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Rare Aggregations: Seasonal Variations and Abundance of the Critically Endangered Widenose Guitarfish (*Glaucostegus obtusus*)

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ABSTRACT

The widenose guitarfish (*Glaucostegus obtusus*) is a Critically Endangered shark-like ray in the Northern Indian Ocean. They aggregate in shallow waters where they may be threatened by nearshore fisheries, tourism and coastal development, yet their use of these spaces is not well documented. Understanding their population sizes and seasonal use of these nearshore waters is crucial in developing effective conservation strategies. We estimated the abundance of juvenile widenose guitarfish across 10 beaches in South Goa, India, and their variation with seasonal, environmental and anthropogenic factors. We walked transects along the wave line (< 30 cm deep) from September 2023 to March 2024 to record guitarfish counts, sizes and distribution. The total juvenile guitarfish abundance was estimated through N-mixture modelling as 538 individuals over 25 km of coastline. Galgibaga Beach had significantly higher juvenile abundances (205 individuals, 95% CI: 191–217), indicating the presence of a nursery ground, and has been identified as an Important Shark and Ray Area (ISRA) based on our work. November showed the highest relative abundance of juveniles (35.14 ± 38.47), suggesting that this month is a potential pupping season. We provide first estimates for the population of this species in India and new insights into their ecology, highlighting critical habitats and seasons where conservation efforts, like spatiotemporal restrictions or live release measures, could be directed.

1 | Introduction

Elasmobranchs or cartilaginous fish (sharks and rays) are one of the most vulnerable taxa globally, with over one-third of their species assessed as threatened (Dulvy et al. 2014; Kyne et al. 2020; Dulvy et al. 2021). Within elasmobranchs, families such as giant guitarfish (Glaucostegidae) are considered to be facing an extremely high risk of extinction (Jabado et al. 2018; Kyne et al. 2020). Giant guitarfish are important prey for non-human apex predators and play a vital role in the functioning of the ecosystem (Moore 2017). Overfishing, especially by large-scale fisheries, is one of the major threats to this species (Dulvy et al. 2021). This is further exacerbated by habitat degradation due to commercial development and modification of natural habitats (Dulvy et al. 2021). Coastal elasmobranchs like guitarfish depend on nearshore habitats for foraging and as nursery grounds, making them especially vulnerable to such nearshore development, pollution and fisheries (Farrugia et al. 2011; Moore 2017).

Nursery grounds are areas preferentially used by newborn and juvenile elasmobranchs, usually due to lower predation risk and greater availability of food (Martins et al. 2018). Since these areas support a high abundance of vulnerable early life stages, it makes them extremely important for endangered species with density-dependent population persistence (Martins et al. 2018). Identification of nursery grounds has been recognised as a research priority for guitarfish globally (Kyne et al. 2024). There is, however, limited research on their nursery grounds and other critical habitats in coastal waters in most countries of their range (Callaghan et al. 2024). In addition, there is a lack of quantitative data on their populations such as abundance—an essential biodiversity variable that plays a crucial role in understanding population changes and recovery over time. Recent studies also indicate that the abundance of some guitarfish species can vary with season, diel period, tidal cycles and lunar phase. For example, blackchin guitarfish (*Glaucostegus cemiculus*) were found to exhibit seasonal patterns in abundance with higher numbers in spring and early summer (March–June) along the Israeli coast (Chaikin et al. 2020). Similarly, the giant shovelnose ray (*Glaucostegus typus*) showed higher numbers of juvenile abundance with high tide and during night time in the Great Barrier Reef, Australia (Freeman 2019; Gaskins et al. 2020). These findings underscore the importance of collecting baseline data on population trends and seasonal use of these nearshore critical habitats.

