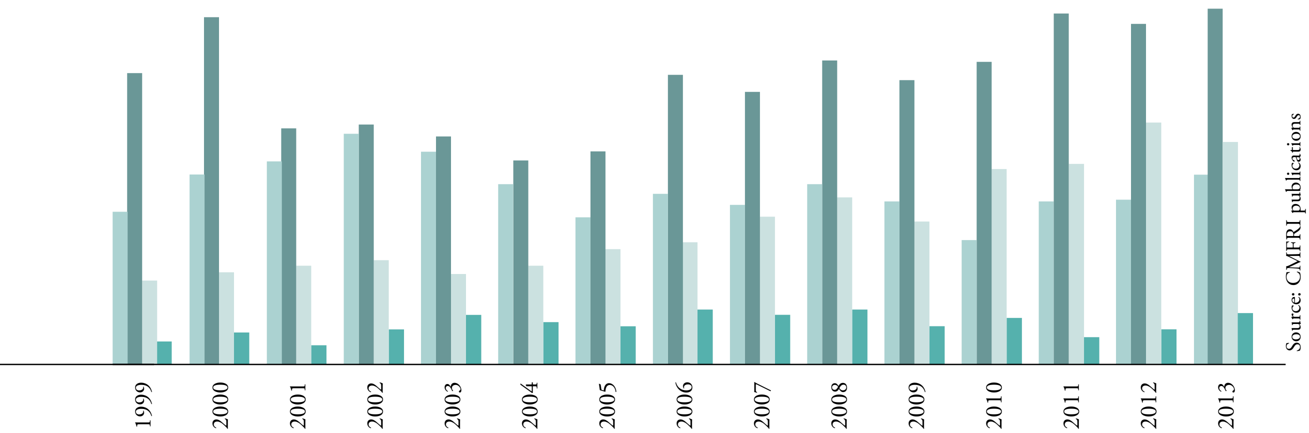
Source: *CMFRI publications*

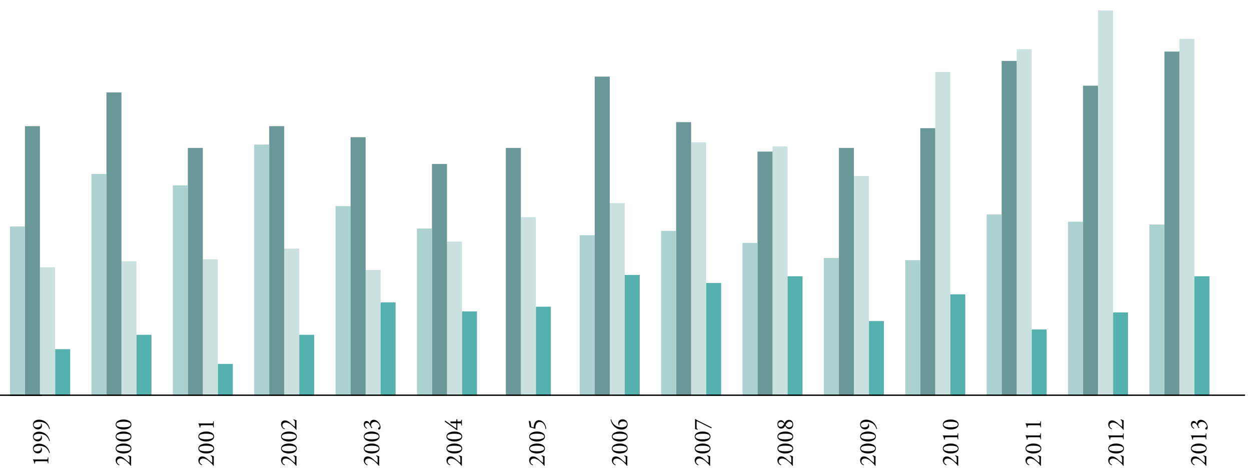
Figure 4: Species wise marine landing of west coast states of India during 1985-2013

