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Impact of Hydroelectric Projects on Commercial Bivalves in a South Indian West Coast Estuary

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ABSTRACT Estuarine bivalves, sedentary invertebrates, in their species-specific spatial niches are more susceptible to hydroelectric projects related ecological changes, especially salinity reduction as the case study in Kali estuary towards the centre of the Indian west coast reveals. A comparison with the situation in Aghanashini estuary in the same district was helpful in unravelling dam-related salinity dilution in Kali estuary and its impact on the bivalves. The pre-dams bivalve scenario as available from secondary sources at four locations away from the Sea reveals a healthier state in the past. Salinity measurement in the study was confined to the pre-monsoon month of February 2012. Releases of freshwater from dams had diluted estuarine salinity in Kali from 33.44, 30.82, 8.76 and 2.43 ppt (pre-dam 1978) to 11.75, 6.40, 0.06 and 0.05 ppt respectively (in the same locations during February 2012). Four notable commercial bivalves had their distribution zones shrunk and shifted closer towards the sea where higher salinity conditions prevail. In comparison in the undammed Aghanashini estuary the commercial bivalve distribution and harvesting goes on rather unchanged. The study cautions damming of Indian west coast rivers can affect estuarine commercial bivalves badly causing also upsets in local livelihoods.

INTRODUCTION

The Molluscs are soft-bodied invertebrates with or without an external protective shell. The Molluscs appeared for the first time towards the end of the Precambrian period, about 550 million years ago (Sturm et al. 2006). It is the second largest phylum of the invertebrates comprising more than 100,000 species worldwide, of which, 5070 species occur in India (Venkataraman and Wafar 2005). They have been exploited worldwide for food, ornamentation, pearls, lime and medicine (Nayar and Rao 1985). Geologic evidence from South Africa indicates that systematic human exploitation of marine resources, including molluscs, started about 70,000 to 60,000 years ago (Volman 1978). Molluscs usually inhabit the marine, estuarine and freshwater ecosystems, although many are also terrestrial, often found associated with moist shaded lands. The class Bivalvia includes clams, mussels, and oysters which contribute to the livelihoods of scores of people in India. Bivalves such as *Crassostrea gryphoides* Schlotheim, *C. madrasensis* Preston, *C. rivularis* Gould, *Marcia opima* Gmelin, *Meretrix casta* Chemnitz, *M. meretrix* Linnaeus, *Paphia malabarica* Chemnitz, *Perna perna* Linnaeus, *P. viridis* Linnaeus, *Pinctada imbricata fucata* Gould, *P. margaritifera* Linnaeus, *Placuna placenta* Linnaeus, *Polymesoda bengalensis* Lamarck, *Saccostrea cucullata* Born, *Tegillarca granosa* Linnaeus, *Tridacna crocea* Lamarck, *T. maxima* Roding, and *Villorita cyprinoides* Gray were cited as utilised in India for food, industrial or ornamental purposes (Appukuttan 2004). In the estuarine villages of Karnataka State, India, molluscan fisheries involving mainly three clams *Meretrix casta*, *Paphia malabarica*, and *Villorita cyprinoides* and oyster *Crassostrea madrasensis*, sustain the livelihood of a good number of coastal people (Boominathan et al. 2008; Rao and Rao 1985; Rao et al. 1989).

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Recent times have witnessed anthropogenic pressures of varied kinds affecting estuarine ecology, including bivalve fishery and diversity. Such pressures are ongoing with scant concern shown especially towards the impact on bivalves. Dam construction is known as one of the major forms of human interventions in the rivers that has consequences on downstream ecology, especially in estuaries. Dams in rivers obviously create alterations in the freshwater flow and input of nutrients into the downstream estuaries (Baisre and Arboleya 2006; Kennish 2002). Salinity has been considered one of the important among the various physicochemical properties of the estuary influencing organisms (Harkantra 1975; Kanaya and Kikuchi 2008; Mohan and Velayudhan 1998; Sundaram and Shafee 1989). The dams for diverting water for irrigation or other human wants can reduce input of freshwater into the estuaries and increase estuarine salinity is quite obvious from several studies (Bernacsek 2001; Chen 2005; Estevez 2002; Rodriguez et al. 2001; Seddon 2000). In the Volta River, for example, regulation of inflow through Akasombo and Kpong dams led to the disappearance of a clam industry due to increased salinity (Chen 2005). The construction of a series of dams in the Colorado River and diversion of freshwater for human uses led to increased salinity in the estuary downstream caused a serious decline in the population of low salinity preferring bivalve *Mulinia coloradoensis* Dall (Rodriguez et al. 2001). A review on the impacts of large dams in rivers for diversion of freshwater caused 40 to 80% decline in downstream molluscan diversity in the Wolf Creek, Caney Fork and Tombigbee River also due to increased salinity (Seddon 2000).