Five of the seven species of giant guitarfish are known to occur in India, making it a hotspot for these species (Akhilesh et al. 2014; Last et al. 2016). However, most of what is known of the species in the country focuses on fisheries landings. India is one of the top three elasmobranch fishing nations globally, with the mechanised and industrial fisheries sectors expanding over four times in the last 50 years (Karnad et al. 2014; Okes and Sant 2019; Jabado et al. 2024). In the year 2023, the estimated elasmobranch landing was 32,000 t, with the west coast of India contributing to the majority of the catch (CMFRI 2024). Data on giant guitarfish are aggregated at the level of families, often reported together with the morphologically similar wedgefish (Rhinidae), making it difficult to understand the impact of various threats at the species level (Mohanraj et al. 2009; Kyne et al. 2020; Karnad et al. 2024). Nevertheless, evidence from aggregated catch landings suggests that the population of guitarfish and wedgefish declined by up to 86% between 2002 and 2006 on the east coast and up to 63% between 1990 and 2004 on the west coast of India (Karnad et al. 2024). A few guitarfish species, including the widenose guitarfish, have been listed on Schedule I of the Indian Wildlife (Protection) Amendment Act (2022), which prohibits their capture and trade. However, since fishers most often catch these species as bycatch, this regulation will have limited success in reducing fishing mortality unless accompanied by practical measures that reduce their capture and mitigate other broader threats (Gupta et al. 2020).

Our study focuses on the widenose guitarfish (*Glaucostegus obtusus*), the smallest member of the giant guitarfish family. This species generally occurs in shallow coastal waters with soft-bottom habitats (Moore 2017; Whelan et al. 2017; Chaikin et al. 2020), using these areas as nursery grounds, and for foraging and resting (Farrugia et al. 2011; Gaskins et al. 2020). They give birth to live young, have low fecundity with a litter size of 4–10 pups and are slow growing with a generational length of around 10 years (Last et al. 2016; Moore 2017; Kakodkar and Patil 2021; Kyne and Jabado 2021). The widenose guitarfish is classified as Critically Endangered on the IUCN Red List (Kyne and Jabado 2021) and is listed under Appendix II of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) (Vincent et al. 2022). They are found across the northern Indian Ocean, ranging from Pakistan to Thailand, including the coastal waters of India.

This study builds upon previous research from the coastal state of Goa, India, which identified South Goa as a key habitat for the widenose guitarfish (Gupta et al. 2023). Anecdotal reports, preliminary surveys and Local Ecological Knowledge from fishers suggest that the widenose guitarfish occurs in shallow nearshore waters in this region (up to 5-m depth) and is caught incidentally in South Goa's fisheries (Dakshin Foundation 2021; Gupta et al. 2023). In this study, we aimed to assess the habitat use and seasonal occurrence of the widenose guitarfish and estimate their abundance, along the South Goa coast. We also explored the variation in abundance with environmental and anthropogenic factors such as tidal cycles, moon phase, fishing pressure and tourism disturbance. Our work produces critical baseline data on the nearshore ecology and population of these Critically Endangered guitarfish, which can inform the development of species-specific conservation and fisheries management plans.

2 | Methods

2.1 | Study Site

This study was conducted along the southern coast of the state of Goa, located on the central west coast of India (Figure 1). Goa has 105 km of coastline, with the south Goa coastline characterised by sandy habitats separated by rocky headlands along with a gentle coastal slope (Kunte et al. 2014). This region exhibits distinct seasons, with the months of June to September comprising the monsoon season and July typically receiving the highest rainfall. This is followed by the postmonsoon season from October to March and the summer season in April and May (Sreekanth et al. 2016; Gupta et al. 2023).

Goa hosts over 800 mechanised and over 2000 traditional motorised and nonmotorised fishing vessels (Government of Goa 2022), landing an average of 61 thousand tonnes of marine fish annually. Additionally, tourism is also a major contributor to the state economy and local livelihoods. Goa is a prominent tourist destination with over 7 million domestic tourists in 2022 (Ministry of Tourism 2023). The rapid increase in tourism, coastal development and population over the last few decades has the potential to cause irreversible damage to the nearshore environment (Vaz et al. 2017).

