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Status of important coastal habitats of North Tamil Nadu: Diversity, current threats and approaches for conservation

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ABSTRACT

Coasts are among the most vulnerable ecosystems to the effects of climate change and the impacts of strong weather events. At the same time, they are also crucial buffers of these phenomena around the world. The current study describes the is ecological and geomorphological uniqueness of North Tamil Nadu's coast. Five important coastal wetlands were identified in this region, namely Pulicat Lagoon, Adyar Estuary, Kovalam-Muttukadu Backwaters, Odiyur-Mudhaliyarkuppam Lagoon and Kaliveli Lake, which were survyed. The variety of habitats found here include mangroves, backwaters and creeks, estuarine areas, oyster reefs, sandy beaches and sand dunes, seagrass beds, salt marshes, and tropical dry evergreen forests. A total of 913 species from eight animals' classes were recorded from these hotspots, of which 709 species were recorded during the study. Species recorded as bycatch have also been identified and marked so in the checklist The hotspots were assessed using a detailed criteria matrix. This study also highlights the ecological importance of these wetlands, discusses the current threats to them and explores conservation challenges and approaches from a socio-ecological and legal-policy framework.

1. Introduction

Coastal landscapes are both frontiers and margins. As frontiers, they are the first bio-shields against strong weather events surging in from the sea. In the Indian peninsula, the Bay of Bengal basin is far more active (Muthuchami, 2009) than the Arabian Sea basin. The eastern coast of India is a densely populated region, especially along its river basins and deltas. Climate change has intensified the strength, frequency and erraticity of strong weather events along shorelines (Berardelli, 2019). Hence, the function, health and integrity of coastal ecosystems become all the more crucial. Coasts are margins – geographical edges of land – but also socio-politically and historically coastal communities are among the most marginalized and vulnerable. They are ecotones, serving as a refuge for a variety of biodiversity.

In India, coastal habitats are also adversely affected by an increasing number of infrastructure projects, which do not consider the unique geomorphology of these habitats and their highly dynamic processes. The eastern coast of India is far more vulnerable to erosion and impacts of climate phenomena (Venkatesh, 2018). Infrastructure projects like large ports, harbours and power stations are known to cause long-standing detrimental effects — including coastal erosion, groundwater contamination, displacement of people, loss of habitats and livelihoods, among other impacts. Pro-industry and socio-ecologically unsound laws and policies like the amended Coastal Regulation Zone Rules (CRZ) 2019 (Khergamker, 2019), Deep Ocean Mission (Press Trust of India, 2020), the Draft Environmental Impact Assessment (EIA) 2020 (Patnaik, 2020), Sagar Mala Mission (The Hindu, 2020) - further pose serious long-term threats to coastal habitats and communities.

The coast of Tamil Nadu and Puducherry is about 1076 km in length and constitutes around 15% of India's total coastline (Government of Tamil Nadu, 2018). A range of unique coastal ecosystems is found here. These include sandy beaches and dunes,

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mangrove forests, mudflats and salt marshes, backwaters and creeks, tropical dry evergreen forests (TDEF), coral reefs, seagrass beds and oyster reefs.

In this paper, the authors have presented the importance of five major coastal habitats from North Tamil Nadu- Pulicat Lagoon, Adyar Estuary, Kovalam-Muttukadu Backwaters, Odiyur-Mudhaliyarkuppam Lagoon and Kaliveli Lake. Scientific literature is crucial for conservation efforts and long-term monitoring. Three of the five sites that were studied, namely Adyar Estuary, Kovalam-Muttukadu Backwaters and Odiyur-Mudhaliyarkuppam Lagoon have little literature on their ecology and biodiversity even though they are rich ecosystems. The data and discussion presented in the study aim to serve as a baseline for further studies on these landscapes and their species biodiversity.

2. Methodology

A total of five hotspots were selected from the North Tamil Nadu coast, namely Pulicat Lagoon, Adyar Estuary, Kovalam-Muttukadu Backwaters, Odiyur-Mudhaliyarkuppam Lagoon and Kaliveli Lake. Out of these, Pulicat Lagoon, Kovalam-Muttukadu Backwaters and Kaliveli Lake are designated as Important Marine and Coastal Biodiversity Areas (ICMBAs). 107 ICMBAs were identified by the Wildlife Institute of India (WII) in India. These locations were selected due to their rich diversity and their ecological and conservation importance. The hotspots have been described in their individual sections.

Regular field surveys were conducted from September 2020 till April 2021. These surveys were conducted at low tide in all five locations. Data was collected using line transects and beachcombing while walking along the shore. Our main aim was to prepare a checklist for animal species from the 8 classes. The boat trips inside lagoons were particularly useful in mapping the distribution of mangroves at these sites. Apart from this, citizen science platforms such as eBird India and iNaturalist were used. In many projects across the world, citizen science has enabled scientific data gathering in spatial and temporal scales never thought possible before (Bland, 2019). Collaboration with local fisherfolk to monitor oceanic parameters, biodiversity, fisheries and other aspects of coastal and marine ecosystems has proven to be very useful in similar initiatives (Fulton et al., 2019).

Previous publications of the faunal diversity from Pulicat Lake and Kaliveli Lake on relevant taxa were also utilized in the preparation of the checklists and listed according to their currently accepted taxonomical names. Species that lacked necessary documentation or were questionable were excluded from the checklists. Species recorded as bycatch have also been identified and marked so in the checklist, by indicating a * next to their names. It was important to feature these species as molluscan and crustacean bycatch often gets ignored by scientific studies from this region. The bycatch that was recorded by the authors was from artesian fishermen and not from large trawl nets from commercial fishing. This method of fishing is small scaled and very community centred, thus could be argued as a natural part of the coastal ecosystem.

Species identifications were done by comparing pictures taken of the various taxa with relevant resources. Mangroves (Sudhakar Reddy, 2008), mangrove-associates and sea grass (Thangaradjou and Bhatt, 2018) were identified in the study. Snake identification was done using (Whitaker and Captain, 2008), birds using (Grimmett et al., 2012) and mammals with (Menon, 2014). Insect identification was done with the help of Azim (2011), Kehimkar (2016), Kritika and Jaimala (2017), Mukherjee et al. (2017), Pearson et al. (2020) and Sondhi et al. (2020). Hermit crabs were identified with the help of Trivedi and Vachhrajani (2017), while brachyuran crabs were identified using (Trivedi et al., 2018). For the identification of spiders (Caleb, 2020) was used. Finally, molluscan diversity was identified with the help of Zoological Survey of India (2007).

Jaccard's Index of Similarity was used to find out how similar are the two areas at a time. The places were selected such that two combinations are selected from the five hotspots surveys to get ten distinct combinations. The percentage of Jaccard's Similarity is calculated to understand which hotspots are the most similar to each other, and which are the least similar.

$$J = \frac{c}{a+b+c} \tag{1}$$

where a = species unique to area 1
b = species unique to area 2
c = species common to both areas

3. Results and discussion

3.1. Hotspots in North Tamil Nadu

In this section, the landscape, ecology and threats faced by the five hotspots surveyed in the study have been elaborated. The hotspots have been marked in Fig. 1 on a map of North Tamil Nadu, to show their location and proximity to each other.

3.1.1. Pulicat Lagoon

3.1.1.1 Location and landscape Pulicat Lagoon (13° 24′–13° 47′N; 80° 03′–80° 18′E), shown in Fig. 2, is the second-largest brackish waterbody in India. It is considered one of the four most ecologically important coastal bioregions in Tamil Nadu along with Palk Bay, Point Calimere and Pichavaram. The lake spreads over an area of 82.4 km^2 in the Thiruvallur district of Tamil Nadu and 383 km^2 in the Nellore district of Andhra Pradesh (Saravanan et al., 2013). Pulicat is the anglicized version of the local name '*Pazhaverkadu*' that translates to 'old jungle of roots' in Tamil, which scholars and locals say refers to the roots of *Avicennia marina* mangroves which were once found in abundance here. These mangroves were the architects of this coastal landscape which formed during the Holocene epoch, about 6000 years ago. Their root systems stabilized the river banks, the shores and barrier islands of the wetland, protecting it from erosion, as well as strong weather events (Das, 2020). By trapping organic matter, they also build substrate for more vegetation, creating new coastlines for centuries (Carlton, 1974).

3.1.1.2 Ecology This bioregion is a mosaic and confluence of diverse ecologies hosting coastal sand dunes, riverine distributaries, backwaters, creeks, salt marshes, mangroves (Farooqui and Vaz, 2000), tropical dry evergreen forests, scrubs, grasslands and the lagoon itself that spills into and is fed by the Bay of Bengal. To the south of the lagoon, the lower courses of Kosasthalaiyar, Arani and Kalangi rivers empty into the brackish waterbody. The lagoon's salinity fluctuates with tidal movement and season. At the peak of the northeast monsoon, salinity drastically falls as freshwater inflows fill the lagoon. The Pulicat sand barrier island and Kattupalli sand barrier island, along with several undersea shoals separate the lagoon from the Bay of Bengal on the east, making it a sheltered marine space. Table 1 gives an insight to the ecology os the hotspot.

Pulicat Lake hosts over 15,000 Greater Flamingos (*Phoenicopterus roseus*) and at times upto 400 Lesser Flamingos (*Phoeniconaias minor*) in Tamil Nadu, as seen in a representative image (Fig. 3). The lagoon is a vital part of the Central Asian Flyway, influencing the paths of various bird species that flock here for roosting and foraging during their winter migration (Kannan and Pandiyan, 2012). Pulicat is designated as a Coastal Regulation Zone CRZ-I A (National Centre for Sustainable Coastal

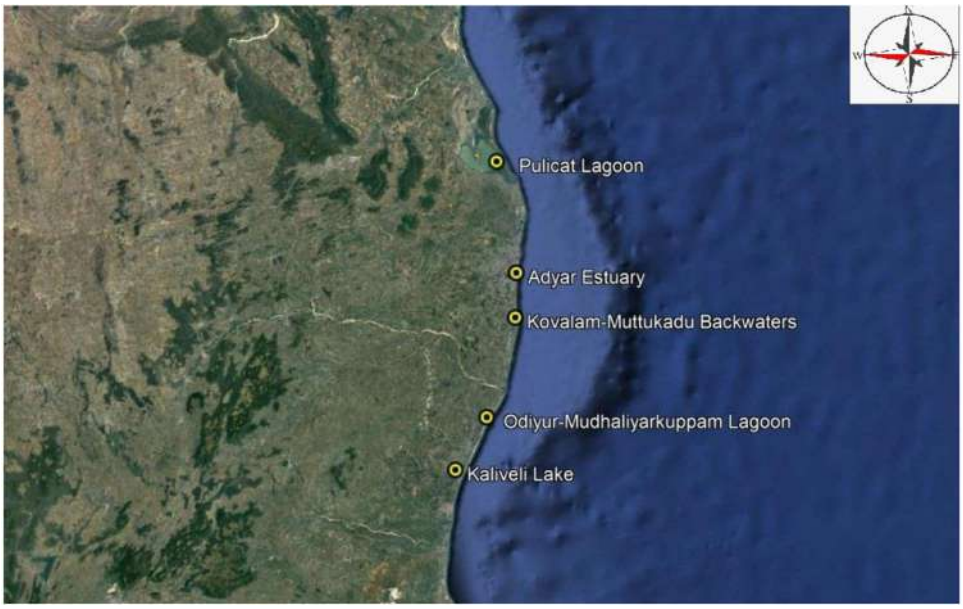

Fig. 1. Map showing the five surveyed coastal hotspots.