Although studies abound on the impact of dams for freshwater diversion for irrigation, etc. only isolated works deal with on the impact of hydroelectric dams on the estuarine bivalves through decreased salinity conditions. In the Ulla River estuary of Spain Parada et al. (2012) observed salinity changes related mortality of bivalves due to the execution of hydroelectric projects upstream. Salinities of < 15 ppt for a mean period of three consecutive days were enough to cause moderate mortalities and salinity of < 5 ppt for an average of four consecutive days led to near-total mortalities in bivalves *Cerastoderma edule* Linnaeus and *Venerupis senegalensis* Gmelin. And also, salinity of < 15 ppt for 9 days caused severe mortality of bivalves *Tapes decussatus* Linnaeus and *Tapes philippinarum* Adams and Reeve (Parada et al. 2012). Likewise, mass mortality of *Soletellina alba* Lamarck occurred when the salinity level became < 1 ppt (Matthews and Fairweather 2004).

The recent decades, particularly after Indian independence in 1947, witnessed the construction of a number of dams in many of the rivers, both for irrigation and electricity generation. Whereas environmental impact assessment was hardly carried out on these projects prior to 1970's, such assessments thereafter hardly ever referred to impact on estuarine biodiversity consequent on especially the execution of hydroelectric projects. In the Sharavathi estuary of Uttara Kannada district of South-west India, Rao and Rao (1985) and Rao et al. (1989) had already alluded to drastic decline of bivalves such as *Meretrix meretrix*, *Meretrix casta* and *Crassostrea madrasensis* because of continuous freshwater inflow from the hydro-electric projects executed upstream. Despite these studies not elaborating further on this aspect they make clear that these bivalves did occur in the Sharavathi estuary about three decades ago and some local people were involved in their fishery. The fisher-folks of the estuary also attributed the recent decline in fish diversity and collapse of bivalve fishery in Sharavathi estuary due to the damming of the river for power generation (Boominathan et al. (2014) Except for sporadic references there has hardly been any efforts to portray what would be the impact of execution of upstream hydroelectric projects on estuarine bivalve fishery. This situation prompted us to undertake the current investigation in the Uttara Kannada district of Karnataka State. Of the four notable west flowing rivers of the district, two (Kali and Sharavathi) have been harnessed for hydro-electric power and the others (Aghanashini and Gangavali) are unaffected. For the current study was chosen the estuary of the river Kali (dam-med) and Aghanashini (undammed). In a pre-dam period study on Kali by Nair et al. (1984) and the earlier situation of commercial bivalves in the Aghanashini estuary is known from Rao et al. (1989).

MATERIAL AND METHODS

Study Area

Both the estuaries studied for bivalves, namely Kali and Aghanashini, are situated towards the central west coast of India, in the Uttara Kannada district of Karnataka (Fig. 1 for locations). The Kali estuary is the northernmost estuary of the district and the Aghanashini estuary is located about 42 km south of it. The Kali River originates near the village Diggi in the densely wooded and hilly Joida taluk of the district. Joined by several streams en route its 184 km course towards the Arabian Sea, is through the rugged terrain of the Western Ghats. Its confluence with the sea is about three km north of Karwar town. Between 1980 and 2000 a series of hydroelectric projects was executed upstream in the river, involving dam constructions at Supa, Bommanhalli, Nagjhari, Kodashalli and Kadra. The estuarine portion of Kali, during the pre-dam period, extended for about 18 km interior from Kodibag at the river mouth to Kerwadi and covered an area of about 30 km^2 (Nair et al. 1984).