2.2 | Study Design

A total of 10 beaches in South Goa were chosen to estimate the abundance of juvenile guitarfish (hereafter called 'population estimation') based on reports of the presence of guitarfish here. Furthermore, to study guitarfish presence across different environmental conditions and seasons (hereafter called 'seasonal monitoring'), we focused on three beaches, which were Palolem, Rajbag and Galgibaga (Figure 1), separated by rocky headlands and estuary systems. These three beaches differed in the level of anthropogenic activity and were thus characterised based on tourism and fishing activity (Table 1). Galgibaga and Rajbag also have the Galgibaga and Talpona rivers at their southern end, which create an estuarine system close to the beach, whereas Palolem only has a small creek at the northern end of the beach. Additionally, Galgibaga is a turtle nesting site and is considered an ecologically sensitive area. It has therefore been classified as Coastal Regulation Zone-1 (CRZ-1) by the Goa Coastal Zone Management Authority (GCZMA), which restricts construction and development activities up to 500 m from the high tide line.

2.3 | Seasonal Monitoring

As widenose guitarfish occupy shallow coastal waters and form aggregations, direct ecological surveys such as walking transects

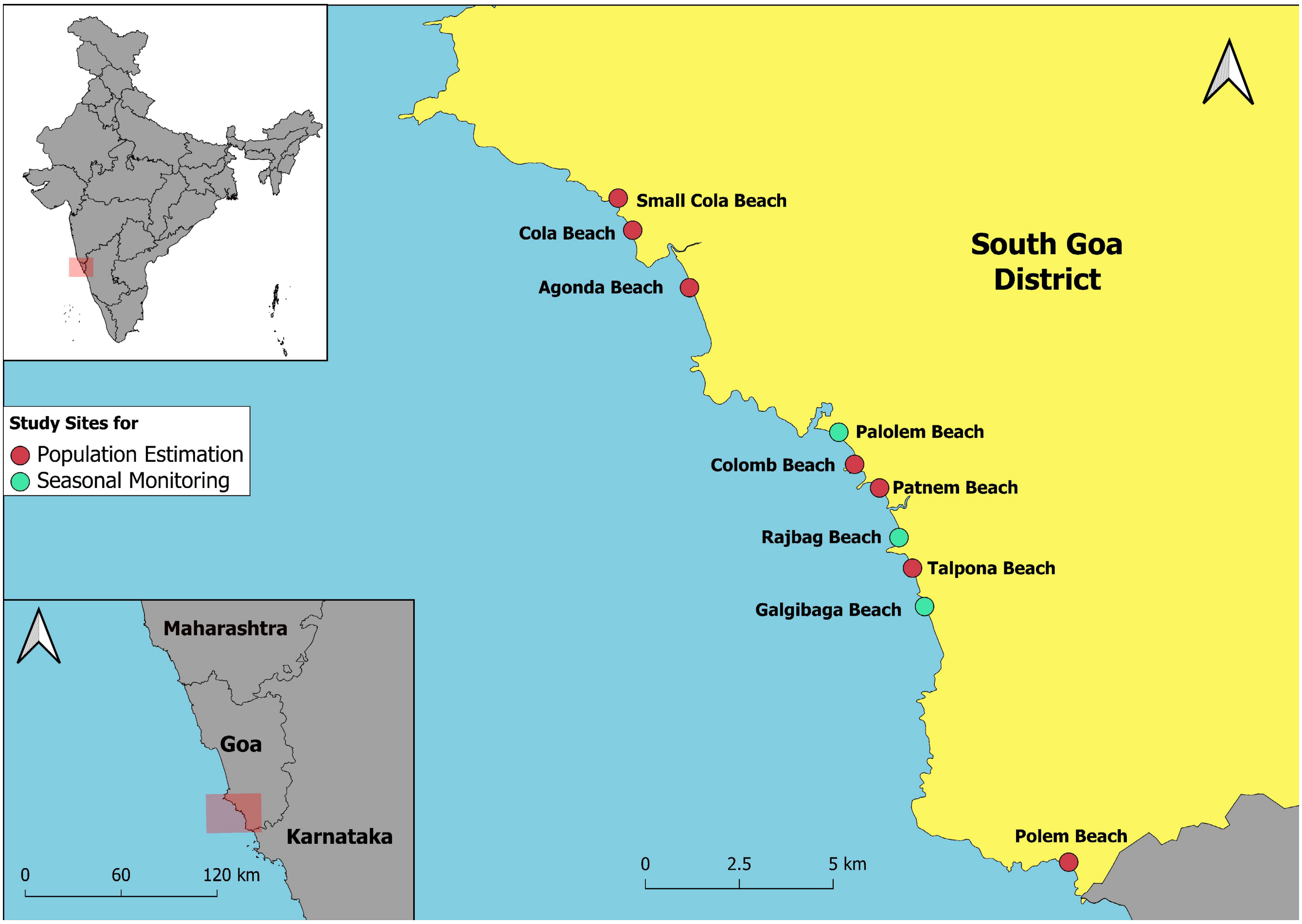

FIGURE 1 | Study sites. The study sites marked in green are those used for seasonal monitoring surveys. Sites marked in red (and also in green) were used for the population estimation surveys, which included the seasonal monitoring sites as well.

TABLE 1 | The difference in anthropogenic activities between the study sites for the seasonal monitoring surveys. The 'number of tourist boats' refers to boats used to conduct boat rides and dolphin-watching trips. The 'number of tourist establishments' refers to the resorts/restaurants situated along the beach.

Sites	Length of the beach (km)	Number of tourist establishments (resorts/restaurants)	Number of tourist boats	Number of fishing boats	Main type of fishing
Galgibaga Beach	1.5	3–4	0	4–5	Shore seines
Rajbag Beach	1	1	0	8–10	Gill nets
Palolem Beach	1.5	> 40	> 70	15–20	Shore seines and gill nets