Fig. 2. ICMBA boundary of Pulicat Lake (Tamil Nadu section) as defined by WII.

Management, 2018a) area for multiple ecological reasons. The sand barrier islands are Olive Ridley Sea Turtle (*Lepidochelys olivacea*) nesting grounds (Vaithianathan, 2014). Pulicat Lagoon hosts seagrass beds, mangroves, biologically active mudflats and coastal sand dunes. It is also an important foraging and breeding ground for numerous marine fauna including the Giant Guitarfish

Fig. 3. A flock of Greater Flamingos (*Phoenicopterus roseus*) at Pulicat Lagoon. Photograph captured by Rama Neelamegam.

Table 1
Ecology of Pulicat Lake.

Pulicat lagoon		
Class	No. of species	Highlights
Bivalves	46	Black-tailed Godwit (*Limosa limosa*)
Gastropods	61	Painted Stork (*Mycteria leucocephala*)
Crustaceans	55	Black-headed Ibis (*Threskiornis melanocephalus*)
Insects	174	Greater Flamingos (*Phoenicopterus roseus*)
Spiders	15	Lesser Flamingos (*Phoeniconaias minor*)
Birds	223	Spot-billed Pelican (*Pelecanus philippensis*)
Mammals	23	Olive Ridley Sea Turtle (*Lepidochelys olivacea*)
Echinoderms	1	Windowpane Oyster (*Placuna placenta*)

(*Rhychobatus djeddensis*), Slender Sunfish (*Ranzania laevis*) and various sharks and rays that are protected under Schedule I of The Wild Life (Protection) Act, 1972. During the winter months, adults and larvae of fishes (Nagarjuna et al., 2010), shrimp and molluscs migrate from the ocean to the lagoon. Hence, the wetland acts as a crucial nursery for marine fauna and as a foraging ground for several species of waders. This season is also characterized by the largest catches of fish and shrimp by local fisherfolk.

About 44,000 artisanal fisherfolk in Tamil Nadu depend on the Pulicat Lagoon. Communities here also collect shrimp, crabs, shells, seaweed and lugworms. As described in Lobe and Berkes (2004) and Dhanuraj (2006), the fisherfolk of Pulicat have their traditional fishing methods like the '*Paadu* system' and various catch-specific gear to catch shrimp, mullets and other fishes.

3.1.1.3 Threats The following were identified as major threats of Pulicat Lagoon during the study. Their effects and conservation strategies have been elaborated in the discussion section.

- Rampant invasion of *Prosopis* into existing mangrove patches.
- Proposed expansion of MIDPL port which will cause erosion of sand barrier islands protecting Pulicat Lagoon.
- Pollution along Ennore Estuary and Kosasthalaiyar River from industries nearby.

3.1.2 Adyar Estuary

3.1.2.1 Location and landscape Adyar Estuary (13°00′48″N; 80° 16′25″E) is situated along the southern coast of Chennai. Here the Adyar river, one of the three main rivers flowing through the city, meets the Bay of Bengal and forms a near-circular creek to its northern bank. The ecosystem defined by the authors spans over an area of 4.2 km^2 and has been shown in Fig. 4, which includes the estuary, creek and the course of the river up to which tidal influence is observed. During the monsoon months, the highest flow of water into the Bay of Bengal recorded is about 2585.08 MLD, whereas during the summer months the lowest is 514.59 MLD (Gowri et al., 2008). Historically, the Battle of Adyar was fought in 1746 between French and British colonial powers on this river's bank. In 1882, the international headquarters of the Theosophical Society was set up south of the estuary. Built in 1967, the 'Broken Bridge' which is the landmark of the Adyar Estuary, was shattered during floods in the 1970s. The work of Chennai River Restoration Trust on restoring and maintaining the Adyar creek at Adyar Eco-Park, created in 2011, has significantly improved this part of the habitat and created awareness about it. This included landfill reclamation, planting of mangroves and mangrove associated flora, removing invasive species and protecting the existing habitat.

Adyar is a tidal river and its backwater effect during high tides is known to be felt up to 4 km upstream (personal communication, B. S. Murty, 2021). The river is rainfed and receives a major portion of its water from Chembarambakkam Lake, along with several other smaller water bodies. Locals say that its name comes from the Tamil words - *Adai* - to block and *Aaru* - river. The river mouth gets blocked very often due to wave action and siltation, therefore dredging activities are often undertaken here. This coastline shows marked morphometric changes over the year due to changing longshore currents, wave action and seasonal differences in river flow.

3.1.2.2 Ecology Table 2 summarizes the ecological diversity of the hotspot. What is extremely noteworthy is that an average of 218 Olive Ridley Sea Turtle nests has been recorded here per year by the Students' Sea Turtle Conservation Network (SSTCN) and the Tamil Nadu Forest Department over the last 5 years

Fig. 4. ICMBA demarcation of Adyar Estuary proposed by the authors.

Table 2
Ecology of Adyar Estuary.

Adyar Estuary		
Class	No. of Species	Highlight
Bivalves	32	Olive Ridley Sea Turtle *(Lepidochelys olivacea)*
Gastropods	53	Painted Stork *(Mycteria leucocephala)*
Crustaceans	41	Spot-billed Pelican *(Pelecanus philippensis)*
Insects	220	Oriental Darter *(Anhinga melanogaster)*
Spiders	30	Black-tailed Godwit (*Limosa limosa*)
Birds	196	Black-headed Ibis (*Threskiornis melanocephalus*)
Mammals	17	Red Ghost Crabs *(Ocypode macrocera)*
Echinoderms	8	Horn-eyed Ghost Crabs *(Ocypode brevicornis)*

(2016–2020) (personal communication, SSTCN, 2021). During the nesting season, the SSTCN have been conducting public walks to create awareness and also transfer turtle nests into the hatchery set up by the Tamil Nadu Forest Department (Arun, 2011). A total of 101 species of fish have been recorded from the Adyar river wetland complex, comprising the Chembarambakkam Lake, Adyar Estuary, the Adyar creek and Adyar Eco-Park (Ramanujam, 2005). The study reported 48 species from the estuary alone, including Indian Threadfish (*Alectis indica*), Tilapia (*Oreochromis aureus*) and Climbing Perch (*Anabas testudineus*).

3.1.2.3 Threats The following were identified as major threats of Adyar Estuary during the study. Their effects and conservation strategies have been elaborated in the discussion section.

- Point source and non-point sources of pollution in the lower course of Adyar River.
- Urbanization pressures and deforestation of mangroves along the river.
- Proposed coastal Road over the Estuary, which violates CRZ (Coastal Regulation Zone) Rules (see Fig. 5).

The lower course of the Adyar and parts of the creek are marked by the presence of mangroves chiefly of *Avicennia marina* and its associates. The sandy regions were dominated by Beach Morning Glory (*Ipomoea pes-caprae*) and Beach Bean (*Canavalia rosea*). Due to the proximity of the site to Edward Elliot's Beach which is a crowded public space, the sand dunes here are disturbed and underdeveloped.

The beaches along this stretch have been designated as CRZ-I A (National Centre for Sustainable Coastal Management, 2018b) areas due to turtle nesting. However, other parts of the estuary, except for a portion on its southern bank, which warrant protection due to the presence of mangroves and biologically active mudflats have been marked as CRZ II, making conservation activities a challenge.

The authors from their interactions with locals found that fisherfolk from over eight hamlets are dependent on the estuary, either directly or indirectly, for their livelihoods. These include Urur Kuppam, Olcott Kuppam, Narayanasamy Thottam, Bhavani Kuppam, Srinivasapuram, Dumil Kuppam, Ettukattadam and Pattinapakkam. Senior fisherfolk testified that decades ago shrimp, shark, barracuda, threadfin and many other species would traverse the river to breed and forage, and would be caught in large numbers till Kotturpuram, which is about 4 km from the river mouth. They also claim that fish have drastically reduced due to pollution of the river. This trend has been observed since 1991 (Srivastava et al., 1991). From mid-July to mid-September sardines are caught in large numbers in nearshore waters. Between January to March when the seas are calm, fisherfolk cast the *Periya-valai* (large shore seine), which is hauled in by over 50 men mainly for shrimp, mackerel, anchovies, silverbelly and perch (personal communication, S. Palayam and other local fisherfolk, 2021).

3.1.3 Kovalam-Muttukadu backwaters

3.1.3.1 Location and landscape The Kovalam and Muttukadu backwaters (12°47′13″N; 80°15′01″E) that span an area of 34 km^2 are fed by the Bay of Bengal through the Kovalam creek. The ICMBA has been demarcated in Fig. 6. The Buckingham Canal

Fig. 5. Resident wader species such as herons and egrets depend on the Adyar Wetland complex as a feeding ground.

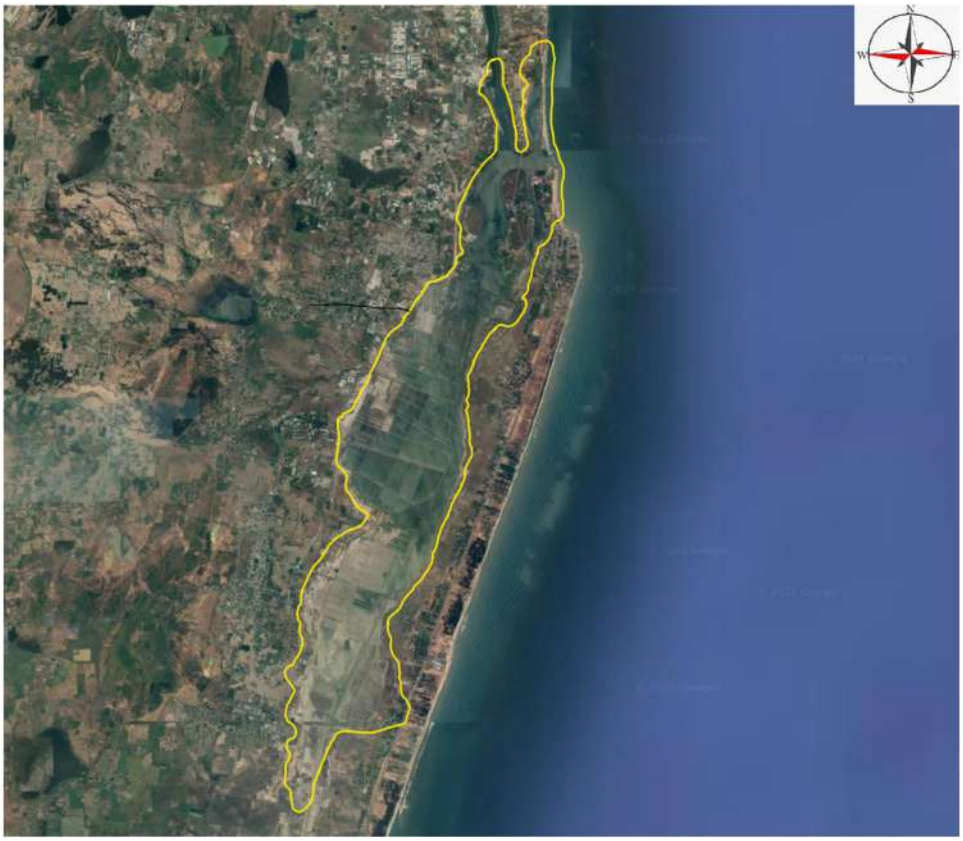

Fig. 6. Map demarcating the Kovalam-Muttukadu ICMBA.

flows from the north on its way out of Chennai city into the backwaters and it joins the Great Salt Lake to the south. The Central Institute of Brackishwater Aquaculture (CIBA), and its aquaculture ponds are part of these backwaters to the north of the estuary mouth. The sandbar at the creek is known to get blocked by longshore drift during the summer months (Gopinath and Natesan, 2013) and opens during and after the monsoon due to inundation and inflow from adjoining wetlands. The maximum depth of the estuary is found to be around 2 m (Krishnamoorthy et al., 2018).