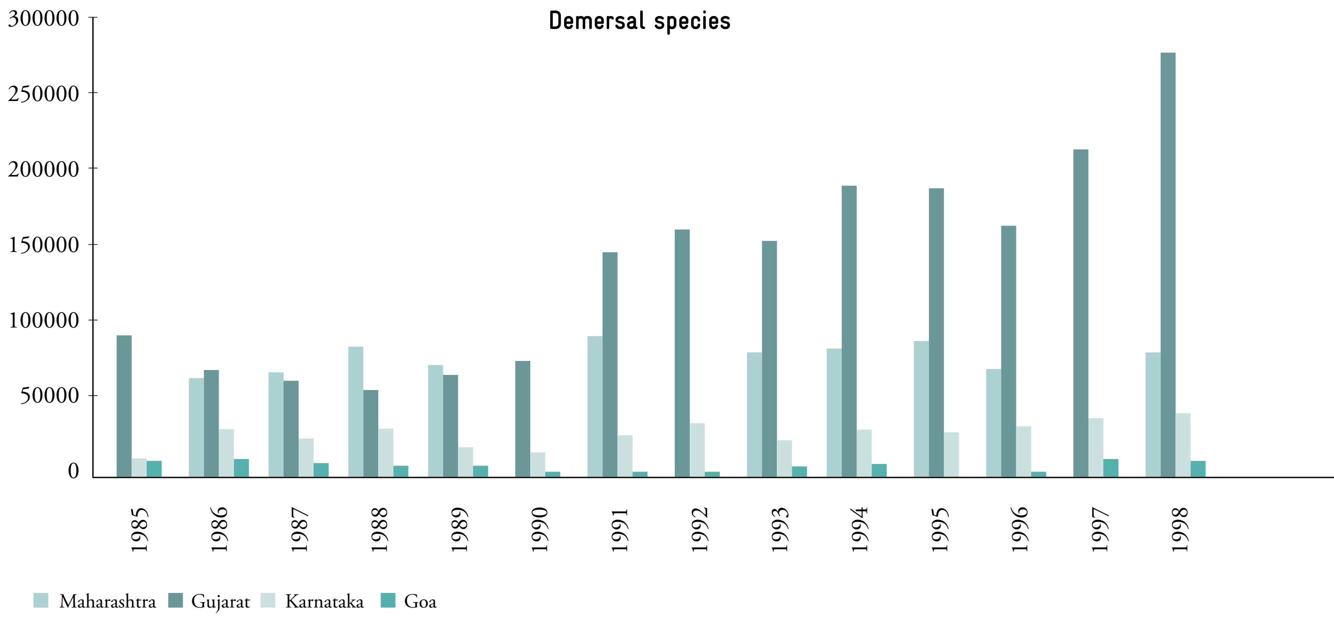


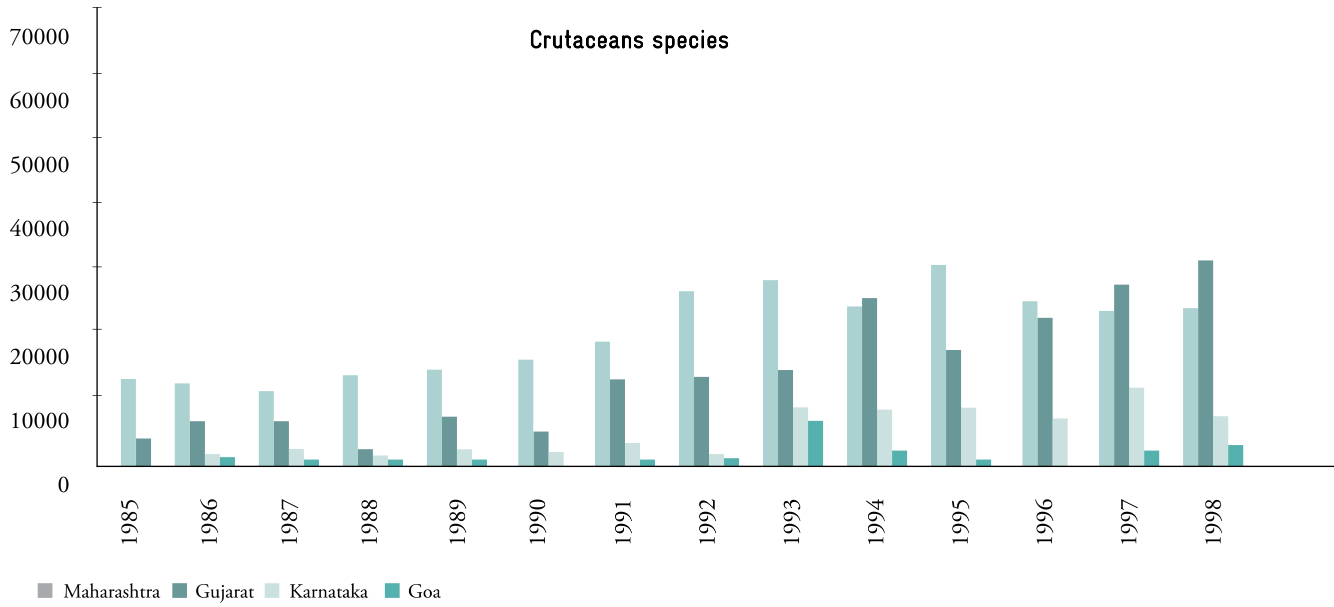
more fish should be available near mangroves), then the benefits in terms of increased catch will accrue to any vessel fishing those species there, but the maximum benefits could go to vessels of Gujarat for whom it is the least expensive to fish in that region if stock is available. So the effect of mangrove plantation on mangrove dependant species can be measured in two different ways, (i) comparing the trend in Gujarat catch with those of other west coast states and (ii) comparing the trend in catch of mangrove dependant species of all states with those of pelagic catches. To control for the fishery policy of different states, data on types of vessels used for fishing and fishery expenditure by respective state governments were used in the analysis.

As it is expensive and difficult to do a representative survey for commercial fishery, secondary data sources have been used in this analysis. Information on number of vessels engaged in fishery

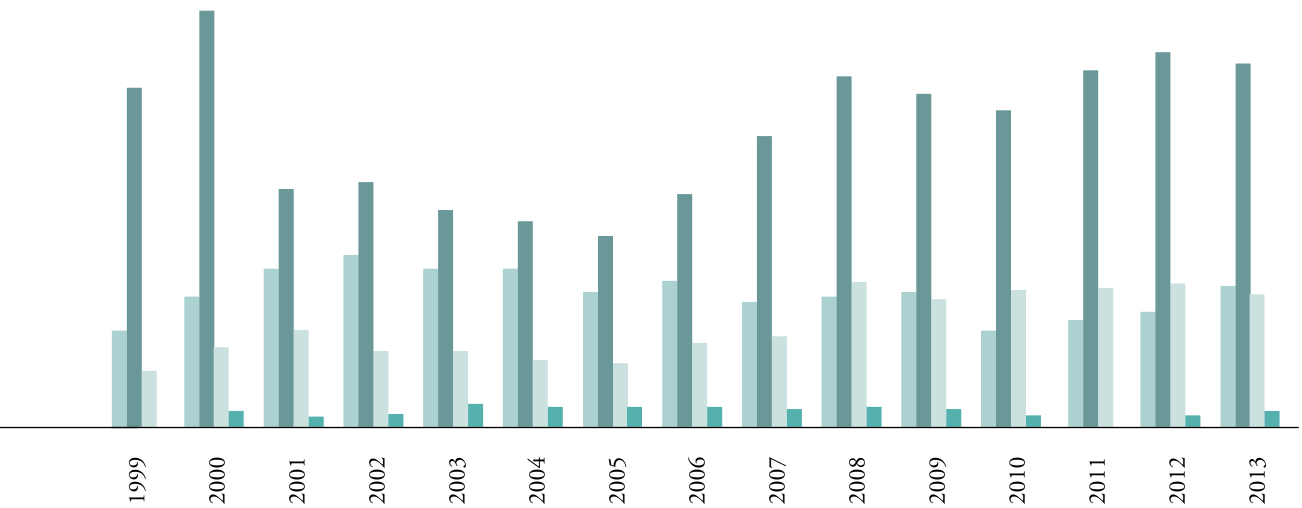


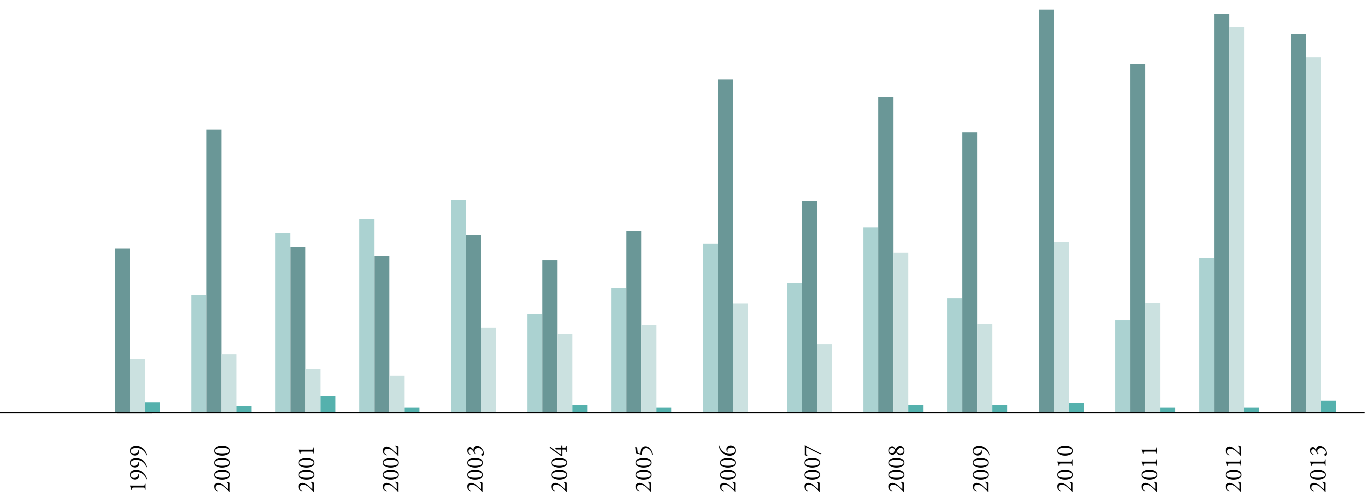






and fishery expenditures were collected from fishery surveys and reports of the Department of Animal Husbandry, Dairying and Fisheries of Ministry of agriculture. Data on fish landing was available from two sources, reports of Central Marine Fishery Research Institute (CMFRI) of India and the Reports of the Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Government of India. While CMFRI compiles the data through their regular multi stage stratified random sampling surveys at different landing centres of India, the source for the later is the fishery department of the respective state governments who also collect information through sample surveys. CMFRI collects species wise and vessel wise data from major landing centres through an intensive and carefully drafted sampling procedure and their enumerators collect at least 20 days of sample data for each month. Usually small, far off landing centres are not represented in CMFRI surveys, but since most of the landing of a state is reported in major landing centres and not in small ones, CMFRI catch data is representative of the state as a whole. In contrast, the