can be used to study them (Freeman 2019; Chaikin et al. 2020; Gaskins et al. 2020; Azrieli et al. 2024). We designed a simple, low-cost walking transect survey methodology, modified from Gaskins et al. (2020) and similar to Azrieli et al. (2024), to understand the effect of various environmental factors on the presence of guitarfish and estimate their abundance. The survey method was similar to a strip transect and involved walking along the beach in shallow waters (< 30 cm deep). Each beach was divided into segments of approximately 500 m to account for the varying water visibility across the length of the beach (see Table 2), with the time taken to cover each segment kept between 10 and 15 min and the width being approximately 10 m. There was a minimum of two observers present for all of the surveys. During the surveys, the observers walked parallel to each other along the wave line while visually scanning in front and in the shallow waters up to a distance of 10 m. Data collected during the transects included the GPS location and the number of guitarfish per sighting event and the size estimate of each individual where possible. A sighting event was defined as a single or a group of guitarfish seen together in a cluster during each scan. Based on our preliminary surveys and their reported size of maturity (for males) being ~48 cm, we classified the guitarfish into four size classes: neonates (< 25 cm), juveniles (25–40 cm), subadults (40–60 cm) and adults (> 60 cm). Each guitarfish recorded was categorised into one of these classes based on visual estimation, with these estimates validated by opportunistically measuring guitarfish (Last et al. 2016).

Our seasonal monitoring was conducted between September 2023 and March 2024. Surveys were conducted once every 2 days, at each site successively; hence, the three sites (Palolem, Rajbag and Galgibaga) were surveyed approximately once a week. On each sampling day, surveys were conducted in three diel periods: Presunrise (starting at 5:00 AM), day (starting between 12:00 and 3:00 PM) and postsunset (starting between 6:30 and 7:30 PM). This allowed us to cover different tidal regimes throughout the month and understand any diurnal variation that exists. Torches were used to scan for guitarfish after dark, with one observer possessing a brighter torch with a wider beam to initially spot the guitarfish, and the other with a narrower beam to facilitate size estimation of each individual. We simultaneously collected data on various environmental variables (Table 2) that could affect the abundance of guitarfish. To account for the effect of variable turbidity of the water on the detection of guitarfish, we created a visibility index (Table S1).