The most important geological influence on this part of the coast is the Palar river to the south. Due to longshore dynamics on the eastern coast of India, sediment brought in by this river plays a significant role in the formation of this coast. Hence protection of the river (Anthony, 1995; Srinivasan et al., 2017), its flow and watershed are important in maintaining the health and replenishment of this shoreline.

3.1.3.2 Ecology Ecological diversity of the hotspot is summarized in Table 3. The breeding of terns, plovers and other waterbirds have been observed in the Kelambakkam tidal flats and a rare

Fig. 7. Fiddler crabs at the Kovalam Creek.

Table 3
Ecology of Kovalam-Muttukadu.

Kovalam-Muttukadu Backwaters		
Class	No. of species	Highlight
Bivalves	31	Spot-billed Pelican *(Pelecanus philippensis)*
Gastropods	59	Painted Stork *(Mycteria leucocephala)*
Crustaceans	28	Black-headed Ibis *(Threskiornis melanocephalus)*
Insects	138	Pallas' Gull *(Ichthyaetus ichthyaetus)*
Spiders	16	Osprey *(Pandion haliaetus)*
Birds	196	Eurasian Curlew *(Numenius arquata)*
Mammals	15	Caspian Terns *(Hydroprogne caspia)*
Echinoderms		Ring-legged fiddler crabs (*Austruca annulipes*)
	1	Southern Birdwing (*Troides minos*)

Table 4
Ecology of Odiyur-Mudhaliyarkuppam lagoon.

Odiyur-Mudhaliyarkuppam lagoon		
Class	No. of species	Highlight
Bivalves	26	Northern Pintails (*Anas acuta*)
Gastropods	34	Northern Shovelers *(Spatula clypeata)*
Crustaceans	24	Garganeys *(Spatula querquedula)*
Insects	190	Eurasian Wigeons *(Mareca penelope)*
Spiders	20	Burnt Murex (*Chicoreus brunneus*)
Birds	212	
Mammals	13	
Echinoderms	3	

record of breeding Caspian Terns (*Hydroprogne caspia*) which are usually migratory. It also hosts a healthy population of fiddler crabs, as seen in Fig. 7. The Kelambakkam region also has a healthy population of the *Avicennia marina*. Fisherfolk use these waters to catch fish, shrimp and crabs. Salt production also happens in the Kelambakkam region. 25 species of edible fish are known to be caught from Kovalam, including *Sardinella fimbriata*, Indian anchovy (*Stolephorus indicus*), Saddle Grunt (*Pomadasys maculatus*), Commerson's sole (*Synaptura commersonii*) and ten species of edible ornamental fish.

3.1.3.3 Threats The following were identified as major threats of Kovalam-Muttukadu Backwaters during the study. Their effects and conservation strategies have been elaborated in the discussion section.

- Illegally built groynes and other manmade structures built along the shoreline triggering erosion.
- Dumping of domestic sewage and domestic household waste into the Muttukadu Backwaters.
- Large tracks of land undeclared as CRZ-I A.

3.1.4 Odiyur-Mudhaliyarkuppam Lagoon

3.1.4.1 Location and landscape The Odiyur Lagoon (12°02′–12° 19′N; 80°03′–80°03′E) and backwaters, as shown in Fig. 8, spans over 32 km^2 and is located 92 km south of Chennai. This wetland system is fed by a long backwater channel. The mouth bar is located between the villages of Nainar Kuppam and Thazhuthali Kuppam. The Buckingham Canal enters this channel from the north. The main lagoon is about 10 km long, 5 km wide and has a maximum depth of about 0.5 m. Several freshwater channels from the nearby villages, fields and waterbodies flow into it. The authors observed that the lagoon functions as a crucial flood catchment and climate buffer for a large part of the Chengalpattu district. The mouth bar opens during the monsoon months due to freshwater flow and is otherwise closed. The waterbody has an annual salinity fluctuation of about 10–28 ppt (Manakadan, 2014).

3.1.4.2 Ecology Ecology of the hotspot is summarized in Table 4. The Asian Waterfowl Census (AWC) conducted over the years records over 16,000 migratory ducks (Aves, 2019a,b; Vidhya Swaminathan, 2019) mainly consisting of Northern Pintails (*Anas acuta*, Northern Shovelers (*Spatula clypeata*), Garganeys (*Spatula querquedula*) and Eurasian Wigeons (*Mareca penelope*), as seen in Fig. 9, making the wetland one of the greatest waterfowl congregation sites in North Tamil Nadu.

A total of 24 species of fish have been reported, though more targeted studies on the ichthyofauna of this lagoon are needed. During the study, the fish species recorded by the authors include Slender Rasbora (*Rasbora daniconius*), Splendid Ponyfish (*Leiognathus splendens*), Orange Chromide (*Etroplus maculatus*), Deep Pugnose Ponyfish (*Secutor ruconius*), Tongue Sole (*Pseudorhombus arsius*), Tripod Fish (*Triacanthus brevirostris*) and Boddart's Blue-spotted Mudskipper (*Boleopthalmus boddarti*).

Near the mouth bar, the authors recorded a mature and healthy population of *Avicennia marina*, along with *Exoecaria agallocha* and *Acanthus ilicifolius* which are uncommon in northern Tamil Nadu. Local boatmen at the Tamil Nadu Tourism Development Corporation report that mangroves and their associates present in other parts of the creek till about 2015, have been

Fig. 8. ICMBA demarcation of Odiyur-Mudhaliyarkuppam Lagoon proposed by the authors.

Fig. 9. Congregation of ducks at Odiyur lagoon during the winter months.

replaced by the invasive *Prosopis juliflora*. The Tamil Nadu Forest Department with the help of local people had planned mangrove afforestation activities, which were later revoked by the Panchayat. Large beds of *Syringodium isoetifolium* and *Halophila ovalis* seagrasses were found during the study and by Shanmugasundharam et al. (2019) across the lagoon. They function as important breeding grounds for marine fauna and as foraging sites for waterbirds and waders (Ramesh et al., 2018). The authors observed that seagrasses sustain small-scale fishing practices and support a large number of fisherfolk who manually catch shrimp and crabs.

Turtle nesting has been recorded along the shoreward side and the beaches adjacent to the backwater channel (Jayaraman et al., 2013). Secondary and tertiary sand dune systems up to 20–30 ft

high, behind which were well-developed TDEF, was observed at southeast parts of the site. The presence of these dunes, according to the locals, has blocked seawater ingress and made the water table rise to sea level, making freshwater available very close to the high tide line. According to locals, dunes protected inland villages by soaking up the water during the 2004 Indian Ocean Tsunami, whereas sections without these dunes suffered damage. Areas where sand dunes had been demolished have also reported freshwater scarcity. (Personal communication with boatmen, 2021; Rajani Priya et al., 2010)

3.1.4.3 Threats The following were identified as major threats of Odiyur-Mudhaliyarkuppam Lagoon during the study. Their effects and conservation strategies have been elaborated in the discussion section.

- Invasion of *Prosopis* in mangrove areas.
- Fertilizer and pesticide runoff from neighbouring agricultural areas.
- Proposed Cheyyur Thermal Powerplant (Stayed by the Madras High Court).

3.1.5 Kaliveli Lake

3.1.5.1 Location and landscape Kaliveli Lake and the estuarine mouth (12°10′ 0″N; 79° 49′ 59″E) is the second-largest brackish water lake in Tamil Nadu. The wetland consists of the estuary between the villages Yedaiyanthittu and Kadappakkam, and the Uppukali Creek whose narrow backwaters extend to feed the expansive Kaliveli Lake. The word '*Kazhuveli*' in Tamil refers to coastal commons, including backwaters, salt marshes, mudflats and creeks. The lake is 12.5 km long and 370 m broad, with an average depth of 1.75 m during high tide (Silambarasan and Sundaramanickam, 2017). It covers an area of 132 km^2 (Ramanujam, 2005) while its watershed area is more than 720 km^2 (Bhalla, 2011). The ICMBA demarcation is as shown in Fig. 10. The authors observed that the wetland system is an important flood catchment and climate buffer for a large part of Villupuram district and Puducherry. The salinity gradient of the wetland is greatest near the estuary and decreases along the neck of the Uppukali Creek. The Kaliveli Lake is largely a freshwater body. The mouth bar of the estuary gets blocked during the summer and opens up during the northeast monsoon (Rivillas-Ospina et al., 2017). It was declared as a bird sanctuary by the Tamil Nadu Forest Department on the 6th of December 2021.

3.1.5.2 Ecology Table 5 summarizes the ecological diversity of the hotspot. Along the estuary and creek, a mixture of mature and young mangroves, largely *Avicennia marina* and some *Rhizophora mucronata,* was observed by the authors. Closer to the estuary seagrass expanses of *Halophila ovalis* and *Syringodium isoetifolium* were recorded. Secondary and tertiary sand dunes sheltering well-developed TDEF patches occur along the coastal area. Numerous freshwater swales dot the dune-scape environment of Kaliveli. Several fishing hamlets have been built upon the undulating sand dunes, due to which they have perennial access to freshwater, while the dunes closer to the East Coast Road have either been destroyed or are under threat due to urbanization. Sand dune stabilization is practised by several other countries to help fight coastal erosion (Schwendiman, 1977). Dune-scapes take several centuries to form and are dependent on the presence of coastal vegetation (Barman et al., 2016; JagdishKrishnaswamy et al., 2008) like Ravana's Moustache (*Spinifex littoreus*.