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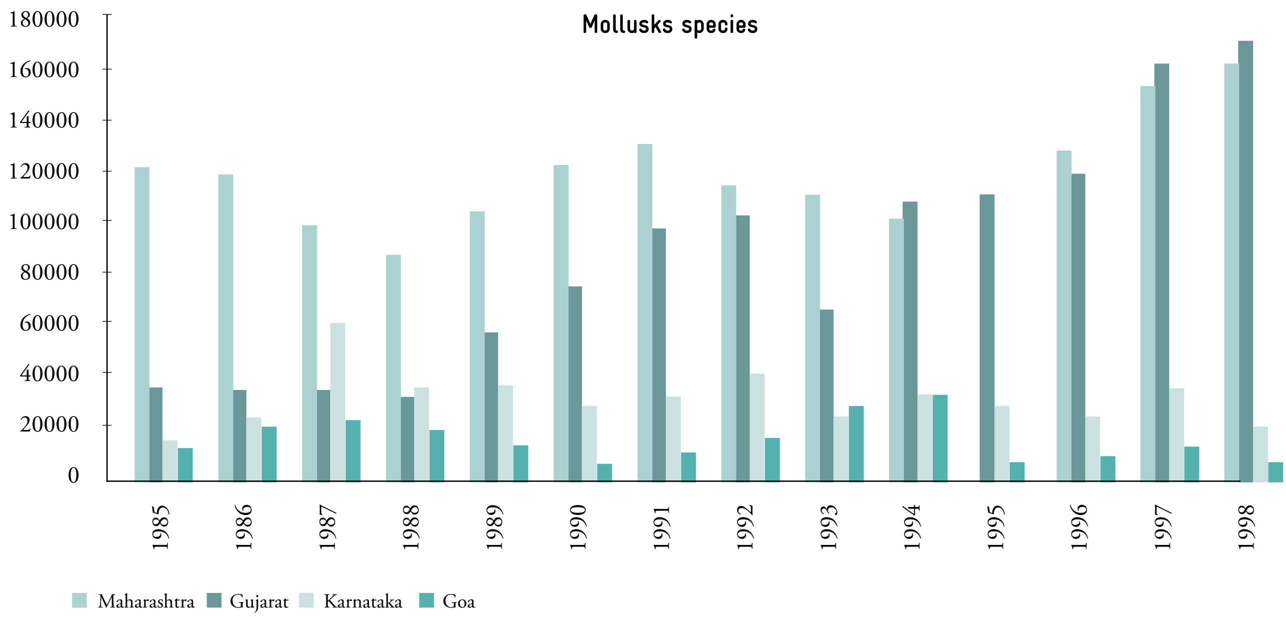
state fishery department data covers all landing centres of the state, but there being shortage of manpower and resources with the district fishery departments, who actually do the surveys and send information to state head quarters, just one or two days of sample are collected from each landing centre in a month[11] and thus, these are less representative of the fishery situation of the state as a whole. However, for carrying out a cross sectional analysis across the landing centres of the state, this data is the only source as every landing centre is represented. One should also be cautious as sometimes far away landing centres are not visited and one finds zero entries for such centres for the month (and even for the whole year, like Lakhpat in Kutch) which means no data, not zero catch.

As landing centre wise, species wise yearly data for the whole state was made available by the fishery department of Gujarat government for years 2011-2013

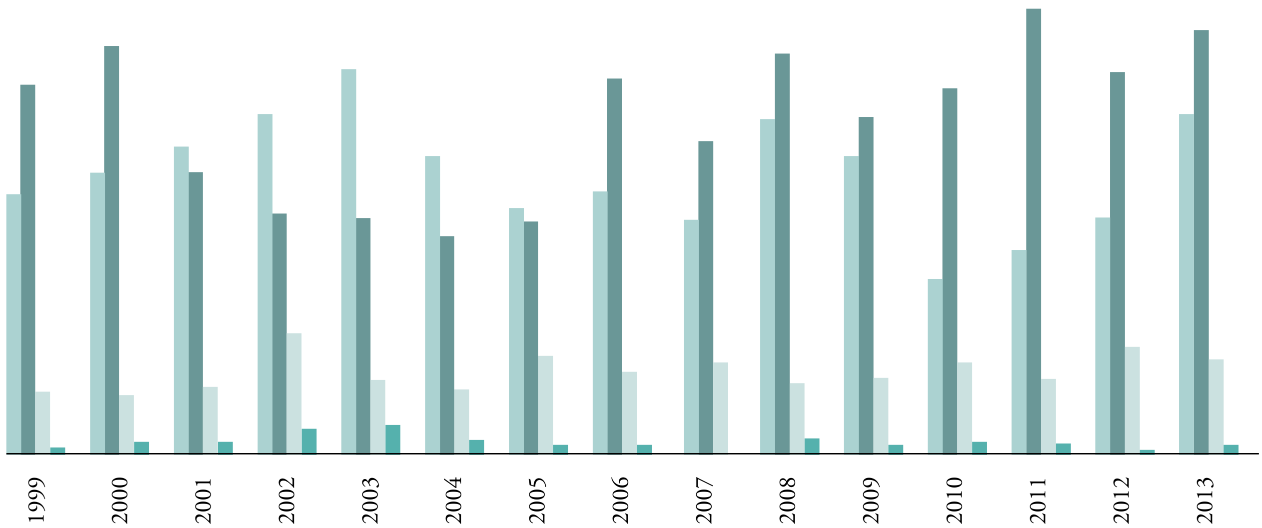
[11] *Personal discussion with fishery department staff of Kutch district, Bhuj , Gujarat on 12th November 2014.*



Source: *CMFRI publications*

and for the Kutch district by Kutch fishery department for years 2004-2013, a landing centre wise regional analysis was carried out to see if landing centres near the mangrove plantation or near existing old mangroves witness more landing compared to centres with no mangroves. Species caught were categorized as either pelagic, demersal, crustaceans or mollusks and total landing of each of these categories was regressed on mangrove cover near the landing centre and vessels registered at the landing centre, but no significant relation between fish landing and mangrove cover or fish landing and vessels registered was observed. Both sets of data gave similar results. This could mean two things: one that the data is not systematically collected or maintained or that mangrove plantation or existence of mangroves near a landing centre does not influence commercial fish landing, neither of mangrove related nor of unrelated species, at the landing centre. Vessels that report their landing could be fishing somewhere else, not necessarily near the landing centre and vessels registered at the landing centre may not report their landing at the same centre. Vessels fish in areas where stock is available and unload their catch at centres depending on the facilities available or prices offered or whichever is convenient to them. So landing data at a landing centre may not reflect the effect of the surrounding ecology. Also sampling surveys followed by government fishery departments may be unrepresentative of the total catch at a centre as the enumerator visits the landing centre just once or twice in a month to collect catch data and these figures are multiplied by number of fishing days to get the total landing of the species at the centre. Whatever may be the reason, landing centre wise catch data provided by the fishery department of Gujarat state government did not show mangrove presence to influence commercial landing of species at the landing centres close to the mangroves in the state.

Next, mangrove effect on commercial fishery was analyzed at the level of the state as increased catch by any vessel because of more availability would be reported at some landing centre and will be reflected in aggregate catch of the state. If the state of Gujarat shows increasing trend in the catch of mangrove dependant species after mangrove cover increased significantly in the state compared to other West coast states (after one controls for vessels and other features affecting fish catch) then the increased amount can be attributed to increased mangrove cover. Similarly, if vessels of other states benefit due to more availability of mangrove related fishery, then the total catch of mangrove dependant species by all west coast states should show an increasing trend compared to the trend of mangrove non-dependant species.[12] Before undertaking this analysis, it was examined whether fish landing in a state in a year is related to mangrove cover in the state or not by regressing fish landing on number of fishing vessels, fishery expenditure, time trend, mangrove cover and 1989 onwards dummy for Gujarat. This equation was also re-estimated after



replacing mangrove with change in mangrove cover. The results are in Annex Table 14 and 15. Mangrove cover is seen to have a significant and positive link with total, demersal, crustaceans and mollusks landing, but not with pelagic landing, confirming the theory that pelagic species are not mangrove dependant unlike the other three. Change in mangrove cover is also seen to have a similar relation. Next a Difference-in-Difference (DID) methodology was used to find out and segregate the planted mangrove effect, if any, on commercial fishery. DID technique separates out the effect of the treatment on treated group and treats the trend in control group as the counterfactual. The estimated DID equation, where the trend in Gujarat is compared with that of other west coast states, is the following:

$$Y_{ijt} = \alpha_0 \ \alpha_1 t_p \ \alpha_2 t_s \ \alpha_3 t_p * t_s \ \alpha_4 V_{it} \ \alpha_5 E_{it} \ \alpha_6 T \ \alpha_7 R_g \ \alpha_8 S \ \alpha_9 \varepsilon_{it}$$

where i is state (Gujarat, Maharashtra, Karnataka and Goa), j is fish category (pelagic, demersal, crustaceans and mollusks), t is year, tp is treatment period dummy (1995 to 2011), ts is treatment state dummy (Gujarat), Vit is vessels of ith state at year t, Eit is fishery expenditure of ith state at year t, T is time trend (1985=1, 1986=2, etc.), Rg is regime shift dummy for Gujarat (=0 if year is <1989, and =1 for other years), S is state fixed effect, ε_{it} is error term. This equation is estimated using panel data on yearly fish catch of west coast states and fixed effect estimates have been used as such estimates control for many fixed features of the states like coastline length, marine cultures, beliefs, etc. which are not likely to have varied during 1985 to 2011. If mangrove plantation will have any effect on any type of catch, that will be captured by a significant value of α_3, the coefficient of the interaction term of treatment period and treatment state dummies. There being no accurate information on annual change in mangrove cover, the treatment is defined as a dummy variable, not the size of planted mangroves. So this study captures the average yearly effect of planted mangroves on fish catch.