2.4 | Population Estimation

For the population estimation, we used the same walking transect methodology as in our seasonal monitoring surveys. These surveys were conducted over a span of 3 weeks in November 2023 and covered 10 sites (including the three sites of our seasonal monitoring surveys), surveyed three times (replicates) each (Figure 1). The replicates for each site were conducted on consecutive days, working under the assumption of a closed population that was required for the analysis. We excluded adults (individuals > 60 cm) because of a low number of observations and included only juveniles (all individuals < 60 cm) for this part of the analysis. The surveys were conducted only during the presunrise diel period, as our preliminary data indicated the highest number of guitarfish were observed during this period.

2.5 | Data Analysis

2.5.1 | Seasonal Monitoring

We used generalised linear models (GLMs) with a negative binomial distribution to understand changes in relative guitarfish abundance between different sites and with different

TABLE 2 | List of explanatory variables used for the seasonal monitoring analysis.

Variables		Description
Month		Ranging from September 2023 to March 2024, to account for variation in guitarfish abundance with different seasons
Site		3 different sites chosen due to the variation in anthropogenic activities and beach characteristics
Visibility		Ranging from values 1 (lowest visibility) to 3 (highest visibility). A visibility index created to account for variation in the visibility of water
Tide	Low tide	Surveys were conducted within 2 h before or after the time of the lowest tide.
	High tide	Surveys were conducted within 2 h before or after the time of the highest tide.
	Mid tide	Surveys were conducted outside the 2 h window around high tide and low tide.
Tidal flow	Rising	Incoming tide
	Receding	Outgoing tide
Diel period	Presunrise	Surveys conducted before sunrise (starting at 5:00 AM)
	Day	Surveys conducted during the day (starting between 12:00 and 3:00 PM)
	Postsunset	Surveys conducted after sunset (starting between 6:30 and 7:30 PM)
Moon phase		The different lunar phases during each day of the survey to look at the effect of lunar cycles on guitarfish abundance

environmental factors (Table 2). For this, we used the *glm.nb* function under the *MASS* package in R. Model selection was done using the small-sample corrected Akaike information criterion (AICc) to account for lower sample size, using a backward selection method starting with a full model and removing variables with the highest *p*-values. The model with the lowest AICc was selected as the best-fitting model. Post hoc pairwise comparison was performed for the best-fitting model using estimated marginal means using the *emmeans* package in R.

2.5.2 | Population Estimation

We used an N-mixture model, a class of models that allows the estimation of species abundance from count data (Royle 2004; Kidwai et al. 2019). There are various methods to estimate the abundance of a species, which can be very labour-intensive. The N-mixture models allow for the estimation of abundance without marking individuals, using spatially and temporally replicated counts at fixed sites (Ficetola et al. 2018). To our knowledge, N-mixture models have not been used to estimate the population size of guitarfish before.

An N-mixture model with a negative binomial distribution was used to estimate the absolute abundance of guitarfish. This was done using the *unmarked* package in R. Explanatory variables used for abundance estimation included the visibility index (Table 2) and a rock cover index. The rock cover index was calculated using QGIS (QGIS Development 2019). For each of the 10 beaches, a 6×6-m grid was created over the study area (which included the intertidal zone where the walking transects took place, up to approximately 150 m into the water). The number of squares that were at least more than 50% filled with rocks was counted. The number of squares with rocks was divided by the total number of squares in the study area to create a rock cover index. We used beach length and rock cover as site covariates and the visibility index as an observational covariate. Additionally, for model selection, we used the small-sample corrected AICc to account for the lower sample size. All of the data analysis was performed in RStudio (R Core Team 2024; Posit Team 2024) and QGIS (QGIS Development 2019).