The Aghanashini River, originating from two sources, at Manjguni and Donihalla, both in the Sirsi taluk of Uttara Kannada, runs its 121 km course winding through deep gorges and valleys towards the Arabian Sea, also through richly wooded landscape of the Western Ghats. The river joins the sea between the villages Tadri in the north and Aghanashini in the south about 10 km towards the north of Kumta town. The high tides from the Arabian Sea reach up to Uppinapattana at about 25 km upstream in the river, conferring estuarine status to about 21 km^2 of water spread area. As Aghanashini has no hydel projects the estuary is expected to retain its original salinity regimes. The study of Aghanashini bivalves is expected to portray a situation unaffected by hydel projects, which could have been similar to that of its counterpart Kali of pre-dam period. The study area map (Fig. 1), covering both the estuaries, was created by using QGIS version 1.7.4 (Quantum GIS Development Team 2011).

Salinity Measurements

In both the estuaries, surface water salinity was measured in February 2012 during high tide using EXTECH EC400 salinity meter. After the subsidence of the torrential monsoon rains, normally in October, salinity starts rising in the estuary, and attain peak salinity conditions by February. Salinity levels that prevailed in the Kali estuary in the pre-hydel power project period were obtained from Nair et al. (1984). Bar graph to show the salinity difference was produced using statistical software R version 3.0.1 (R Development Core Team 2013).

Bivalve Data Collection

The presence of different commercial bivalves in both the estuaries were obtained from Alagarswami and Narasimham (1973) and Rao et al. (1989). Nair et al. (1984) had provided data on distribution range of bivalves in the pre-dam Kali estuary. A later study by Rao et al. (1989) on bivalve diversity in Kali is also quite informative. Live and dead bivalves, the latter represented by shells, were collected randomly from different parts of both the Aghanashini and Kali estuaries, and from persons involved in bivalve fishery. A questionnaire was also used to gather information from the fisher-folks of Kali estuarine villages on bivalve diversity and distribution in the pre-dam period and current times. About 50 members of the fisher-folks were interviewed for this purpose. The data gathered covered the occurrences of commercial bivalves *Tegillarca granosa*, *Meretrix casta*, *M. meretrix*, *Paphia malabarica*, *Polymesoda erosa* Solander, *Villorita cyprinoides* and estuarine oysters. As sand mining from both the estuaries was taking place at different localities, searches were also made in the excavated sands for bivalve occurrences. The bivalves collected were identified using diagnostic characters given by Apte (1998), Dey (2006), Morton (1984), Rao (1989), and Rao et al. (1989).

RESULTS

Salinity

In the current study during February 2012, in Kali estuary, Kodibag station, nearest to the Arabian Sea had highest high tide salinity of 11.75 ppt, followed by the mid-estuary Sunkeri (6.40), and upper estuary Ambejug (1.71). Kinnar (0.06) and Kerwadi (0.05) stations further upstream (Fig. 1), which were earlier in estuarine domain due to higher salinity upwards of 0.5ppt, had freshwater conditions prevailing during the current study (February 2012). In Aghanashini estuary, unaffected by any upstream dams, all the stations, viz. Aghanashini closest to the sea (28.55) followed by Gudkagal (28.00), Hini (26.35), and Masur (23.80) in mid-estuary and Divgi (12.00)