Table 8 shows DID estimates for Gujarat state vs. other west coast states. The first column describes the explanatory variables and other columns, the estimated coefficients of these variables when the dependant variable was total catch (second column), pelagic catch (third column) etc. Coefficient of treatment (plantation) effect variable captures the change in catch of Gujarat over the other three west coast states from 1995 onwards. As observed from the table, except pelagic species, all other types of catch have significantly increased in Gujarat compared to other states after controlling for other variables like vessels,

[12] *However, such an analysis using mangrove dependant species as the treated units and mangrove unrelated species as control unit has not been tried due to shortage of time.*

Table 8: Random effect coefficient estimates of different species of commercial fish atch of Gujarat compared to other west coast states

Explanatory variables	Dependent variables (catch in '000tons)				
	Total catch	Pelagic catch	Demersal catch	Crustaceans catch	Mollusks catch
Time_trend	1.51 (0.85)	0.876 (0.99)	0.236 (0.33)	-0.107 (0.21)	0.504*** (2.77)
Treatment district (Gujarat)	202.815*** (4.53)	89.283*** (3.99)	93.923*** (5.25)	19.161 (1.51)	0.449 (0.1)
Treatment (high mangrove plantation) period (1995 -2011)	-14.554 (0.55)	-12.431 (0.95)	1.219 (0.12)	-1.996 (0.27)	-1.345 (0.50)
Treatment effect or Plantation effect on Gujarat (1995 onwards)	137.182*** (3.58)	30.163 (1.58)	50.821*** (3.33)	44.717*** (4.12)	11.481*** (2.93)
Fishing vessels	-0.001 (0.67)	-0.001 (1.46)	-0.0003 (0.58)	0.00003 (0.09)	0.0004** (2.57)
Fishery expenditure	0.005* (1.61)	0.004** (2.30)	0.002 (1.43)	-0.0005 (0.54)	0.0001 (0.43)
1989 onwards dummy for Gujarat	156.540*** (3.88)	58.109*** (2.89)	44.011*** (2.74)	46.935*** (4.11)	7.485* (1.81)
Karnataka fixed effect	137.318*** (6.53)	77.205*** (7.35)	36.18*** (4.31)	19.658*** (3.30)	4.274** (1.98)
Maharastra fixed effect	267.516*** (13.10)	79.240*** (7.78)	77.501*** (9.51)	95.161*** (16.44)	15.614*** (7.47)
Constant	61.453*** (3.30)	48.463*** (5.21)	5.437 (0.73)	13.097** (2.48)	-5.545*** (2.9)
Wald chi sq value	Wald chi2(9) = 791.83	Wald chi2(9) = 332.77	Wald chi2(9) = 730.26	Wald chi2(9) = 757.13	Wald chi2(9) = 379.9
Number of observations	108	108	108	108	108

***, **, * imply level of significance to be 1%, 5%, and 10% respectively.

fishery expenditure by governments, state specific fixed features, etc. affecting fish catch and this increase can be attributed to mangrove plantation.

The pelagic catch in Gujarat shows no significant increase during 1995-2011 compared to other west coast states. The coefficients of treatment period dummy variable is mostly negative and insignificant for all types of catch after other variables are controlled which means catch in west coast of India has been nearly similar to what it was during 1985-1994, but the Gujarat state has experienced significantly higher catch than other states.

To cross check, if there are some confounding factors not controlled in the model, but responsible for the increased catch in Gujarat these years (1995-2011), the same set of equations were estimated repeatedly taking each of the other states as a treatment state. If either Maharashtra or Karnataka or Goa shows increased catch for any of the mangrove dependant fish categories during 1995-2011, then the hypothesis that the significantly increased catch of Gujarat during this period is due to mangrove plantation will not hold true. Table 9 below shows just the estimated coefficients of the treatment effect variable for each of the states for different species of fish.

Table 9 clearly establishes that Gujarat has benefited significantly because of mangrove plantation as the treatment effect for period 1995-2011 is found either insignificant or a decrease in case of all other states. This also rules out the existence of confounding factors as had such a factor been there, at least one of the other states would have witnessed increased catch during 1995-2011. Thus the increased catch of demersal, crustaceans and molluscs in post 1995 period in Gujarat can be attributed to increased mangrove cover or regenerated mangroves of the state. There is another reason to support these estimates as true reflectors of mangroves' contribution to offshore fishery. Gujarat being the international border state, the chances of Pakistani vessels which are closer to Kutch coast (having maximum mangroves) compared to the vessels of other Indian west coast states, fishing in Gujarat coast or Gujarat vessels fishing in Pakistan coast is very low. So the increased fish stock due to increased mangrove cover in Gujarat is likely to be caught mostly by Gujarat vessels and thus, the above estimates should be taken as accurate contributions of mangrove to offshore fishery. Compared to Maharashtra, Goa and Karnataka, the average landing centre prices of important fish species are the lowest in Gujarat (CMFRI, 2013) and this also rules out vessels of other states to be reporting their catch in Gujarat, rather there are chances that vessels of

Gujarat could be reporting their catch in these states to take advantage of high prices. Thus, there could be chances of catch data underestimating the actual catch of Gujarat and, to that extent, the results of table 8 underestimating the planted mangrove contribution to Gujarat fishery, but chances of overestimation or wrong attribution are low.

3.4. Valuing Mangrove Contribution to Fishery

3.4.1. Offshore Commercial Fishery

Value of marginal product (VMP) approach is followed here to value the contribution of mangrove plantation to commercial fishery sector of Gujarat. As per table 8, the commercial fishery sector of the state is witnessing increased annual catch of 50821 tons of demersal species, 44717 tons of crustaceans and 11481 tons of molluscs each year on average after 1995 due to increased mangrove cover. Pelagic catch is excluded as such species are less dependent on mangroves and the plantation effect on pelagic catch is also not significant in table 8.

Using average approximate market prices of ₹250 per kg for demersal, ₹500 per kg for crustaceans and ₹80 per kg of molluscs, the annual monetary gain to commercial fishery sector of Gujarat comes out as ₹3598 crores (US$571.15 million at 2013-14 prices). This is the yearly gain to all the commercial offshore fishermen engaged in demersal, crustacean and mollusc fishery. As there are around 62000 fishermen families, it comes around a yearly gain of ₹5,80,358 per family.