3 | Results

3.1 | Seasonal Monitoring

We conducted a total of 206 surveys between September 2023 and March 2024 at Palolem ($n = 67$, where n is the number of transects), Rajbag ($n = 71$) and Galgibaga ($n = 68$), divided between the presunrise ($n = 65$), during the day ($n = 61$) and postsunset diel periods ($n = 80$).

The best-fitting model [Deviance explained = 70.28%, calculated as (Null Deviance − Residual Deviance)/Null Deviance * 100] included diel period, month and site as significant variables (Table S2). The variables moon phase, tide, tide action and visibility were not significant (Table S3). Post hoc pairwise comparisons found a significant difference in the relative abundance of guitarfish between all three study sites (Figure S1). Galgibaga, with the lowest level of anthropogenic activity, showed the highest average number of guitarfish with 48.47 (±33.42) individuals, followed by Rajbag, which had moderate levels of anthropogenic activity, with 14.94 (±12.8) individuals. Palolem had the highest level of anthropogenic activity and showed the lowest number of guitarfish with 2.26 (±3.76) individuals. The relative abundance of guitarfish varied across the different diel periods (Figure S1), with a significantly higher number of guitarfish present during presunrise and postsunset compared with daytime ($p < 0.05$), especially the presunrise diel period, which showed the highest number of guitarfish. After September and October, there was a significant increase in guitarfish numbers with November (35.14 ± 38.47) and December (33 ± 41.9) showing the highest average number of guitarfish (Figure 2).

Preliminary analysis of the different size classes revealed a seasonal and spatial pattern in the use of nearshore waters. In Galgibaga, the first few survey months (September 2023–November 2023) were dominated by guitarfish of the juveniles (25–40 cm). This shifted in December when there was a sharp increase in neonates (< 25 cm), which continued to dominate the guitarfish assemblage till March. The abundance of all other size classes in Galgibaga decreased relatively with very few larger guitarfish (> 40 cm) recorded from December onwards. A similar trend was seen in Rajbag, although the appearance of neonates was noted earlier, in November. In Palolem, guitarfish abundances were low overall, and differences between size classes were not as apparent. Palolem also exhibited a relatively higher proportion of adult guitarfish as compared with the other sites (Figure 3).

3.2 | Population Estimation

We estimated the abundance of juvenile widenose guitarfish across 10 sites. The best-fitting model with the lowest AICc value was found to be the null model (Table S4). None of the independent variables were significant. The null model gave a $\hat{c}$ value (variance inflation factor) of 0.79. $\hat{c} > 1$ indicates overdispersion, and our data give a value of 0.79, which indicates a slight underdispersion. The detection probability obtained was 0.54. Through this model, the abundance was estimated as 538 individuals, 95% CI [489, 591] across 25 km of coastline. Among the 10 sites (Figure 1), Galgibaga showed the highest estimated abundance with 205 individuals, 95% CI [191, 217], followed by Patnem with 140 individuals, 95% CI [128, 152]. We did not find evidence of guitarfish presence at four sites (Figure 4).

4 | Discussion

This study provides the first quantitative abundance estimate of widenose guitarfish (*G. obtusus*) in the world, with 538 juveniles (individuals < 60 cm) in extremely nearshore environments across 25 km of coastline, using a novel, low-cost method of walking transect surveys with N-mixture models. Furthermore, through our seasonal monitoring, we found clear differences in abundance between our three study sites, potentially linked with anthropogenic disturbance. We identified a potential nursery ground for these threatened species in Galgibaga Beach, as well as a possible pupping season in November/December. Our findings provide valuable insights into widenose guitarfish