The area regularly hosts over 30,000 ducks (Davidar, 2011), 20,000–40,000 migratory shorebirds and 20,000–50,000 terns in winter (BNHS India, 2012). The Grey-tailed Tattler (*Tringa brevipes*), a rare migratory wader, has been recorded only here and in Pulicat across the country (eBird India, 2021b; Prince Frederick, 2021) (see Fig. 11).

Table 5
Ecology of Kaliveli Lake.

Kaliveli lake		
Class	No. of species	Highlight
Bivalves	26	Eastern Imperial Eagle *(Aquila heliaca),*
Gastropods	37	Greater Spotted Eagle *(Clanga clanga)*
Crustaceans	27	Red-necked Falcon *(Falco chicquera)*
Insects	179	Grey-tailed Tattler *(Tringa brevipes)*
Spiders	20	Indian Pangolin *(Manis crassicaudata)*
Birds	226	Girdled Horn Snail *(Cerithidea cingulata)*
Mammals	39	Golden Jackal (*Canis aureus*)
Echinoderms	2	

In the early 2000s, 42 species of fish were recorded at Kaliveli (Ramanujam and Anbarasan, 2007). Of these species, six were confined to the floodplain, 19 were recorded as brackish water species and 17 species were seen in both ecosystems. Species such as Catla (*Catla catla*), Rohu (*Labeo rohita*), Mrigal (*Cirrhinus mrigala*) and Carps (*Cyprinus spp.*) have been introduced in the larger watershed, but have so far not made their way into the floodplains (Ramanujam, 2005). These species have been introduced for commercial purposes and export. Local fisherfolk, as with the case along the entire coast, depend more on marine fish than estuarine fish, except few fish species such as Hilsa (*Tenualosa ilisha*). Subsequent studies along the Yedayanthittu Estuary recorded 75 species of fish, almost all being estuarine species (Ramanujam and Anbarasan, 2009). Oyster reefs were observed by the authors around the Alamparai Fort. The lake contains large expanses of reeds including *Chrysopogon zizaniodes* and other species.

There are 22 villages that surround the lake and 16 of them share their revenue boundaries with the Kaliveli Lake (Sricandane and Vaidyanathan, 2004). The wetland's watershed area supports around 65,000 people who depend on it for irrigation, pastures, reed collection and other non-timber forest produce, fishing, shrimp farming and salt production (Bhalla, 2011).

3.1.5.3 Threats The following were identified as major threats of Kaliveli Lake during the study. Their effects and conservation strategies have been elaborated in the discussion section.

- Proposed commercial fishing harbour by Tamil Nadu Government at Alamparai.
- Proposed Public Works Department water catchment area which plans to cut off the lake from the creek and ocean.
- Pressure caused by commercial salt extraction units.

3.2 Species diversity of the region

A total of 913 species from 8 animals' classes – Crustacea, Insecta, Arachnida, Mollusca, Echinodermata, Reptilia, Aves and Mammalia – have been recorded from the five hotspots. Out of these, 709 species were recorded during the study period by the authors from September 2020 to April 2021. The remainder 203 species listed in the appendix are based on previous records and relevant references have been cited in the appendix. 332 species are protected by Schedules I–IV of The Wild Life (Protection) Act, 1972, while 34 species are globally threatened.

3.2.1 Crustacean diversity

A total of 95 species of crustaceans have been documented from these five hotspots — five species of barnacles, two species of mantis shrimps, 12 species of shrimp, two species of spiny lobsters, 63 species of true crabs, nine species of hermit crabs and two species of mole crabs. They have been presented in Appendix 1. Through interactions with fisherfolk and surveying

Fig. 10. Map showing the Kaliveli ICMBA.

Fig. 11. The Girdled Horn Snail (*Cerithidea cingulata*), the most common intertidal gastropod from the hotspot. Picture captured by Mahathi Narayanaswamy.

their catch, a glimpse into the diversity of marine crabs such as Asian Blue Swimming Crab (*Portunus pelagicus*) and Common Moon Crab (*Matuta victor*) was possible. The most diverse hotspot was Pulicat, followed by Adyar Estuary and Kovalam. Many studies on crustacean diversity have been undertaken from Pulicat Lagoon as compared to the other hotspots. This accounts for the

large difference in crab diversity recorded among the sites. Due to the pandemic, the authors were unable to record the crustacean diversity from Odiyur and Kaliveli. However, high diversity of crustaceans is expected from these regions.

Mudflats are important habitats for crustaceans. They are key habitats for sand-sifting crustaceans such as the Red Ghost Crab (*Ocypode Macrocera*), Ring-legged Fiddler Crab (*Austruca annulipes*) and Motley Fiddler Crab (*Austruca variegata*).

Crustaceans due to their feeding mechanisms are important niche holders in any coastal ecosystem. In mangrove forests across the Indo-Pacific region, grapsid crabs are significant contributors to the structure and function of these ecosystems, as they are important mangrove detritus feeders (Lee, 1998). Ghost crabs have been recognized as bio-indicators of the health of beaches throughout the world, though, there are still aspects of their ecology and responses to anthropogenic stimuli that are not well understood (Gül and Griffen, 2018). Ghost crabs are crucial scavengers in sandy beaches, feeding on a variety of organic matter that gets washed ashore and can be analogized as the vultures of the coast. Since there is a deficit of microbial life in sandy beaches, their role is significant. Thus, healthy the presence of species such as the Horn-eyed Ghost Crab (*Ocypode brevicornis*), shown in Fig. 12, is vital for the Chennai coast. Fiddler crabs have been used as indicators of climate change and respond differently to the rise in temperature in vegetated and un-vegetated zones. Fiddler crabs from more vegetated ecosystems were observed to be more vulnerable to a rise in temperatures than those in less vegetated ecosystems, as concluded by a recent study (Vianna et al., 2020). Thus, it would be important to monitor the fiddler crab populations as climate indicators in larger mangrove forests in the Tamil Nadu coast such as Pichavaram, Vedaranyam and Pazhaiyar. A more imminent threat to the crabs of the region, especially marine crabs, is from the bioaccumulation of heavy metals. *Portunus pelagicus* and *P. sanguinolentus* have been recorded with heavy metals in their gills from the Ennore-Pulicat wetland complex, Adyar Estuary (Pattinampakkam), Kovalam and near Kaliveli Lake (at Marakanam) by Barath Kumar et al. (2019). Coupled with the possibility of microplastic accumulation in mole crabs along the intertidal zone (Nagarajan et al., 2020a), the risks associated with the consumption of these crabs along the study sites need to be researched. This can cause a trophic transfer to human beings and the threatened species that feed on them. Regulations on garbage disposal and solid waste management along coastal habitats must be made effective to address these issues.

3.2.2 Insects and spider diversity

Insects are the most diverse faunal class in the world, with over 900,000 species known to science. Many studies have been conducted on various groups of insects across the country. However, studies on the diversity of Hemiptera (Debdas Jana et al., 2014) and Orthoptera (Jana et al., 2015) of Midnapore (East), West Bengal and a study on the insects from the southeastern Tamil Nadu coast (Balakrishnan et al., 2014) are the only recent studies on the insect diversity along the east coast of India. From the current area of study, very few reports on the insect diversity of the five selected hotspots exist. Nagarajan and Theivaprakasham (2020) recorded 52 species of butterflies from the Tamil Nadu section of Pulicat Lagoon. Amruth (2005) recorded 18 species of butterflies from Kaliveli wetland, while noting that there were several other species of insects present at the hotspot. Appendix 2 is a preliminary checklist of species from class Insecta recorded in the hotspots by the current study and by previous authors. A total of 246 species of insects from eight orders have been recorded, including 110 species of lepidopterans, nine species of dipterans, five species from order Mantodea, 32 species of coleopterans, 30 species of hemipterans, 16 odonates, eleven species of orthopterans, and 33 species of hymenopterans. Apart from this rich insect diversity, 30 species of arachnids were also recorded by the authors in the surveyed hotspots and have been listed in Appendix 3.

Out of the 246 species recorded in the study, 142 species are pollinators, which accounts for nearly 60% of the insects seen. Among the butterflies, Crimson Rose (*Pachliopta hector*), Gram Blue (*Euchrysops cnejus*), Pea Blue (*Lampides boeticus*) and Danaid Eggfly (*Hypolimnas misippus)* are protected under The Wild Life (Protection) Act, 1972. The Crimson Rose (*Pachliopta hector*) is endemic to Peninsular India and Sri Lanka. Most of the butterflies observed during the study were dry forest species. Among the 40 species of moths sighted in the study, the most important pollinators are hawkmoths. *Macroglossum gyrans* was observed to be the most predominant moth pollinating mangroves and mangrove associates present in the study area. The most important pollinators of the habitat were hymenopterans. This order, especially bees, are vital for the pollination of mangrove species in this belt such as *Avicennia sp, Acanthus sp, Excoecaria sp* and *Rhizophora sp* (Kathiresan and Bingham, 2001). A notable pollinator of mangroves observed was the Slender-scaped Carpenter Bee (*Xylocopa tenuiscapa*).

3.2.3 Molluscan diversity

A total of 162 species of molluscs, comprising 105 gastropods, 53 bivalves and four cephalopods, have been recorded from the five hotspots. This includes 45 species (27.8% of species recorded) that were recorded as part of bycatch from artesian fishing. Of these, Spiral Tudicla (*Tudicla spirillus)* is protected under Schedule I (Part IV B) and Windowpane Oyster (*Placuna placenta)* under Schedule IV of The Wild Life (Protection) Act, 1972. Due to a deficit of historical records on the molluscan diversity in the southern section of the survey region, targeted studies must be conducted from Kaliveli and Odiyur, The checklist presented in Appendix 4–5 of this study, especially from the southern section, will serve as a baseline for future studies. The checklist is a compilation of historical studies, personal records and surveys conducted by the authors from these regions (Raj, 2006; Ramanibai and Govindan, 2017).

Preston (1916) conducted surveys from the Ennore Estuary in 1916 and these are an important piece in understanding the mollusk diversity during that period. The below table, Table 6, lists the species recorded during his work.

The most abundant bivalves seen from the five hotspots are Cuneate Wedge Clam (*Donax cuneatus), Donax scortum*, *Anadara spp., Sunetta meroe, Sunetta scripta, Perna viridis* and *Mactra sp.* Sudden spikes in the population of Sunset Siliqua *(Siliqua radiata)* were periodically recorded along the Adyar Estuary during the study. A similar phenomenon has been reported before from the west coast of India (Sundaram et al., 2010). Reefs of the Indian Edible Oyster *(Crassostrea madrasensis),* which is regarded as a keystone species (Raj, 2006), were recorded in Pulicat Lake, Odiyur and Alamparai by the authors. Oyster reefs create a habitat and breeding ground for a range of brackish and marine fauna. They are a substrate for reef-building corals. They act as fish aggregation sites, making them important ecosystems that support small-scale fisherfolk. They have also been reported to retain fresh water and influence salinity over an extensive area in estuarine ecosystems, which is a keystone ecosystem service. The authors recommend that oyster reefs must be recognized as a CRZ I-A criteria. Despite their importance, there is very little scientific research on oyster reefs from India.