3.4.2. Inshore Mixed Fishery

The effect of planted mangroves on inshore coastal fishery described in table 5 above shows mangroves planted in mudflats to be increasing the catch by 0.948 kg per day compared to no mangrove area in the villages studied during the Pagediya fishermen survey conducted under this study. The survey data also showed enriched mangrove plantations increasing fish catch by 3.923kg per day and natural mangrove, 4.237kg per day. Enriched plantations are mangroves planted in sparse natural mangrove area, but it being difficult to distinguish old planted mangroves from natural (ones existing from historical time) as all are mostly single species and such detailed data on mangrove plantation being unavailable, it was difficult to do a systematic valuation of mangroves contribution to inshore fishing. Taking the average of the contributions of mudflat planted and enriched plantation mangroves to 2.436 kg per day, the value of planted mangroves to inshore fishery has been estimated. The villages and creek studied had 800 hectares of mangroves planted in mudflats and in sparse natural mangrove area which results in a contribution of 0.003044 kg per day or 1.096 kg per year to inshore fishing by a hectare of planted mangroves. In between 1990 and 2013, 817.52 km^2 of mangroves were planted and assuming that all mangroves contribute to inshore fishery similarly, the yearly contribution comes to 89,600.08 kg or ₹89, 60, 008/ (≈Rs0.9 crores) or US$ 0.14 million using ₹100 per kg as the price of mixed fishes caught by Pagediya fishermen in Gujarat. Thus, the yearly contribution of planted mangroves of Gujarat to both inshore and

Table 9: Estimated treatment effect of fish catch for 1995-2011 period on west coast states

Treatment States	Total catch	Pelagic	Demersal	Crustaceans	Mollusks
Gujarat	137.18*** (3.58)	30.16 (1.58)	50.82*** (3.33)	44.72*** (4.12)	11.48*** (2.93)
Maharastra	-26.64 (0.78)	-18.49 (1.14)	-24.62* (1.84)	12.81 (1.30)	3.66 (1.07)
Karnataka	14.23 (0.98)	5.98 (0.42)	13.11 (1.12)	-7.90 (0.92)	3.04 (1.02)
Goa	-69.36** (2.36)	-8.44 (0.59)	-22.36* (1.91)	-26.33*** (3.17)	-12.25*** (4.43)

offshore fishery comes to be ₹3599 crores per annum approximately (US$ 571.29 million).

4. Planted Mangroves and Protection from Coastal Erosion

Mangroves are proved to provide coastal protection by reducing erosion of the coastline. The ecological process is that mangroves work like a strong wall that breaks the high waves and do not allow the high velocity water to enter land area. This stops the washing out of soil. Secondly, they have deep, twisted roots spread over the coast like a net which trap the soil that not only stop erosion, but help in further deposition. Thus, mangroves are called shoreline binders as the rate of deposition is usually higher than the rate of erosion in mangrove areas. This ecological service of mangroves has been explained in terms of the protection mangroves provide to various coastal assets, like bunds (Othman, 1994). Receding mangrove belt has been proved to cause increased erosion (Mazda et al. 2002; Winterwerp 2005) which is due to significant wave reduction (Mazda et al. 1997) and sediment accretion (Furukawa et al. 1997) they provide. Using remote sensing techniques, Thampanya et al. (2006) found strong evidence of reduced erosion in coastal areas with mangroves and a meta-analysis of wave attenuation data showed mangroves to provide context-dependent but effective protection from erosion and waves (Gedan et al. 2011). However, there have been few attempts at valuation of this service of mangroves, although it occurs from many important regulatory and habitat functions of mangroves, like wave attenuation, wave dissipation and sediment stabilization (Barbier 2012) etc.

Sathirathai (1998) estimated the economic value of erosion control service of mangroves using a replacement cost method, the cost of putting up breakwater dams to stop erosion. It was measured to be US $478.63 per rai (nearly 1600 sq meters) of coastline, though there is a risk of overestimation here, as breakwater dams do not use as much land area as the mangrove covers. Recent literature however asserts that the connection between ecosystem structure, function and economic value is critical as the ecosystem services change non- linearly with habitat variables and shoreline protection via wave attenuation is highly dynamic in nature and changes non-linearly over both space and time (Barbier et al. 2008; Woch et al. 2009). Therefore, in order to accurately estimate the value of coastal protection, temporal and spatial non-linearities as well as cumulative effects of wave attenuation should be taken into account.

This study attempted to examine shoreline protection in the mangrove areas of Gujarat by collecting block-level GIS data on mangrove cover, erosion and accretion for 1990-2013 period for 44 coastal talukas of the state. The coastline of the state as existed in 1990 was compared to the coastline in 2013 and the changes were detected. The satellite images of 1990 refer to the month of March and those of 2013 to the month of October when the chances of rain and wrong detection of coastline due to water logging etc. is negligible. The conversion of any part of the coastline from land in 1990 to a water body by 2013 was taken to be erosion and conversion from water in 1990 to land by 2013 was taken to be accretion. Figure 5 below shows the position of erosion and deposition along with mangrove cover in Gulf of Khambat, Gulf of Kutch and Kori Creek region of Gujarat. Whereas Gulf of Khambat clearly shows more erosion and Gulf of Kutch more deposition, Kori Creek area shows both erosion and deposition at different areas. Using the erosion, deposition and mangrove cover of 1990 and 2013 data for all talukas along the entire Gujarat coast, quantitative comparison between change in mangrove cover and erosion, deposition was tried. The coefficient of correlation between change in mangrove cover and erosion, accretion and net accretion separately were found to be 0.33 ($P<0.05$), 0.68 ($P<0.01$) and 0.65 ($P<0.01$) respectively indicating that talukas where mangrove cover has increased have witnessed both erosion and deposition, but association between increase in mangrove and deposition is more than two times stronger than the association between increase in mangrove and erosion. They are so in more than 95% of the cases as seen from the probability values (P values in parenthesis are the probability of correlation coefficient being zero). Table 10 (below) lists out talukas as per their change in mangrove forest cover and the rates of erosion and deposition. Eleven talukas have seen decrease in mangrove cover in between 1990 and 2013, of which only four have a higher rate of erosion than deposition (net erosion) whereas other seven have net accretion.

Similarly, of the 25 talukas having increase in mangrove cover, net accretion has happened in 17 of them and net erosion in eight (five in south Gujarat and three in gulf of Khambhat) and of the eight talukas having no or very little mangrove, net accretion has happened in seven and erosion in one implying that factors other than mangroves are also important determinants of erosion. Similarly, total mangrove cover and where they are, not just its increase or decrease, could be better determinants of erosion and deposition.

To compare the role of different factors simultaneously including total mangrove cover, three multiple regressions were estimated using erosion, deposition and net accretion as dependant variables. The equation is:

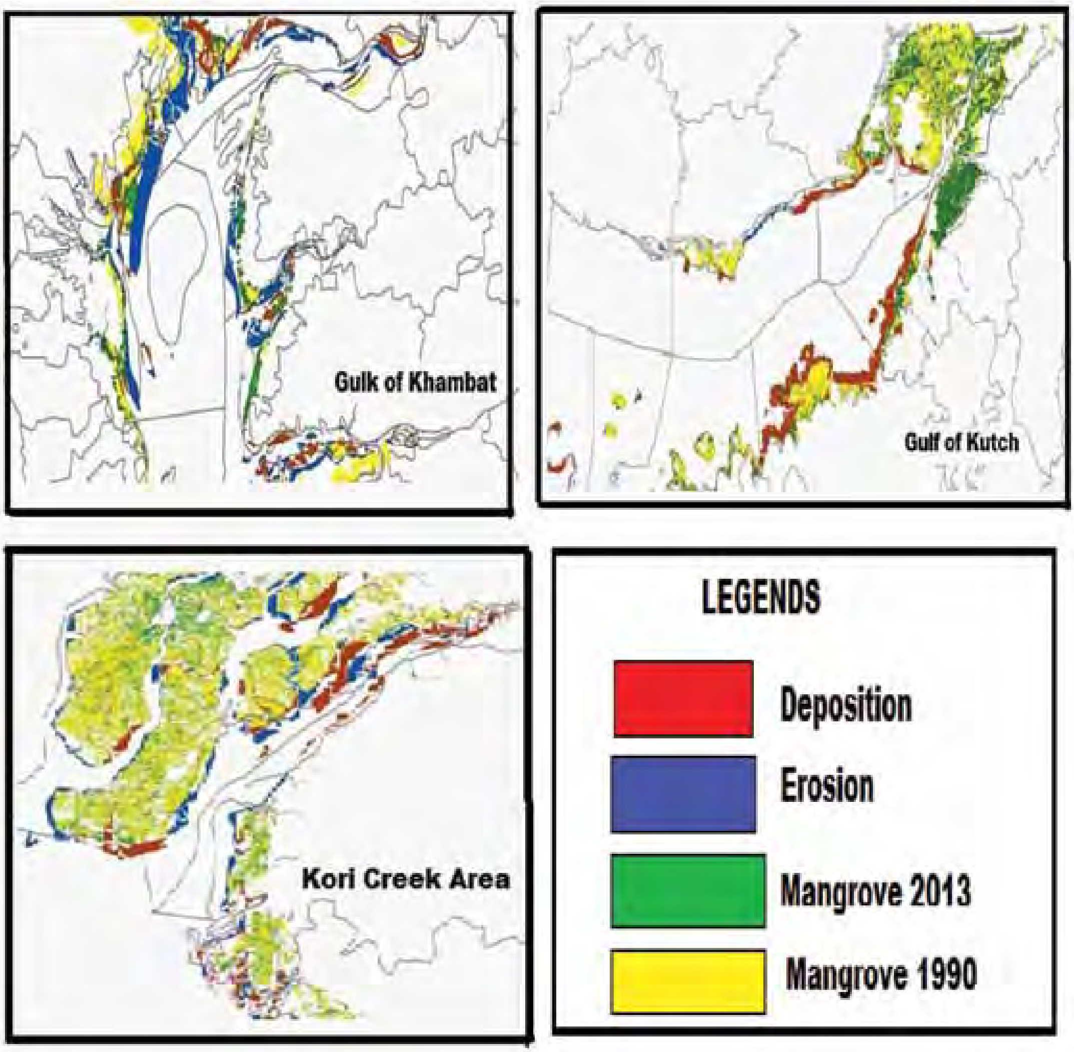
$$Y_i = \beta_0 \; \beta_1 M_i \; \beta_2 \, pop\_gth_i + \beta_3 gulf\_dummy_i + \varepsilon_i$$