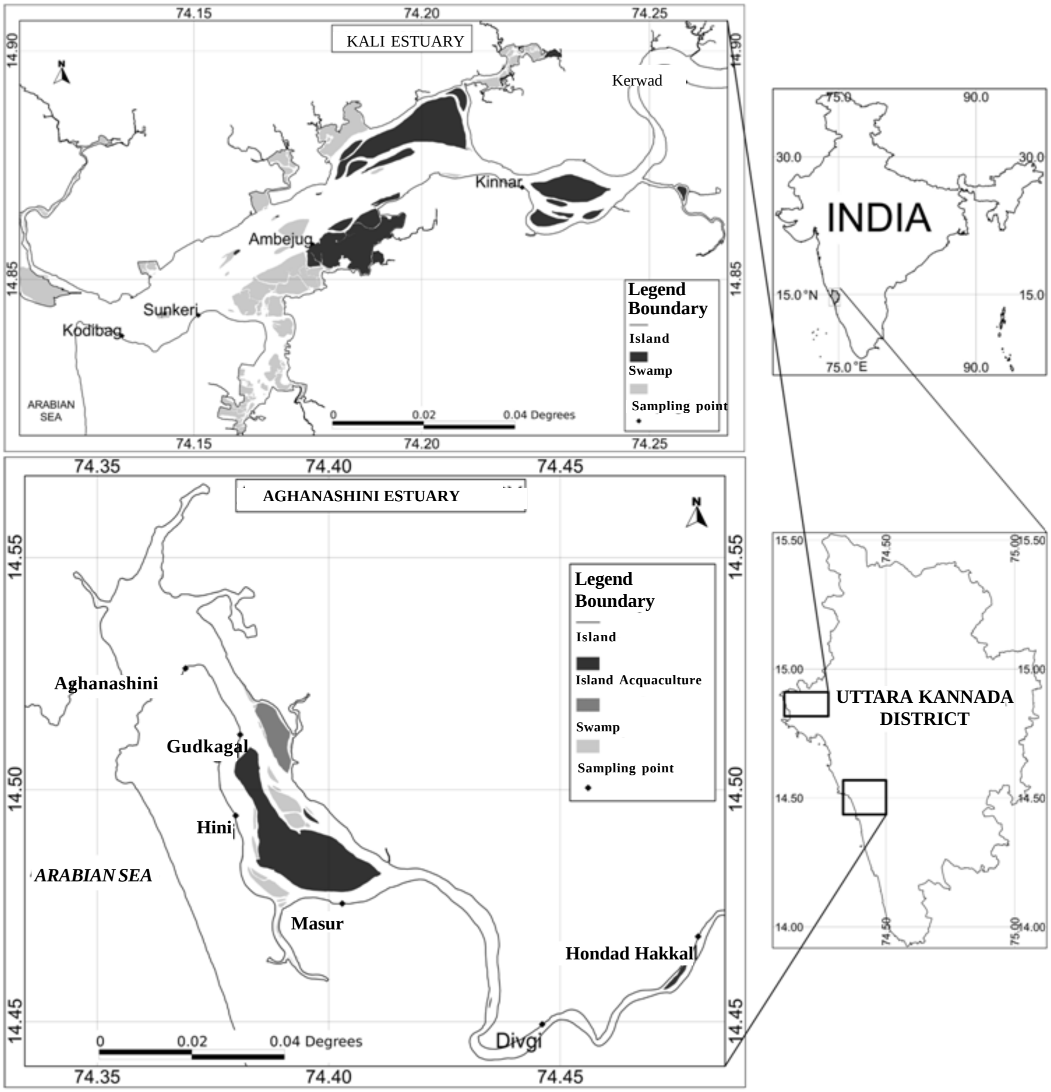

Fig. 1. Sampling sites in Kali and Aghanashini estuaries of Uttara Kannada District

and Hondad Hakkal (4.61) in upstream estuary continued to be in estuarine condition, having salinity exceeding 0.5 ppt.

Commercial Bivalves

Aghanashini and Kali estuaries had same eight species of commercial bivalves (six clams and two oysters) viz. *Tegillarca granosa*, *Meretrix casta*, *Meretrix meretrix*, *Paphia malabarica*, *Polymesoda erosa*, *Villorita cyprinoides*, *Crassostrea madrasensis*, and *Saccostrea cucullata* Born.

DISCUSSION

Salinity

Based on February 2012 high tide salinity conditions that prevailed in Kali estuary, three of the five sampling stations from the river mouth towards upstream, viz. Kodibag, Sunkeri and Ambejug, a total distance of about 6 km, where minimum salinity exceeded 0.5 ppt, have been considered estuarine in accordance with the norms by Dahl (1956). On the contrary, the pre-dam Kali estuary had extended at least to Kerwadi, 18 km upstream from the river mouth, due to prevalence of over 0.5 ppt salinity. In fact Nair et al. (1984) had reported salinity of 2.43 ppt prevailing in Kerwadi way back in November-December 1978, just after the cessation of the monsoon season (Fig. 2). As a result of the continuous discharge of freshwater from the hydel projects upstream even Kinnar (12 km upstream) had freshwater conditions during our survey in February, 2012. Obviously due to the impact of releases of huge quantity of freshwater from the hydel projects, after power generation, the area under estuary got reduced from what was almost 30 km^2 in the pre-dam period to mere 16 km^2 in the post-dam.