The most common gastropods seen from the hotspots are Indian Babylon Snail *(Babylonia zeylanica),* Grey Bonnet Snail *(Phalium glaucum),* Paper Fig Shell (*Ficus ficus),* Olive Sea Snail

Fig. 12. Horn-eyed Ghost Crab is the most common intertidal crustacean in Chennai's coast.

Table 6
Species recorded historically from Pulicat Lake and status currently.

Species as reported by preston	Current species name	Presence at pulicat in current study
1. Retusa ennurensis	*	–
2. Nassa denegabilis	Nassa subconstrictus	–
3. Nassa orissanesis	Nassarius orissanesis	–
4. Nassodonta gravelyi	Nassodonta annesleyi	–
5. Tiara scabra	Pagoda scabra	–
6. Littorina arboricola	Littorina pallescens	–
7. Conradia cancellata	*	–
8. Alaba rectangulata	#	–
9. Iravadia ennurensis & 10. Iravadia annadales	Iravadia ornata	–
11. Natica marochiensis	Natica marochiensis	–
12. Theodoxus sowerbyana	#	–
13. Solariella deliciosa	*	–
14. Cyclostrema micans	Pseudoliotia micans	–
15. Ostrea madrasensis	Mangallana bilineata	–
16. Placuna placenta	Placuna placenta	+
17. Modiola taprobanesis	*	–
18. Arca granosa	Tegillarca granosa	+
19. Arca lactea	Striarca lactea	–
20. Meretrix casta	Meretrix casta	–
21. Meretrix zonaria	Meretrix petechialis	–
22. Chione imbricata	#	–
23. Anomalocardia squamosa	Anomalodiscus squamosus	–
24. Cultellus subillipticus	Cultellus subillipticus	–
25. Codokia fischeriana	Pillucina angela	–
26. Tellina ennurensis	Pulvinus micans	–
27. Tellina brunneo-flavida	*	–
28. Theora opalina	Theora opalina	–
29. Theora translucens	Theora translucens	–
30. Cuspidaria annandalei	Indosphenia abbreviata chilkaensis	–

Key to table: * Taxon inquirendum, # Species not listed in WORMS, – Not seen in study, +Seen in study.

(Oliva olive), Ribbon Bullia *(Bullia vittata)* and Spotted Tun (*Tonna dolium).* Among the Conidae family recorded during the study, *Conus amadis* was the most common, followed by *Conus monile*. Predation of Cuneate Wedge Clam (*Donax cuneatus)* by Olive Sea Snail *(Oliva oliva)* was frequently observed, as seen in Fig. 13.

Molluscs are the primary source of food for a variety of shorebirds including storks, egrets, plovers, sandpipers and oystercatchers. Asian Backwater Clam *(Meretrix casta)* and Cuneate Wedge Clam (*Donax cuneatus),* distributed on the estuarine and intertidal habitats respectively, are food sources for the local communities. Historically, cowries were used as currency for commodity exchange in maritime trade (Yang, 2019). The current study recorded three species of cowries — Arabian Cowry (*Mauritia arabica),* Ocellate Cowry *(Naria ocellata)* and Chocolate Beauty *(Erronea adusta).* Four species of cephalopods were recorded from the study sites — Marbled Octopus (*Amphioctopus aegina),* Pharaoh Cuttlefish (*Sepia pharaonic)*, Ram's Horn Squid *(Spirula spirula)* and Indian Squid (*Uroteuthis duvaucelii)*. Squids are an important part of the diet of toothed whales.

3.2.4 Echinodermata diversity

777 species of echinoderms have been reported from India (Parameswaran et al., 2018). Out of the 42 echinoderms found in Chennai (Venkataraman, 2007), eight have been recorded in the present study (shown in Appendix 6), with six of these recorded as part of by catch . The most observed species were the Plain Sand Star (*Astropecten indicus*) and Pansy Shell (*Echinodiscus bisperforatus*).

Gomathy et al. (2018) reported large quantities of Keyhole Sand Dollar (*Echinodiscus bisperforatus*) and Tiny Maretia Heart Urchin (*Maretia planulata*) in Mudaliyarkuppam during September 2017. All Holothuroidea species are protected under Schedule I (Part IV-C) of The Wild Life (Protection) Act, 1972. A sea cucumber (*Bohadschia sp.)* was recorded at Adyar Estuary by the authors. The presence of the Brittle Star (*Ophiocnemis marmorata*) and *Acudina molpadioides* in the Ennore-Pulicat region was mentioned by James (1983).

3.2.5 Reptile diversity

A total of 47 species of reptiles have been reported from the five hotspots. This includes 27 snakes, four chelonids and 16 lizards that were reported and been presented in Appendix 7.

Of the reptiles recorded, three species are protected under Schedule I (Part II), while five species under Schedule II (Part II) and 24 species under Schedule IV of The Wild Life (Protection) Act, 1972. According to the IUCN, four species have been classified as near-threatened, while two others as vulnerable. The conservation status of 18 species has not been evaluated by the IUCN. Of the species recorded, CITES has listed three species under Appendix I, seven under Appendix II and five under Appendix III.

Of the 12 species of sea snakes recorded from Chennai (Venkataraman et al., 2015), four have been observed in the study. The Hook-nosed Sea Snake (*Enhydrina schistosa*) was observed to be

Fig. 13. *Oliva oliva* feeding on *Donax cuneatus*.

the most common elapid from the Chennai coast. On various occasions during the study, more than a dozen Hook-nosed Sea Snakes (*Enhydrina schistosa*) were observed as by-catch in shore-seines at the Adyar Estuary, indicating their sub-tidal habitat.

Out of the four species of sea turtles recorded in India, the Olive Ridley Sea Turtle (*Lepidochelys olivacea*) is the only species that has been recorded from Chennai's beaches. This species has been listed under Appendices I and II of The Convention on Migratory Species (Bonn Convention) and is protected under Schedule I (Part II) of The Wild Life (Protection) Act, 1972. It is listed under Appendix I of CITES and is a vulnerable species. Between November and March, the turtles lay their eggs along the Chennai coast (Zoological Survey of India, 2007). Turtle Nesting Zones are found across the coast of Chennai and legally need to be declared as CRZ-I A zones. Pulicat, Adyar Estuary, Kovalam, Odiyur, and Marakanam (adjacent to Kaliveli) coasts are Olive Ridley Sea Turtle nesting sites. Current threats to the species include coastal erosion, light pollution, stray dogs, urbanization, ghost nets and marine pollution.

The Fan-throated Lizard (*Sitana ponticeriana*) was found to be very common in the sandy regions of all the study areas. The Common Green Forest Lizard (*Calotes calotes*), a species rare to the Coromandel Coast, was reported by Ramanujam and Anbarasan (2007) from Kaliveli.

3.2.6 Avian diversity

A total of 277 species of birds have been recorded in the five hotspots and have been listed in Appendix 8. A complete checklist of the birds reported along with their conservation status has been presented in Appendix 1. Of the birds recorded, 25 species are globally threatened, including two endangered species, six vulnerable species and 17 near-threatened species. 28 species of birds are protected under Schedule I (Part III) of The Wild Life (Protection) Act, 1972 and the rest under Schedule IV. It must be noted that the Indian Grey Hornbill (*Ocyceros birostris*) and Lesser Frigate (*Fregata ariel*) do not have any legal protection from the above-mentioned act. A total of 21 species of birds listed in the United Nations Convention on Migratory Species (Bonn Convention) were recorded. 14 species have shown a strong decline in their population and are of the highest conservation concern according to the recently released State of India's Birds report (The SoIB Partnership, 2020). Among these species, the Pacific Golden Plover (*Pluvialis fulva*), Common Greenshank (*Tringa nebularia*) and Gull-billed Tern (*Gelochelidon nilotica*) are regular winter visitors. The Pacific Golden Plover (*Pluvialis fulva*) in particular was observed in congregations of up to 800 individuals at Kovalam and occasionally over 1000 individuals from Pulicat. The State of India's Birds report stresses the strong long-term decline of waders. On comparing eBird data from different hotspots across India, the authors inferred a higher congregation of waders in coastal wetlands than inland wetlands. Thus, the preservation of these hotspots would be an important strategy in the conservation of waders in South Asia.

Waders such as sandpipers, shanks, plovers and allies, are a characteristic part of any coastal wetland. Some uncommon species of waders reported include the Grey-tailed Tattler (*Tringa brevipes*), Great Knot (*Calidris tenuirostris*), Red Knot (*Calidris canutus*), Broad-billed Sandpiper (*Calidris falcinellus*), Long-toed Stint (*Calidris subminuta*), Common Ringed Plover (*Charadrius hiaticula*), Caspian Plover (*Charadrius asiaticus*) and the Eurasian Oystercatcher (*Haematopus ostralegus*). Among these, the Grey-tailed Tattler (*Tringa brevipes*) is of special significance, as this vagrant bird has only been reported from Pulicat (Shanmugasundaram and Palanivelu, 2017) and by the authors at Yedayanthittu Estuary of Kaliveli Lake, in the whole of India. The Great Knot (*Calidris tenuirostris*) was recently classified by the IUCN as an endangered species, making it the most threatened wader in the region. It is a regular winter visitor to Pulicat and has been reported once from Kovalam and Kaliveli, making the protection of these three hotspots vital for the conservation strategy of the bird. A recent study has shown the risk of microplastic pollution for the species (Nagarajan et al., 2020a) from the Chennai coast, thus highlighting the importance of protecting these coastal habitats from pollution. Among the larger waders, the most charismatic species are the Greater and Lesser Flamingo. The study area is an important feeding ground for the Greater Flamingo (*Phoenicopterus roseus*) in the state, while the Lesser Flamingo (*Phoeniconaias minor*) is not known to be seen in any part of South India, in flocks as large as the ones seen in Pulicat. Another prevalent group of birds are terns and gulls, which are known to congregate at estuaries, salt marshes and creeks. Though most of the recorded species are winter visitors, the over-wintering of terns such as the Caspian Tern (*Hydroprogne caspia*), Gull-billed Tern (*Gelochelidon nilotica*), Whiskered Tern (*Chlidonias hybrida*) and Common Tern (*Sterna hirundo*) was noted from seasonality charts (eBird India, 2021a) and personal observations. Another notable sighting is the Indian Skimmer *(Rynchops albicollis)* which has been recorded on several occasions by birdwatchers

since 2010 (Nagarajan, 2010). The bird has also been reported from the southern districts of Tamil Nadu and is thought to be a passage migrant along the Tamil Nadu coast. Given the decline of the species, it is recommended that the bird be included in Schedule I of The Wild Life (Protection) Act, 1972 (Rahmani, 2012). Thus, it is important that these wetlands are protected as they form migratory flyways for various birds. The study area is also one of the most important wintering grounds for a variety of ducks such as the Northern Pintail (*Anas acuta*), Northern Shoveler (*Spatula clypeata*), Garganey (*Spatula querquedula*) and Eurasian Wigeon (*Mareca penelope*), especially at Pulicat, Odiyur and Kaliveli. The Bar-headed Goose (*Anser indicus*) winters in small populations at Odiyur and is rarely found elsewhere in North Tamil Nadu. The current study recorded the Graylag Goose (*Anser anser*) (Nagarajan et al., 2020b) from Kaliveli, an addition to the avian fauna of North Tamil Nadu.