where Y is total km^2 of erosion, deposition or net deposition in ith taluka,

M is mangrove (three variant of mangrove variable was used in estimation, i.e. change in mangrove cover, mangrove cover of 1990, and mangrove cover of 2013), pop_gth is population growth in these talukas in between 2001 and 2013[13] which was used as a proxy to anthropogenic pressure on coast, two gulf_dummy, one for Gulf of Kutch and one for Gulf of Khambhat, were used to control for different wave action in these regions, and ε is the error. Of the three variants of mangrove variable, mangrove cover of 1990 best explained the erosion, deposition scenario statistically, though results using any of the three variants of the mangrove variable were very similar. Table 11 below shows the estimated coefficients with mangrove of 1990 as mangrove variable. The standard errors were clustered for each district to get the most consistent estimates.

In terms of level of significance, Table 11 proves

Figure 5: Erosion and Deposition in major gulf areas of Gujarat in between 1990 and 2013



[13] *1991 data was not compared to 2013 as taluka demarcations have changed in between 1991 and 2013 in Gujarat.*

Table10: Listing of Talukas as per change in mangrove cover and net erosion

Change in Mangrove cover	Name of Talukas	Erosion/ Accretion	Number of Talukas
Decreased Mangrove Cover	Ankleshwar, Bharuch, Dholka, Mahuva, Padra, Porbandar and Talaja	Net Accretion	7
	Chorasi, Dhandhuka, Ghogha Mahal and Khambhat	Net Erosion	4
Increased Mangrove Cover,	Abdasa, Anjar, Bhachau, Hansot Mahal, Jamnagar, Jodiya Kalyanpur, Khambhaliya, Kodinar, Kori Creek, Lakhpat, Lalpur, Maliya Hatina, Mundra, Okhamandal, Rajula and Una	Net Accretion	17
	Bhavnagar, Gandevi, Jambusar, Navsari, Olpad, Umargam, Vagra and Valsad	Net Erosion	8
No Mangrove Cover	Amod, Borsad, Jafrabad Mahal, Maliya Miyana, Mandvi, Mangrol and Veraval	Net Accretion	7
	Pardi	Net Erosion	1
Total:			44

mangrove to be the most important variable explaining erosion and deposition followed by the wave action in the two gulfs. Mangroves have come up or have been planted in muddy vulnerable areas prone to erosion and as expected, Talukas having mangroves in 1990 did witness both erosion and deposition, but deposition has been much larger than erosion. In between 1990 and 2013, talukas have witnessed net accretion due to mangrove presence at the rate of 0.50 km^2 per taluka that makes total increase of 22.04 km^2 or 2204 hectares of coastal land during 1991-2013 because of mangroves. This analysis does not answer the question 'whether planting mangroves reduces coastal erosion' as this requires location wise time series data on coastal erosion and mangrove cover which was expensive and beyond the budget of the project, but the findings of the study make it clear that having mangroves generates a rate of deposition which is much higher than the rate of erosion finally increasing the land area of the region.

Land is a precious asset in coastal Gujarat as it is elsewhere and land prices vary. Records show the Gujarat government to have received ₹116 crores of rupees from industrial houses for allocating 2200 hectares of coastal land for port and industrial development which happen to be mangrove adjacent areas which means the market price of mangrove adjacent land is ₹5,27,272/

Table 11: Estimated Coefficients of determinants of erosion and deposition in Gujarat in between 1900 and 2013

Explanatory variables	Dependant variables (in km^2)		
	Erosion	Deposition	Net deposition (accretion)
Mangrove cover in 1990	0.301*** (9.72)	0.801*** (43.52)	0.500*** (11.86)
pop_gth	0.914 (0.14)	-22.539 (0.77)	-23.452 (0.80)
gulf_katch	-9.402* (1.75)	28.200 (1.58)	37.602** (2.13)
gulf_khambhat	10.241* (1.94)	-1.673 (0.32)	-11.914** (2.07)
Constant -	11.577** (2.28)	8.875* (2.05)	2.702 (0.48)
Nu.observations	44	44	44
R squared	0.45	0.84	0.68
Root mean sq error	21.425	26.164	30.054
F values of explaining model fit	F(4, 14) = 53.53	F(4, 14) = 1451.56	F(4, 14) = 224.51

per hectare. Thus, mangroves have generated land worth ₹116, 21, 09, 090/ (₹116.21 crores) during 1990-2013 or the land accretion value of mangroves comes to be ₹5,05,26,482/ (₹5.05 crores) per year. Though, mangrove of 1990 was used as the mangrove variable while estimating the above equation that generated the coefficients shown in Table 10, replacing mangrove of 1990 by change in mangrove cover didn't alter the coefficients much. So this value of 1990 mangroves is also used as the coastal protection/land accretion value of mangroves regenerated during 1990-2013 and thus, the annual contribution of regenerated mangroves to Gujarat economy comes to be ₹3604.17 crores just by accounting two ecosystem services of the mangroves, (i) nursery and habitat services to fishery and (ii) coastal protection/land accretion.

Mangroves also provide provisional services, which this study did not attempt to evaluate due to shortage of time. Review of literature on Gujarat mangroves does reflect some societal dependence for provisional services like for fuel, fodder, etc. on mangroves and some of these dependencies are described below based on others' studies.

5. Provisional Services from Mangroves of Gujarat

The major provisional services of Gujarat mangroves are fodder (perceived to be as nutritious as cotton seeds), fuel wood, construction material for boats & houses, medicinal resource, tannins & dyes, food (use of mangrove seeds as vegetables in some parts of Gujarat) as well as collection of crabs, mudskippers and fishes in the waterways of mangroves. Mangroves also serve as significant raw materials in the manufacturing of products like alcohol and vinegar, gum and honey, while some are also useful as sources of tea, cholesterol feed for prawns, mosquitocides, UV-absorbing compounds and bacterial bio-fertilizers (Hirway and Goswami 2007; Pandey and Pandey 2009; Vishwanathan et al 2012; Parthasarathy and Raja 2012). In Gulf of Kutch, where the surrounding area is semi-arid, *Avicennia Marina* mangroves are described to be most popular for fodder since there is no easy availability of alternate sources of fodder for cattle.

Bahuguna (2000) found 48.7% of the total income of poor household in Gujarat who live near the mangroves to be coming from the economic benefits received from mangroves. Hirway and Goswami (2007) surveyed 9 mangrove adjacent villages from different parts of Gujarat and estimated the direct and indirect use values of mangroves in these areas to be ₹827.6 million from fodder, ₹44.9 million from fuel wood, ₹728.8 million from collection of mudskippers, crab, fish etc, and ₹1.7 million from construction materials based on the 2003-04 prices.