In the case of the Aghanashini River untampered to this day by hydroelectric projects, only minor interventions happened with the diversion of some amount of river water for a drinking water project for the coastal towns of Kumta and Honavar. All the sampling stations in Aghanashini estuary, including the most upstream station Hondad Hakkal located about 23 km were also in estuarine condition, showing more than 0.5 ppt salinity. The situation was not different earlier as the *Gazetteer of Uttara Kannada District* (Kamath 1985) also had reported that the marine tides had travelled upstream for over 23 km. High tide salinity conditions of Aghanashini at comparable distances from the river mouth were substantially higher in Aghanashini than in Kali. The present salinity conditions of Aghanashini estuary are comparable to the pre-dam estuarine situation of Kali (Fig. 2).

Commercial Bivalves

The dam constructions for electricity generation in Kali and the fall in salinity on account of continuous release of freshwater after electricity generation, however, has not eliminated the bivalves from the estuary. But what is glaring is major shifts in the occupation zones (in km from the river mouth), and shrinkage in occupied areas of bivalves, after the dams getting commissioned. *Tegillarca granosa*, a bivalve reported to be associated with salinity in the range of 13.69 - 34.40 ppt (Narasimham 1988) was restricted to the extreme river mouth at the Kodibag in Kali, where alone this medium

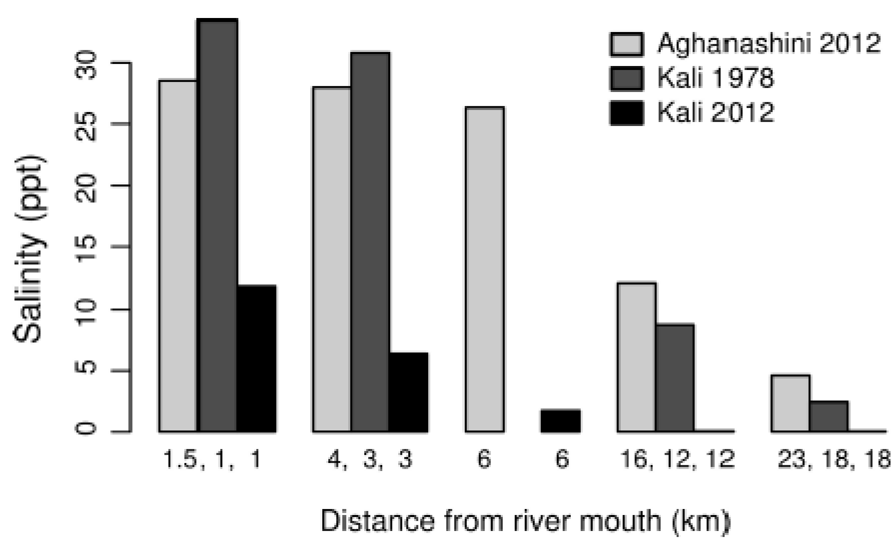

Fig. 2. High tide salinity from river mouth to upstream for Aghanashini estuary (2012) and pre-hydel (1978) and post-hydel (2012) Kali estuary. Kali 1978 based on Nair et al. (1984).

to high range of salinity conditions prevailed after the execution of dams upstream. Even in the Aghanashini estuary its preferred zone was closer to the river mouth.

Meretrix meretrix, one of the most abundantly used commercial bivalve from Kali estuary in 1978, had a wider distribution zone from 2-12 km in the salinity range of 30.82 ppt to 8.76 ppt (Nair et al. 1984). It may be assumed from Rao et al. (1989) that with the commissioning of the first hydroelectric project at Nagajhari, in 1980-1984, the species got confined to a narrower zone of 1-4 km, indicating the influx of freshwater driving the species towards a more seaward position. The situation worsened with still more hydel projects as the habitation zone of the species during the current study was just 1-3 km (Kodibag to Sunkeri) (Fig. 3a) where the salinity prevailed ranged from 11.75 ppt to 6.40 ppt. The decline of this popular commercial clam in the Kali has affected badly both the fisher-folks and the consumers. In the Aghanashini estuary, *M. meretrix* which had an earlier (in 1984) reported distribution zone from 1-3 km upstream from the river mouth (Rao et al. 1989), continues unchanged to this day. The mudflat of this zone accounted for the highest production of bivalves from the estuary (Boominathan et al. 2008).