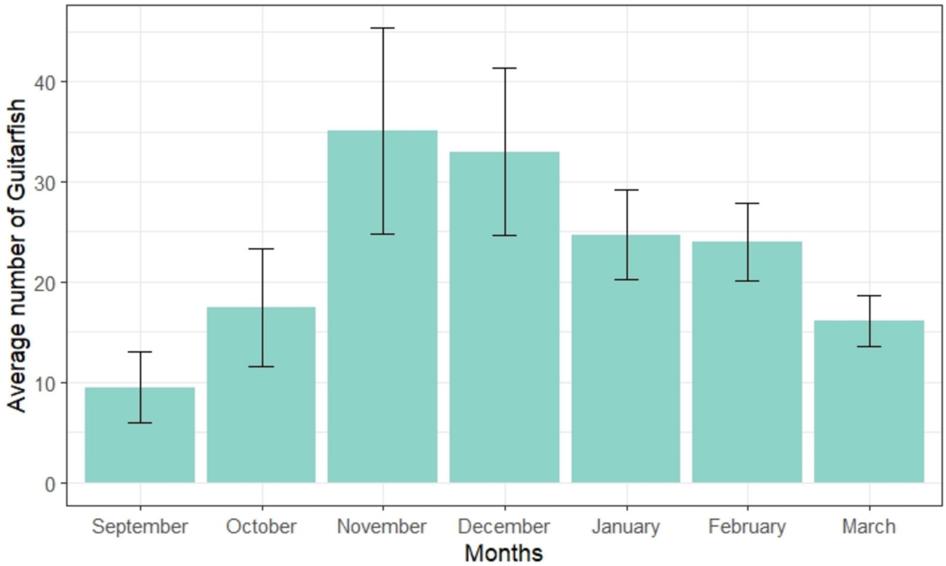

FIGURE 2 | Average number of guitarfish observed per survey month through seasonal monitoring surveys starting from September 2023 up to March 2024.

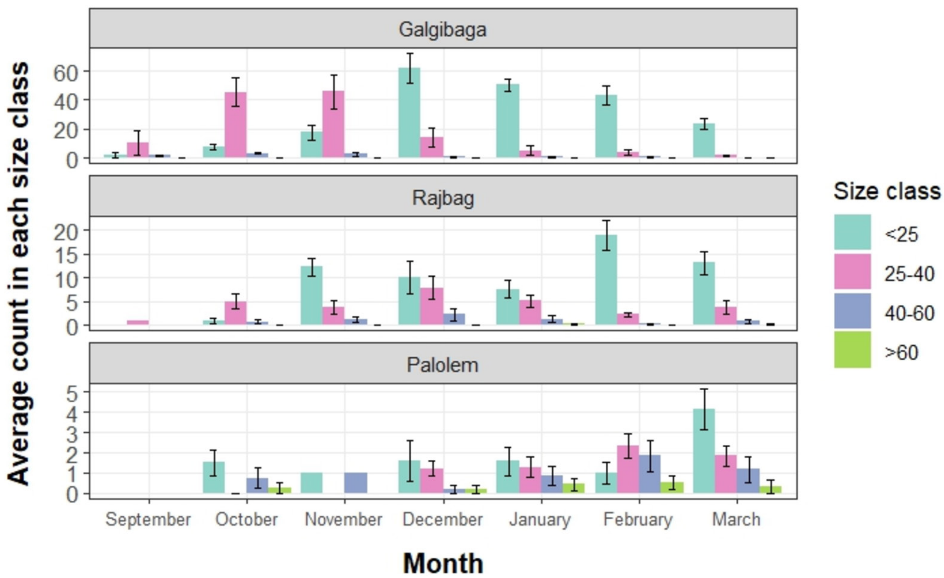

FIGURE 3 | The average number of guitarfish in each size class across different months starting from September 2023 up to March 2024.

ecology, abundance and use of nearshore critical habitats and will contribute to the conservation and monitoring of their populations in Goa and beyond.