Subsequently the study by Pandey and Pandey (2009) found substantial decrease in people's dependence on mangrove for provisional services like fodder and fuel wood requirement in Gujarat due to various reasons like growth of salt pans in the nearby area (increase in distance to mangroves), meeting fuel wood requirement through *Prosopis Julifora* (also called Baval) as well as crop residue after harvesting as such sources are more readily available compared to mangrove wood (located more than 3-4 km away from their village) and which require lesser hard labour than cutting, transporting and drying of mangrove wood. This was the case in Gulf of Kutch and Gulf of Khambhat region. However, in some areas, especially in South Gujarat, societal dependency for firewood and fodder was still found to be higher.

The recent study by Vishwanathan et al. (2012)[14] also describes mangroves as a valuable source of wood for the coastal communities. Due to the strength and burning capacity of wood from mangroves, society prefers it as a cooking fuel or for construction of fish traps, wharves, roofing and fencing. The percentage of households cutting mangroves reported the primary purposes to be fodder (80%), fuel (23%), seed (5%), etc. The value of mangroves as fodder was highly valued by households owning livestock, as it has increased their savings due to reduced dependence on marketed fodder and improved the milk production in cattle[15] which again has improved their income. All studies reported villages dominated by poor people and located close to mangroves are the ones more dependent on mangroves for fodder and fuel wood. Some of these studies used the market price method for valuing these provisional services, but the values are over estimates as the cost of extraction has not been accounted for in any of the studies. Though households have used family labour, mostly women, to cut and carry the mangroves home, the opportunity cost of their time and transportation and other cost should have been taken into account. Thus the value of provisional services was not added

[14] *They also studied some of the villages (5 of the 9 villages) studied by Hirway and Goswami (2007).*

[15] *Many reported mangroves leaves as excellent fodder as it increases the fat content of the milk compared to fodder available in the market.*

to the yearly value of regenerated mangroves measured in this study. Mangroves also provide many other ecosystem services like storm protection, carbon sequestration, etc, but this study did not attempt these values due to time constraint.

6. Cost Benefit Analysis for Planted Mangroves of Gujarat

The annual value of planted mangroves of Gujarat from two indirect uses is calculated to be ₹3604.17 crores to the economy of Gujarat which is calculated to be ₹4,40,866.48 or nearly ₹4,40,867 per hectare per year as there has been an addition of 817.52 km^2 of mangroves in between 1990 and 2013 as per the mangrove cover estimates generated in this study for the state of Gujarat. There are different estimates of cost of planting or regenerating mangroves per hectare in Gujarat and these vary from ₹12800 (seed sowing method) to ₹24400 (nursery method), though cost can also go up to ₹66,240 per hectare if one considers soil testing, nursery development, plantation, scientific consultancy, maintenance and upkeep, etc.[16] The other important determinant of cost is the rate of survival of planted mangroves, which can vary between 15 and 50 percent depending on the location. In Gujarat the survival rates are reported to be low, so different cost calculations are shown in Table 12 using different survival rate and plantation methods. Under the best situation, cost of regenerating 817.52 sq km of mangroves can be as low as `399 crores and it can go up to as high as `3610 crores if survival rate is low and expensive plantation methods are followed (See Table 12). So, to regenerate 817.52 km^2 of mangroves in between 1990 to 2013, the government would have spent hundreds of crores of rupees depending on the plantation techniques followed. Table 12 shows the sum of discounted present values of planted mangroves from two ecological services over different periods of time at different discount rates.

7. Conclusion

The state of Gujarat has achieved remarkable success in planting thousands of hectares of mangroves over the coastal mudflats of the state. This study used imagery from US archives of army crops and satellite images of Indian satellite LANDSAT TM – 1990 and RESOURCE SAT – 2 – LISS-III – 2013 to assess the mangrove cover of the state in 1939, 1990 and 2013 and to measure the hectares of planted mangroves. It was found that the mangroves cover of the state has doubled to 1693.881 km^2 by 2013, compared to the cover of 854.931 km^2 as existed in 1939. Next, the study attempted to assess the contribution of these planted mangroves to Gujarat's economy by examining two important ecosystem services of mangroves, role of mangroves as nursery ground and habitat for fish fry and coastal protection from erosion/land accretion. Forest survey of India being the only source providing regular estimate of mangrove cover, that showed steep increase in mangrove cover of Gujarat from 1995 onwards, the effect of planted mangroves on off shore commercial fishery sector was measured from 1995 till 2011 using Difference-in-Difference technique with the help of secondary data. For onshore coastal fishery, the effect of planted mangrove was assessed through a questionnaire survey that recorded the fish catch diary of 57 pagediya fishermen living across four talukas of Kutch district. This unique daily panel data was econometrically examined and contribution of planted mangroves to daily catch of

Table 12: Sum of discounted present values (in ₹ Crores) of planted mangroves at different discount rates

Number of Years	0% discount rate	1% discount rate	2% discount rate	3% discount rate	5% discount rate
10	96	91	88	84	77
15	143	133	125	117	104
25	283	212	190	171	141
50	477	378	306	253	183
100	955	608	420	310	199
Cost of planting 81752 hectares by seed sowing method				₹104 crores	
Cost of planting 81752 hectares by nursery method				₹183 crores	

[16] *These estimates are obtained from GUIDE, Bhuj, Gujarat and can be shared if needed.*

It was found that mangroves have helped to generate a total of 2206 hectares of coastal land between 1990 and 2013. Multiplying this area to per hectare land price generated a yearly coastal erosion control/ protection value of ₹5.05 crores for the state as a whole

fishermen was estimated. The yearly contribution of planted mangroves was calculated to be ₹3598 crores to offshore commercial fishery and ₹0.9 crores to onshore coastal fishery or a total contribution of ₹3599 crores per annum to fishery sector of the state.

Next the role of mangroves in coastal erosion/ accretion was examined by comparing the coastline change of the state in between 1990 and 2013 with the help of satellite imagery data. The same source, used for measuring the mangrove cover of the state, was used to measure the extent of erosion and deposition along the coast. A taluka level econometric analysis was conducted using erosion, deposition, mangrove cover, and other data that were used to control for anthropogenic pressure and differential wave action along the coast line. It was found that mangroves have helped to generate a total of 2206 hectares of coastal land as mangrove areas have witnessed a much faster rate of deposition than erosion. As this much of land was generated over 23 years (1990 through 2013), multiplying this area to per hectare land price generated a yearly coastal erosion control/ protection value of ₹5.05 crores for the state as a whole. Though, some scholars report the value of provisional services of mangroves to be high for some coastal communities living close to mangroves, this study could not evaluate this service due to time and resource constraint. Thus the annual value of planted mangroves of Gujarat from two indirect uses was calculated to be ₹3604.17 crores to the economy of Gujarat or ₹4,40,867 per hectare per annum. There are different estimates of cost of planting or regenerating mangroves in Gujarat and these vary from ₹12800 to ₹66240 per hectare and the rate of survival of mangroves is also low in the state. Cost benefit analysis shows plantation cost recovery to be possible before 12th year of plantation irrespective of discount rates and the type of plantation method being followed. Commercial fishery sector is the highest beneficiary and approximately every commerical fisherman family is deriving a benefit worth ₹5,80,358 per annum due to planted mangroves.

However, there are many limitations of this conclusion and the study, as detailed plantation and cost data is not available and these results are average findings. The erosion protection service is based on two point analysis as time series data on coastline change could not be arranged. Prices used are average prices that may be over/under estimating the values. None the less, the planted mangroves of Gujarat in spite of being single species, being over mud flats with high salinity, being stunted and with limited or no source of fresh water, are making significant contribution to the state's economy.