Meretrix casta in the Aghanashini estuary had a distribution range from near the river mouth to Mirjan, 10 km upstream (Rao et al. 1989). In the current study it occurred up to seven km upstream. The researchers do not rule out its sporadic occurrence up to Mirjan itself, despite the instability conditions in the estuary due to both natural (flooding from excess rainfall) and anthropogenic causes (mainly intensified sand extraction from its habitat). Whereas *M. casta* was earlier reported in Kali in the mid-estuary zone of 7-11 km interior (Rao et al. 1989) in the current study its range was found restricted more seaward to a narrower zone at 1-3 km (Kodibag to Sunkeri) (Fig. 3b), obviously on account of dam related salinity reduction in the estuary.

Paphia malabarica, known as a high salinity zone estuarine bivalve, requiring 20 to 30 ppt for survival (Mohan and Velayudhan 1998) had its reported occurrence in Kali in a two km range from the river mouth to Nandangadda (Nair et al. 1984). The species apparently underwent local extinction in Kali, after the execution of the first hydroelectric project itself, as it was not reported in the study by Rao et al. (1989), who testified to its presence until 1982. It's near decimation from the estuary can be attributed to lower salinity in the estuary. In contrast, in the Aghanashini estuary, it is one of the most abundant commercial bivalves, occurring in the river mouth region itself, from where supplies are made even to Karwar and Goa.

Polymesoda erosa, another clam, confined mostly to mangrove areas, has a reported salinity tolerance range of 7 to 22 ppt (Modassir 2000). Though the species was hardly reported earlier from both the estuaries, it occurred sporadically in Kali estuary in some semi-stagnant mangrove swamps, in pockets of salinity from 10-12 ppt, between 1-6 km distance from the river mouth. Its occurrence in Aghanashini was, however, in higher salinities (23.80 to 28.55 ppt) from the river

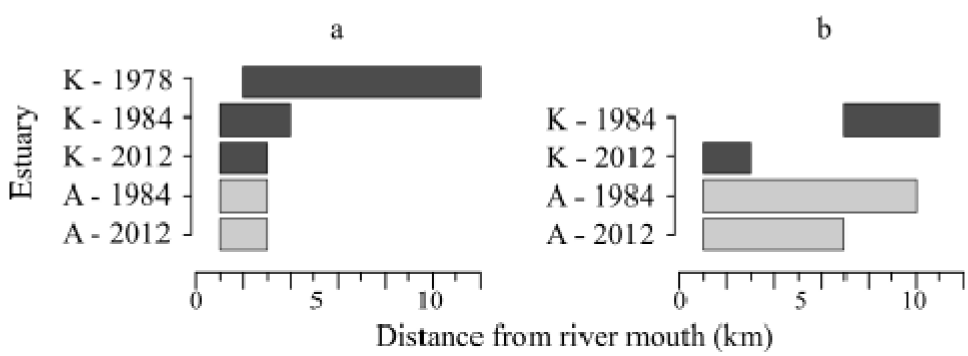

Fig. 3. Distribution of (a) *Meretrix meretrix* and (b) *Meretrix casta* in Kali and Aghanashini estuaries. K – Kali estuary, A – Aghanashini estuary, K - 1978 (Nair et al. 1984), K - 1984 and A - 1984 (Rao et al. 1989), K - 2012 and A - 2012 (Current study). *Note: K – 1978 pre-dam Kali, K – 1984 and K – 2012 post-dam Kali*

mouth (1-8 km zone). Based on the rarity of the species, it is difficult to make any pronouncement on the species and its preferred distribution ranges in both the estuaries.

Villorita cyprinoides is a low salinity preferring estuarine bivalve, able to withstand prolonged freshwater conditions (Nair et al. 1984; Rao et al. 1989), although the latter conditions are not favourable for its growth (Arun 2009; Laxmilatha et al. 2005). In the pre-dam Kali, its presence was mainly in 11-26 km zone (between Kinnar and Mallapur) within salinities of 8.76 to 2.43 ppt (Nair et al. 1984). It got shifted to 7-24 km after the commissioning of the first hydroelectric project (Rao et al. 1989). The current study reveals a further narrowing of its zone from 6 to 12 km (Ambejug to Kinnar) (Fig. 4), within the salinities of 1.71 to 0.06 ppt. This pronounced habitat shift towards downstream, was obviously necessitated by a steep decline in salinity in Kali. In Aghanashini, *V. cyprinoides* occurred in a wider zone of 8-23 km (Masur to Hondad Hakkal) within the salinity ranging from 23.80 to 4.61 ppt, as measured during February 2012. Rao et al. (1989) reported *V. cyprinoides* distribution from 8-15 km only, probably not prospecting for the species in more upstream areas.