A total of 26 species of raptors have been recorded from these hotspots. Among them, globally threatened species such as the Eastern Imperial Eagle (*Aquila heliaca*), Pallid Harrier (*Circus macrourus*), Indian Spotted Eagle (*Clanga hastata*) and Greater Spotted Eagle (*Clanga clanga*) were recorded. Rahmani (2012) has stressed the importance of protecting hotspots of threatened birds such as the Greater Spotted Eagle (*Clanga clanga*), especially large wetland ecosystems and has called for community conservation in these locations. These hotspots also serve as the last stronghold for the White-bellied Sea Eagle (*Haliaeetus leucogaster*) in the Chennai region. Along with these species, other passerine birds have also been recorded due to the diversity of habitats in the surveyed hotspots. Few notable sightings include the Eastern Yellow Wagtail (*Motacilla tschutschensis*), Black-breasted Weaver (*Ploceus benghalensis*), Tree Pipit (*Anthus trivialis*) and Asian Pied Starling (*Gracupica contra*). Of these, the migratory Eastern Yellow Wagtail (*Motacilla tschutschensis*) is a recent addition to the avian fauna of Tamil Nadu, which was recorded during this study at Pulicat Lake and Kaliveli Lake and by other birdwatchers at Chennai (Narayanaswamy, 2020).

3.2.7 Mammalian diversity

A total of 48 species of mammals, listed in Appendix 9, were recorded from the five hotspots, including three globally threatened species. The Indian Pangolin (*Manis crassicaudata*) is protected under Schedule I, Bonnet Macaque (*Macaca radiata*), Indian Fox (*Vulpes bengalensis*), Golden Jackal (*Canis aureus*), Asian Palm Civet (*Paradoxurus hermaphroditus*), Small Indian Civet (*Viverricula indica*), Smooth-coated Otter (*Lutrogale perspicillata*), Cetaceans, Jungle Cat (*Felis chaus*), Indian Grey Mongoose (*Herpestes edwardsi*) under Schedule II, Chital (*Axis axis*) and Wild Boar (*Sus scrofa*) under Schedule III, and Black-naped Hare (*Lepus nigricollis nigricollis*), Madras Hedgehog (*Paraechinus nudiventris*) and Indian-crested Porcupine (*Hystrix indica*) under Schedule IV of The Wild Life (Protection) Act, 1972. Several records of sperm whale (Physeteridae) beachings have been recorded along the Chennai coast, including one by the authors at Yedayanthittu. Most of the mammals recorded belonged to orders Chiroptera (Bats) and Rodentia (Rodents). Chiropterans are important pollinators and biological pest control agents. A preliminary study from Kaliveli recorded 39 species of mammals, including rare species such as the Indian Fox (*Vulpes bengalensis*), Indian Pangolin (*Manis crassicaudata*), Madras Hedgehog (*Paraechinus nudiventris*) and the Painted Bat (*Kerivoula picta*) (Ramanujam and Anbarasan, 2007). This study reported the maximum mammalian diversity at Kaliveli because of the extensive field studies conducted and habitat variety at the hotspot. Pulicat Lagoon was the second most diverse hotspot, recording 23 species. Most of the observations made were by the authors and through interactions with the local community. Recently in the winter of 2020, experienced local boat guides spotted an animal referred to in Tamil as "*neer naai*" and identified the mammal as a Smooth-coated Otter (*Lutrogale perspicillata*) (personal communication Yuvaraj, 2020). The species, though reported from Nallavadu backwaters in Puducherry, has not been recorded from Pulicat Lagoon in the past. This would be a new addition to the mammalian diversity of the lake and from the Chennai region. Fig. 14 shows a pair of Wild Boars (*Sus scrofa*), a species regularly observed at Pulicat. The reduced mammalian diversity in Adyar Estuary and Kovalam might be attributed to the urbanized nature of these locations. The complete list of mammals recorded from these locations has been presented in Appendix 9.

4 Discussion

The surveyed hotspots were seen to be biodiverse as discussed in the earlier sections under the various animal taxa. Fig. 15 summarizes the diversity richness of the five hotspots together to give a useful comparative static.

Jacard's indices were computed using Eq. (1), shown under the methodology section. The results of the same have been depicted in Fig. 16 in the form of a histogram. Kaliveli and Odiyur share the greatest number of species observed in the study with 71.12% Similarity. Adyar estuary and Pulicat share the least percentage of Similarity at 49.71%. On average, all 5 locations shared 56.33% Similarity in the species observed during the study.

4.1 Pulicat Lagoon

During the surveys made by the authors in 2020–21, it was found that the mangroves were nearly absent within the bird sanctuary from the Tamil Nadu section. Mangroves here were primarily found inside the 10 km Eco-Sensitive Zone (ESZ) of the bird sanctuary in villages like Thangalperumbalam, Senganimedu and others adjoining the Buckingham Canal. Port building undertaken by the Dutch during the 17th century is the first documented large scale destruction of mangroves in Pulicat (Kannan, 2013). This also resulted in siltation of the lagoon, significantly reducing its depth and adversely affecting the benthic life, seagrass beds and other fauna of the site (Tamil Nadu Forest Department, 2007). The mouth bar opens during the monsoon months which according to the local communities is most favourable for fishing. Siltation due to freshwater inflow and eroding river banks remains one of the chief threats to Pulicat's ecology. This is known to cause mass death of benthic species which affects fish and birds (Saraswathy and Pandian, 2016).

In a 2006 report, Ministry of Earth Sciences (2007) the Ministry of Earth Sciences stated that coastal infrastructure south of Pulicat was causing coastal erosion of up to 50 m (Jayakumar and Malarvannan, 2016) per annum of the North Tamil Nadu landscape, and if no intervention is made, the threat to Pulicat is inevitable. Despite this, the Adani Group has proposed an expansion of the Kattupali port from the existing 300 acres (L & T Infra Engineering, 2020) to 6111 acres, the northern boundary being merely 2.1 km from the sanctuary boundary. The proposal has several illegalities, including being inside the Eco-Sensitive Zone (ESZ) of the bird sanctuary (L & T Infra Engineering, 2020) (L & T Infra Engineering, 2020), sited on a high erosion zone (Ministry of Environment Forests and Climate Change, 2009), and encroachment of large tracts of riverbed and wetlands — including the Kosasthalaiyar, backwaters, salt marshes and creeks. Chennai gets about 200 MLD (about 1/4th) of its drinking water from this region (Salamander, 2021), which will also be threatened by seawater contamination. Pulicat also happens to be the largest flood catchment area and climate buffer for the surrounding districts. After the expansion of the port was proposed, the state government has requested a reduction of Pulicat's ESZ, which

Fig. 14. Wild Boar (*Sus scrofa*) from Pulicat Lagoon (Tamil Nadu section).

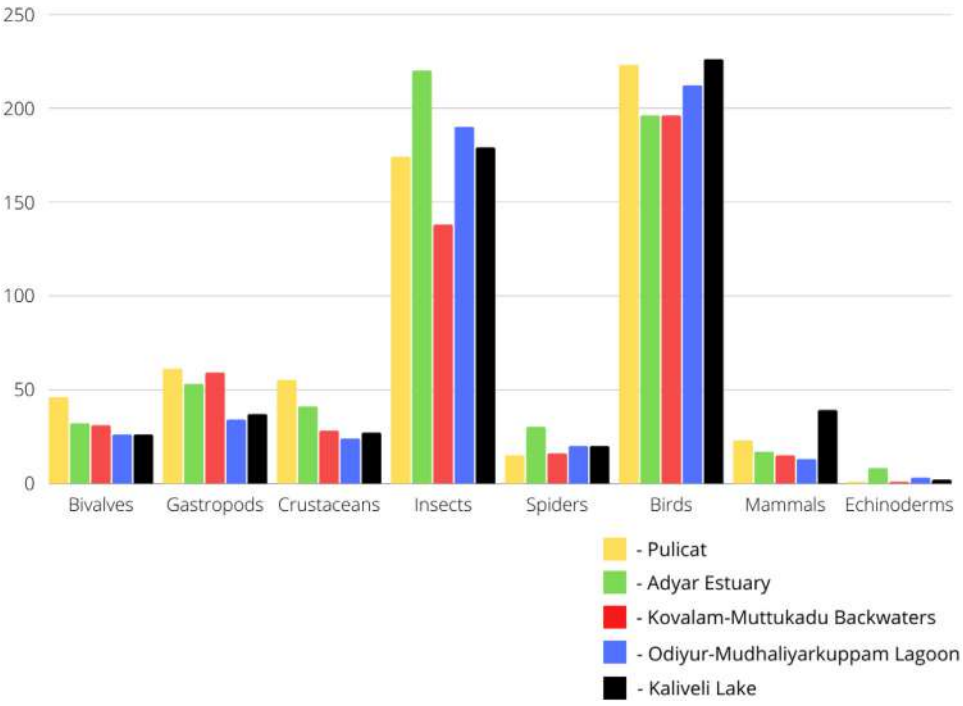

Fig. 15. Comparative static on the assessed five hotspots from the north Tamil Nadu coast.

would pave the way to the legalizing of the proposed port. The megaport proposal, if pushed through, would massively block littoral drift moving from south to north, which is then expected to erode the Kattupalli sand barrier island which shelters the lagoon area and merge it with the Bay of Bengal. The fisherfolk here have been actively protesting against various destructive development and infrastructure projects proposed in the Tamil Nadu section of Pulicat for a long time (Salamander, 2021).

Erosion triggered by unplanned coastal infrastructure all along the Indian coast has been well documented. Studies on infrastructure-induced coastline changes have been conducted at Vizhinjam, Tuticorin, Visakhapatnam, Ennore, Paradip, and many other locations (Sarma, 2015; Shaji, 2019).