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ANNEX 1

Table 13: Fishing creeks where Pagediya fishermen fish and features of the creek

Name of the Taluka	Name of the fishermen villages	Name of the creek where fishing is done.	Features of the creek
Abdasa	Budiya, Lala & Ranpar	Shiyari Creek	No mangrove Muddy creek Low pollution
Anjar	Vandi	Dhanwal Wada Area	Sparse natural mangrove Enriched plantation Muddy creek Moderate pollution
Anjar	Vandi	Dhawat Vada Area	Dense natural mangrove Muddy creek High pollution
Anjar	Vandi	Jetty Area	Dense natural mangrove Muddy creek High pollution
Anjar	Vandi	Kara Creek	Sparse mangrove Muddy creek High pollution
Anjar	Vandi	Kukadsar Nar	Planted mangrove Sandy beach Low pollution
Anjar	Vandi	Light House	Sparse mangrove Muddy creek Moderate pollution
Anjar	Vandi	Nakti Nar Area	No mangrove Muddy creek High pollution
Anjar	Vandi	Tuna port Area	Dense mangrove Muddy habitat Heavy pollution
Anjar	Vandi	Vira Var Area	No mangrove Muddy creek Moderate pollution
Mandvi	Modhva	Dhrbudi	No mangrove Muddy/sandy creek Moderate pollution
Mundra	Luni and Sekhdiya	Hamira-Mora Bandar	Planted mangrove (2006) Muddy creek Low pollution
Mundra	Luni & Sekhdiya	Luni Bandar	Planted mangrove Muddy creek Low pollution
Mundra	Luni & Sekhdiya	Sekhadia Bandar	Planted mangrove Muddy creek Low pollution

Table 14: Mangrove cover and total landing of different categories of fish in west coast of India (Period of analysis: 1985 – 2011; Fixed-Effect estimates)

Variables	Dependent variables (in '000)				
	Total catch	Pelagic catch	Demersal catch	Crustaceans catch	Mollusks catch
fishing_vessels	-0.002 (1.31)	-0.001 (1.01)	-0.001* (1.67)	-0.0004 (1.03)	0.0002 (1.47)
fishery_expenditure	0.006* (1.91)	0.004*** (2.78)	0.002* (1.50)	-0.0005 (0.58)	0.0002 (0.74)
Mangrove cover	0.285*** (4.10)	0.029 (0.82)	0.124*** (4.51)	0.1025*** (5.30)	0.0302*** (4.36)
Time trend	-0.042 (0.04)	0.230 (0.41)	-0.071 (0.16)	-0.5179* (1.7)	0.3167*** (2.9)
1989 onwards dummy for Gujarat	157.601*** (4.12)	67.329*** (3.45)	39.579*** (2.63)	44.7478*** (4.22)	5.9451* (1.57)
Constant	192.686*** (9.95)	103.280*** (10.47)	50.627*** (6.65)	40.4202*** (7.53)	-1.6411 (0.85)
Number of observations	108	108	108	108	108
F value (5,99)	22.08 (P=0.00)	9.27 (P=0.00)	17.54 (P=0.00)	22.87 (P=0.00)	30.81P=0.00)

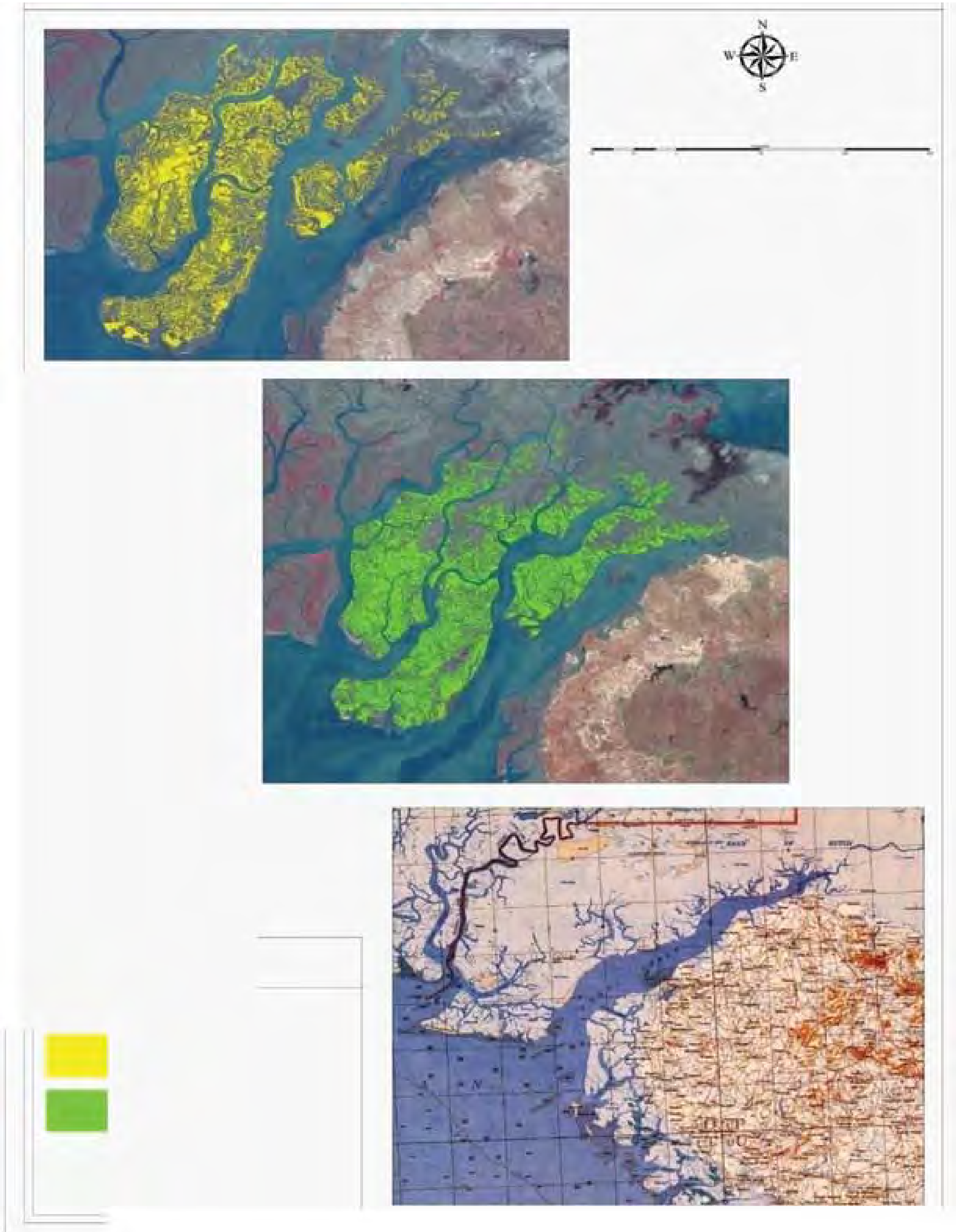
****, **, * means level of significance being 1%, 5% and 10% respectively*

Table 15: Change in mangrove cover and total landing of different categories of fish in west coast of India (Period of analysis: 1985 – 2011; Fixed-Effect estimates)

Variables	Dependent variables (in '000)				
	Total catch	Pelagic catch	Demersal catch	Crustaceans catch	Mollusks catch
fishing_vessels	0.003** (2.10)	-0.0002 (0.33)	0.001** (2.14)	0.001*** (3.01)	0.001*** (5.20)
fishery_expenditure	0.004 (1.39)	0.004*** (2.76)	0.001 (0.89)	-0.001 (1.03)	0.000 (0.19)
Change in mangrove cover	0.543** (2.13)	0.165 (1.35)	0.217** (2.15)	0.138* (1.85)	0.023 (0.88)
Time trend	2.202** (2.07)	0.411 (0.81)	0.949** (2.25)	68.953***	0.552*** (5.12)
1989 onwards dummy for Gujarat	232.317 ***(5.66)	74.097*** (3.77)	75.231*** (4.36)	(5.72) 28.453***	14.036*** (3.37)
Constant	153.266*** (7.15)	98.587*** (9.6)	31.613*** (3.73)	(6.29) 104	-5.387** (2.48)
Number of observations	104	104	104	11.69	104
F value (5,99)	15.32	8.43	11.96		20.26

****, **, * means level of significance being 1%, 5% and 10% respectively*

Figure 6: Mangroves in Kori Creek Region of Gujarat



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