Oysters as a group of bivalves belonging to several species are known to inhabit coastal waters of higher salinities. In Aghanshini estuary its occurrence was from the river mouth to seven km upstream, in the high tide salinity range of 28.55 to 26.35 ppt. In Kali estuary the oysters were once distributed up to eight km upstream, and their high density occurrence was found at 30.82 ppt (Sunkeri at 3 km from seafront) in 1978 (Nair et al. 1984). In the current study on Kali, for reasons explicit, its distribution zone was found to limit to three km upstream only from the earlier eight km. The salinity range in its current distribution zone was from 11.75 in the river mouth area (at Kodibag) to 6.40 ppt, at Sunkeri where the pre-dam salinity was as high as 30.82. The case of oysters also underscores the crucial role of salinity in the distribution of estuarine bivalves.

CONCLUSION

Estuaries although ranked among the highest productive ecosystems of the earth, have not merited to this day enough attention to safeguard their ecological integrity due to ever increasing anthropogenic interventions along the coastal zones in general. The fact notwithstanding that estuarine productivity is sustained naturally without any inputs from humans, unlike in agricultural ecosystems or fish farming systems, most estuaries, of the Indian west coast are subjected to increasing stress from humans.

Salinity changes due to dams constitute a single major factor that can undermine estuarine ecology. The current study clearly shows that the lowered salinity in the Kali River estuary, due to the constant release of freshwater from hydroelectric projects upstream, has seriously impacted the bivalves that constituted an abundant food resource from the estuary. The distribution zones of most such bivalve species

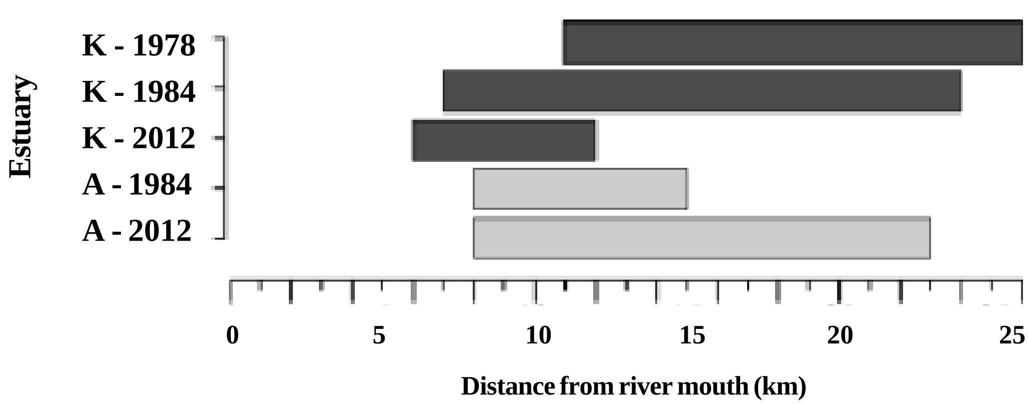

Fig. 4. Distribution of *Villorita cyprinoides* in Kali and Aghanashini estuaries. K – Kali estuary, A – Aghanashini estuary, K - 1978 (Nair et al. 1984), K - 1984 and A - 1984 (Rao et al. 1989), K - 2012 and A - 2012 (Current study). *Note: K – 1978 pre-dam Kali, K – 1984 and K – 2012 post-dam Kali.*

have become narrower than in the pre-dam scenario, shifting more towards the estuarine mouth to whatever relatively safer salinity zones available, due to the constant onrush of freshwater from hydel projects upstream. Such major habitat shifts and shrinkage happened in the cases of *Meretrix meretrix, M. casta, Villorita cyprinoides,* and estuarine oysters and near decimation happened for yet another bivalve *Paphia malabarica.* The surviving bivalves themselves appear to be combating with low salinity conditions in their present occupation zones as well, and their diminished availability has affected the livelihoods of traditional bivalve collectors and the consumers of bivalves, bulk of whom are from the poorer segments of the coastal society. The study, while clearly establishing that the execution of hydel projects in the Kali River has adversely affected the estuarine commercial bivalve community as a whole, also implies that through upsets in salinity regimes a state of the imminence of ecosystem collapse could be happening not merely for bivalves, but also involving fishes, and shrimps and even mangroves.

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