Pollution and bioaccumulation (Batvari et al., 2016) are a threat to the ecology of the Ennore-Pulicat wetland system. This is attributed to improperly treated industrial effluents (Kamala-Kannan et al., 2008) from power stations, chemical and other red category industries in the south, which reach the lagoon via the Buckingham Canal and the Bay of Bengal. Illegal coal ash dumping by thermal powerplants in Pulicat has been well documented, which causes loss of aquatic life and thereby local livelihoods (Srikanth and Rohit, 2019; Special Correspondent, 2020)

Legal measures and proper enforcement are needed to halt infrastructural activities in North Chennai and the Thiruvallur coast, which have been triggering massive erosion of the coastal landscapes here (Jayakumar and Malarvannan, 2016). A 2019 study by Anna University (Manivannan and Elango, 2019) shows that this region is the most affected by sea water contamination of aquifers in the entire Indian coastline, with sea ingress recorded up to 14 km inland. The authors during their field surveys found that the decline of mangroves is very severe, and are being replaced by the invasive *Prosopis juliflora* - which is bound to severely affect marine fauna and local livelihoods. Prosopis species are known to be able to withstand and flourish in alkaline and saline soils with a level of salinity equal to sea water (Walter, 2011). Efforts of mangrove afforestation around Pulicat by groups (Salamander, 2021) and individuals have resulted in mangrove revival in over 500 acres of wetlands, but increased mangrove restoration is needed within the sanctuary as well.

4.2 Adyar Estuary

This region is highly urbanized, which exerts various kinds of pressures on this ecosystem, resulting in its deterioration over

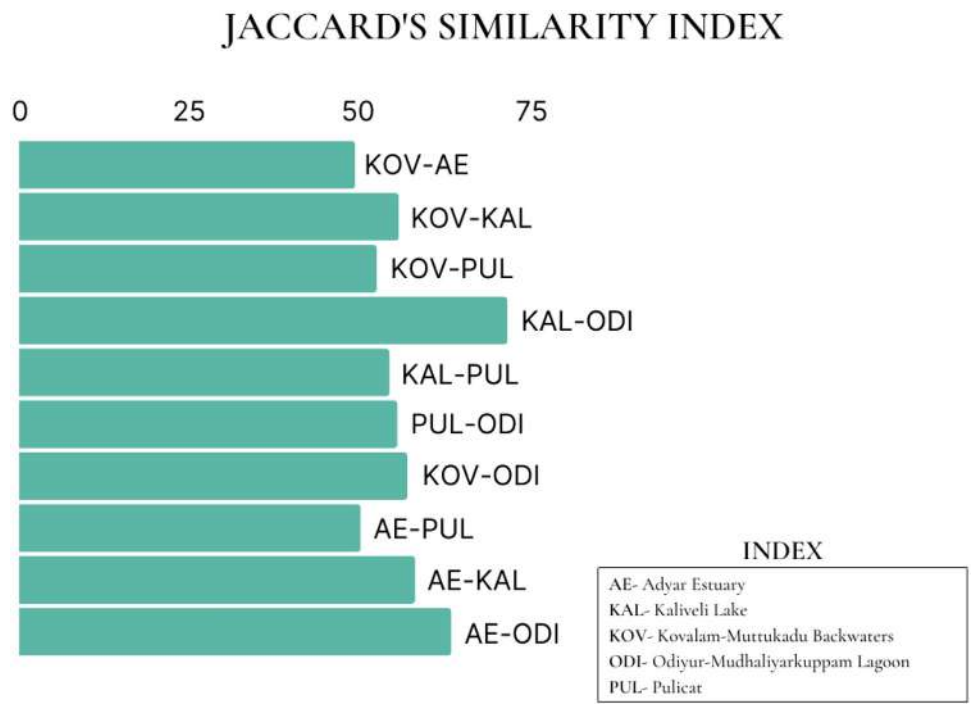

Fig. 16. Jacard's index histogram for the five hotspots.

the years (Shanmugasundharam et al., 2019). About 58 sewage discharge points empty into the river during its course through the metropolis. Effluent from the Common Effluent Treatment Plant (CETP) of 150 tanneries and the Sewage Treatment Plant (STP) of Nesapakkam are released into the river as well. It is estimated that about 1 MLD of industrial effluent and 8 MLD of domestic sewage enters Adyar (Gowri et al., 2008; Jayakumar et al., 2013; Nammalwar and Pakshirajan, 1995). A lot of the released sewage is alleged to be untreated or partially treated. Due to this, studies show that the water is measured to have zero Dissolved Oxygen (DO) for most of the year after the river crosses Saidapet (Vaithyanathan et al., 2016). This has affected marine and coastal life significantly, as well as the health and livelihoods of the local communities (Walther et al., 2003). Several mass mortalities of fish have occurred on this coast, notably in December 2014 and November 2017 (Saleem Raja et al., 2019). This has been attributed to chromium concentration in the water that exceeds normal values by 30 times. Edible fish caught at the estuary exhibit high levels of bioaccumulation of heavy metals, and dumping of domestic waste in the river adds to this problem (Janakiraman et al., 2017; Rubalingeswari et al., 2021). The authors also observed solid waste including plastic, Thermocol, and glass and domestic hazardous waste dumped and even buried at the beach. The plastic and garbage were maximum here compared to all the other study locations.

During the monsoon months, authors observed excessive frothing of the sea near the river mouth and the nearshore acquiring a greenish colour. This is possibly due to the dysfunction of effluent treatment plants especially during rains, resulting in poorly treated effluent discharge.

Another problem is deforestation of mangroves along the river banks due to unchecked urbanization which is also likely to exacerbate siltation (Gibson and Carter, 2003) and blockage of the river mouth, making the surrounding regions more flood-prone.

While addressing encroachments has always been a complex issue along waterways, thousands of families from slums and fishing hamlets have been evicted while managing and restoring Chennai's rivers (Coelho and Raman, 2010). On the other hand, large hotels, residential complexes and IT office buildings which have also encroached upon the estuary, have been allowed to stay. In February 2020, the Madras High Court wanted to explore the possibility of a coastal road over the estuary, a project the state government had shelved after years of protest by fisherfolk and the public. This violates CRZ regulations and would result in the eviction of fisherfolk also causing irreparable damage to this coastal ecology.

Adyar Estuary, given its easily accessible location and unique socio-ecology within a densely urbanized area, offers a rare opportunity for public awareness about and engagement with issues around coastal habitats. This can be facilitated through organizing shore walks, citizen science initiatives, school projects and interactions with the fisherfolk, and learning from their traditional knowledge of this landscape. Carbon sequestration in mangrove forests are three to four times more than in tropical forests (Nyanga, 2020), thus protecting the existing vegetation in this hotspot will function as a lung-space and climate regulator. Stricter regulations have to be framed and enforced on effluent discharge into the river, which is currently poorly regulated. The region needs to be protected from any further development as it is an important flood safety valve and climate buffer for a densely populated and sizable part of Chennai. The local communities who have been on the Adyar's banks for centuries need to be part of the decision-making and conservation efforts. Thus, due to its important ecosystem services and functions, and considerable biodiversity seen here, Adyar Estuary qualifies to be declared as an ICMBA.

4.3 Kovalam-Muttukadu backwaters

Several criteria, including mangroves, biologically active mudflats, turtle nesting and waterbird breeding, make these coastal wetlands eligible for CRZ-I A including having. However, the Coastal Zone Management Authority has demarcated this entire portion as CRZ III (National Centre for Sustainable Coastal Management, 2018d), making conservation of this landscape very difficult.

The northern shore from the estuary mouth is part of an actively eroding coast and seven groynes have been built so far to prevent erosion here (Jayakumar and Malarvannan, 2016; Sundaravadivelu et al., 2015). Hard structures built near or on the shoreline block longshore currents and the eastern coast cause erosion to the north and accretion to the south (Krishnamoorthy et al., 2018). This is a pronounced and well-documented phenomenon, especially on the North Tamil Nadu coast. Illegally built groynes (Krishnamoorthy et al., 2018) and other structures like bungalows and resorts have contributed significantly to the erosion around the creek. A few have also been demolished or penalized under law (Chaitanya, 2017). During surveys by the authors, it was discovered that many private properties along this coastal landscape are still in violation of CRZ rules as they are located within the 'no development zone' or blocking off the beach for more than 500 m from public access. Erosion triggered by these structures have also affected fisherfolk livelihoods and turtle nesting grounds (Poorvaja, 2019; Silambarasan, 2017; Silas and Rajagopalan, 1985).

Inlets and dumping of domestic sewage and waste also threaten the Muttukadu backwaters (Natesan and Srinivasan, 2013). This causes low dissolved oxygen levels, harmfully high concentration of nutrients and toxic algal blooms (Vasudevan et al., 2015) which cause mass fish mortalities. In 2020, the southern bench of the National Green Tribunal formed a committee to study the damage to these wetlands (Down to Earth, 2020) and take measures to check pollution.

These coastal wetlands need greater legal protection to ensure their long-term conservation, and need a CRZ-I A status. Measures need to be taken to check the disposal of untreated sewage (Chaitanya, 2021a) and domestic waste into the backwaters. Unplanned development, such as beach resorts and gated communities, triggering erosion of this shoreline, needs to be regulated, and authorities need to make sure that developers strictly follow the law. Although groynes arrest erosion in one section of the beach, end up displacing erosion effects further north. Effective solid waste management regulations also need to be in place to prevent the dumping of garbage (Chaitanya, 2021b) in the backwaters by the local administration. Due to this site's proximity to moderately urbanized areas and being a tourist site, hosting activities like surfing and scuba-diving allow an opportunity for engaging the public in coastal awareness walks and several citizen science initiatives.

4.4 Odiyur-Mudhaliyarkuppam Lagoon

Threats to Odiyur Lagoon and its associated backwaters include fertilizer and pesticide runoff from nearby agricultural areas, *Prosopis juliflora* invasion and likely domestic sewage inflow from the Buckingham Canal (Santhosh Kumar et al., 2018; Shanmugasundharam et al., 2019). A study (Santhosh Kumar et al., 2018) reported Total Dissolved Solids (TDS) near Cheyyur in the range of 2100 mg/L due to inflow of industrial effluents. The 4000 MW Cheyyur thermal power plant proposed here was stayed by the Madras High Court (Nityanand Jayaraman, 2014, 2015) in 2014. An assessment (Manakadan, 2014) concluded that the sanctioning of the project would cause irreversible environmental degradation, especially to the estuarine habitat. Breeding and foraging habitats of local and migratory birds would be affected due to the discharge of harmful chemical effluents into the lagoon, apart from the effects of air pollution. The project was not executed due to issues with a sudden change in the proposed fuel source type and public protests by residents and environmentalists (Pheba Mathew, 2016). Recently, there has been some political discussion on reviving the project, which would affect the ecosystem (DT Next, 2017; Express News Service, 2014).

As a post-tsunami measure, the Tamil Nadu Forest Department took up large scale plantation of *Casuarina equisetifolia* along this stretch of coast and many others (Fourqurean et al., 2012). This has been criticized as unscientific and harmful to sand dune ecosystems as they are alien/invasive species, in addition to not being found to play a protective role. These trees have been observed to suppress native vegetation (JagdishKrishnaswamy et al., 2008), affect sand transport and lower the water table. Planting of native salt-tolerant vegetation like *Callophyllum inophyllum*, *Azadirachta indica*, *Milletia pinnata* and *Thespesia populnea* among others is suggested instead.

Considering its IBA status, diversity of birds seen and population of migratory species, the wetland qualifies to be declared as an ICMBA. It also needs a higher legal tag such as a bird sanctuary or community reserve. The region has a higher potential for ecotourism such as guided tours, shore walks, migrant watch and hosting local seafood festivals, thereby providing prospective alternative livelihoods for the local communities, as well as creating public awareness. Mangrove afforestation, its preservation and regular removal of *Prosopis juliflora* are crucial for the health of the coastal ecosystem. Despite this wetland system's rich ecology, very scarce literature and scientific work from here exist. In spite of fulfilling various criteria for CRZ-I A, most of it has been marked as CRZ III (National Centre for Sustainable Coastal Management, 2018e), making conservation initiatives a legal challenge.

4.5 Kaliveli Lake

Kaliveli has been declared an Important Bird Area (IBA) and also satisfies several criteria for a Ramsar site (Bhalla, 2011)-namely criteria 2, 4, 5 and 6 (Ramsar Convention On Wetlands, 1971). The proposed bird sanctuary supports over 20,000 waterbirds and at least one percent of the population of a species. Its ecological significance has been highlighted in the national report on the implementation of the Ramsar Convention and the National Wetland Conservation Programme (Conservation and Survey Division Ministry of Environment and Forests Government of India, 2009; Management of Wetlands, 2017), although the region is yet to be declared as a Ramsar wetland (Siva Sekaran, 2019; WWF India, 2021). In February 2021, the Villupuram district administration issued the first declaration to notify Kaliveli wetlands as a bird sanctuary under The Wild Life (Protection) Act, 1972 (Prasad, 2021). Large chunks of the habitat have been demarcated as CRZ-I A (National Centre for Sustainable Coastal Management, 2018c) areas by the Tamil Nadu Coastal Zone Management Authority due to the presence of mangroves, seagrass beds, turtle nesting beaches and biologically active mudflats, in addition to the archaeologically important heritage site of Alamparai Fort.

Over the years, the commercial saltpans owned here by the government (Silambarasan and Sundaramanickam, 2017) as well as private companies have substantially (Bhalla, 2011) increased area, covering the bulk of the southern side of Yedaiyanthittu estuary. This has resulted in the considerable conversion of wetland and creek area for salt production, which could have affected the mangrove growth (JagdishKrishnaswamy et al., 2008).

Recently proposed project which will strongly impact the Kaliveli ecosystem is the Public Works Department's proposal to convert Kaliveli into a freshwater tank entirely for agriculture which will cut off the wetland from the creek and ocean (Tamil Nadu Government, 2021).

Another growing destructive practice that threatens Kaliveli and its mangrove ecosystems are the aquaculture farms (Ashton, 2008), many of which violate CRZ norms (Karal Marx, 2018). Apart from causing habitat encroachment, untreated chemical effluents from shrimp farms (DT Next, 2017) have been reported

Table 7
CPI score evaluation of the five hotspots according to criteria matrix used by WII.

Criteria	Indicators	Threshold	Points	Maximum score	Pulicat Lagoon	Adyar Estuary	Kovalam-Muttukadu Backwaters	Odiyur-Mudhaliyarkuppam Lagoon	Kaliveli Lake
Coastal ecosystem resilience	Total area (km^2)	<5 km^2	0						
		5–10	1						
		10–15	2						
		>15	3	3	3		3	3	3
	Ecosystem continuity to the nearest ICBCA	Continuous	2	2				2	2
		Separate patches	1		1	1	1		
	Habitat diversity (mangrove, mud flat, coral, seagrass, sand beach/dune, TDEF, backwater)	1 to 2	1						
		3 to 4	2			2	2		
		> 4	3	3	3			3	3
	Adequacy of the site to maintain ecosystem level process	Adequate	1	1	1		1	1	1
		Needs addition	0			0			
	Whether a prominent wildlife corridor (connected by forest, water etc.)	Yes	1	1	1				
		No	0			0	0	0	0
Life support systems	Freshwater discharge	Significant	2	2	2	2			2
		Marginal	1				1	1	
		None	0						
	Coastal erosion control	Significant	2	2					
		Marginal	1			1		1	1
		Not al all	0		0		0		
	Carbon sequestration value	Significant	2	2	2			2	2
		Marginal	1			1	1		
		Not al all	0						
	Natural protection against disaster	Significant	2	2	2			2	2
		Marginal	1			1	1		
		Not at all	0						
Unique biodiversity (fauna and flora)	Number of Globally threatened species	None	0						
		1 to 3	1						
		4 to 8	2			2	2		
		>9	3	3	3			3	3
	Number of regionally threatened species (IWPA 1972)	None	0						
		1 to 5	1						
		6 to 10	2						
		>10	3	3					
	Number of restricted-range species	None	0		0	0	0	0	0
		1 to 4	1						
		5 to 8	2						
		>9	3	3					
	Number of keystone species	None	0						
		1 to 4	1						
		5 to 8	2			2	2		
		>9	3	3	3			3	3
	Number of endemic species	None	0						
		1 to 3	1						
		4 to 8	2						
		>9	3	3	3	3	3	3	3
	Nursery and breeding site provisions for species of conservation significance	None	0						
		1 to 3	1			1	1	1	1
		4 to 8	2		2				
		>9	3	3					
	Congregation area for species of conservation significance	None	0						
		<2	1						
		3 to 5	2			2			
		6 to 8	3				3		
		>9	4	4	4			4	4
	Congregation area for migrant species	Yes	1	1	1	1	1	1	1
		No	0						

(*continued on next page*)

to affect birdlife, as well as the health of local people. Chemically intensive agriculture practised around this region and runoff from the fields pose a similar threat. A study (Gowri et al., 2014) conducted showed that the brackish waters of Kaliveli are heavily contaminated with petroleum hydrocarbons (1.78 mg/l) which poses a serious threat to aquatic organisms and birds.

Like other coastal habitats, the rapid invasion of *Prosopis juliflora* (Bhalla, 2011) is a serious problem as it has led to the diminishing of mangrove and TDEF cover. Within the freshwater ecosystem, *Ipomoea aquatica* is posing a threat to the reed habitats which is the most crucial vegetation in the wetland. Other adverse anthropogenic impacts include poaching, excessive

Table 7 (*continued*).

Criteria	Indicators	Threshold	Points	Maximum score	Pulicat Lagoon	Adyar Estuary	Kovalam-Muttukadu Backwaters	Odiyur-Mudhaliyarkuppam Lagoon	Kaliveli Lake
Cultural, Religious and Aesthetic significance	Cultural value	High	2	2	2				
		Medium	1			1		1	1
		Low	0				0		
	Religious value	High	2	2		2			
		Medium	1		1		1		1
		Low	0					0	
	Historical value	High	2	2	2	2			2
		Medium	1				1		
		Low	0					0	
	Aesthetic value	High	2	2	2			2	2
		Medium	1			1	1		
		Low	0						
Economic potential	NWFP extraction opportunity	High	2	2	2			2	2
		Medium	1			1	1		
		Low	0						
	Ecotourism	High	2	2	2	2	2	2	2
		Medium	1						
		Low	0						
	Agriculture	High	2	2	2			2	2
		Medium	1						
		Low	0			0	0		
	Aquaculture and fisheries	High	2	2	2		2	2	2
		Medium	1			1			
		Low	0						
Land tenure	Ownership	Government	2	2	2			2	2
		Partial ownership	1			1	1		
		Private ownership	0						
Total				59	48	30	31	43	47
CPI score					0.81	0.51	0.53	0.73	0.80

reed collection, fires and overgrazing (Silambarasan and Sundaramanickam, 2017)

The most recent threat to the entire Kaliveli wetland system is the proposal (Express News Service, 2019) for a commercial fishing harbour by the Tamil Nadu Government at Alamparai, mainly for large-scale mechanized fishing. This will entail the construction of two breakwaters of 600 m and 400 m, which will trigger erosion along this coast and endanger several fishing villages and the Alamparai Fort, a site of archaeological importance. Dredging parts of the lagoon for the project will detrimentally affect its ecology and also affect artisanal fisherfolk livelihoods. Allied infrastructure which will come up due to the harbour will have an adverse long-term effect on the wetland. The fishing harbour violates the EIA notifications of 2006 and the Ancient Monuments and Archaeological Sites and Remains Rules, 1959 (Special Correspondent, 2021).

The Kaliveli wetland system, though one of the most ecologically richest in Tamil Nadu, requires more legal protection and better management, in collaboration with the local communities dependent on it. Studies mention that invasive species threatening the native vegetation have to be removed (Bhalla, 2011). The Kaliveli wetland system has great potential for ecotourism, educational projects and citizen science initiatives. Notifying it as a bird sanctuary and Ramsar site would greatly help in the conservation of this coastal habitat.

5 Criteria matrix evaluation

The criteria matrix developed by WII in the assessment and declaration of ICMBAs (Saravanan et al., 2013) was used by the authors for this study. The WII ICMBA survey in 2014 was based on the Aichi Biodiversity targets 11 and 14 in the UN Convention on Biodiversity. The authors have changed the sub-criteria 'flagship species' into 'keystone species' to evaluate the biodiversity uniqueness of the sites better. Endemism has been considered for the entire Indian subcontinent. Any species listed from Schedule I to IV in The Wild Life (Protection) Act, 1972 were considered regionally threatened species. The maximum score attainable in the matrix was 59 and assessed scores were normalized. All of the sites assessed in North Tamil Nadu had a Conservation Priority Index (CPI) of more than 0.5 and therefore qualify to be declared as ICMBAs. Three of the five hotspots had a CPI of more than 0.7, making them conservation priority sites (see Table 7). .

6 Conclusion

Five major ecological hotspots from the North Tamil Nadu coast were identified and surveyed. These coastal habitats host tremendous species diversity and also act as indispensable climate buffers for their surroundings. Large numbers of threatened species such as the Olive Ridley Sea Turtle (*Lepidochelys olivacea*) and strongly declining species such as the Pacific Golden Plover (*Pluvialis fulva*) depend on the health of these ecosystems. Targeted scientific studies, documentation and regular monitoring of these hotspots are needed to aid conservation efforts in these hotspots. Work to increase awareness about them amongst the general public especially via citizen science initiatives would turn out to be a strong factor in their collaborative conservation in the long term. Poor regulation, unchecked urbanization and policy/decision-making, especially without the involvement of local communities pose serious conservation hurdles. Odiyur and Adyar Estuary have not yet been declared as ICMBAs, though they qualify for the same by the assessment of the authors. Their recognition as ICMBAs, coupled with greater conservation importance for ICMBA sites in India is vital. Three of these wetlands – namely Adyar Estuary, Kovalam-Muttukadu Backwaters and Odiyur Lagoon — qualify to be entirely declared as CRZ-I A zones due to various parameters. The authors have also provided a

comprehensive baseline and repository for the biodiversity found in these ecosystems which will be of use to further studies. It also highlights the unique conservation challenges in each of these regions and suggests some ways forward.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.rsma.2021.102106.

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