4.1 | Variation With Anthropogenic and Environmental Factors

We found a significant difference in the relative abundance of guitarfish in nearshore waters between Galgibaga, Rajbag and Palolem, with all three sites having varying levels of fishing and tourism. Galgibaga Beach is a turtle nesting site with little to no light pollution and the highest abundances of guitarfish. Palolem has the highest number of tourist establishments and fishing pressure, resulting in increased artificial light, disturbances and alteration of the coastal habitat.

These nearshore waters and intertidal areas harbour several coastal elasmobranch species, with benthic predators such as guitarfish playing an important role in the ecosystem by maintaining prey population and diversity as well as facilitating foraging for a number of different species (Flowers et al. 2021; Leurs et al. 2023). These habitats are particularly threatened by coastal development and climate change, which cause habitat degradation and consequently endanger these important species (Leurs et al. 2023). Coastal development generally involves construction and deforestation, which could increase terrestrial runoff and reduce water quality, thereby having a detrimental effect on these nearshore environments (Knip et al. 2010). Other disturbances such as artificial light at night can have a negative impact on many elasmobranch species (Carroll and Harvey-Carroll 2023). For example, a study on the swimming of Port Jackson shark (*Heterodontus*

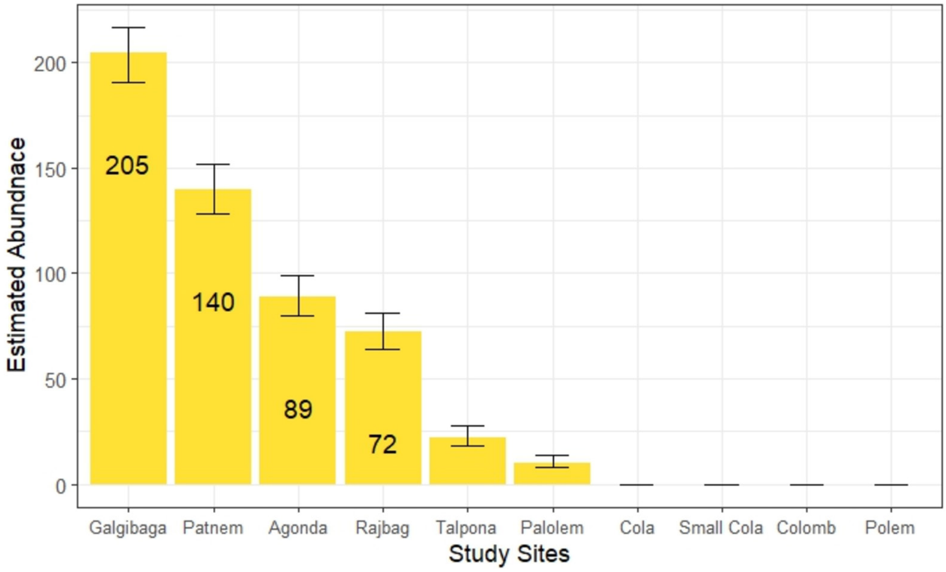

FIGURE 4 | Estimated abundance of guitarfish at sites along the South Goa coastline.

portusjacksoni) found a preference for nocturnal swimming, which was disrupted by constant light (Kelly et al. 2020). Furthermore, small-scale fisheries, such as shore seines, operate along the coast of Goa where benthic elasmobranchs are frequently caught (Yogi et al. 2022). Benthic species such as the widenose guitarfish are generally considered bycatch, with the catch being dominated by juveniles (Yogi et al. 2022; Gupta et al. 2023). Therefore, higher anthropogenic pressures at Palolem may have contributed to the lower number of guitarfish observed in comparison to Galgibaga. However, there could be several other confounding factors such as prey availability, benthic substrate and temperature that influence the presence of guitarfish (Schlaff et al. 2014). Salinity and nutrient influx can also play a role since Galgibaga and Rajbag are both situated close to large rivers (Schlaff et al. 2014). We need more studies to examine these specific parameters and understand the influence of anthropogenic disturbance on guitarfish distribution and abundance. With the tourism industry expanding in Goa, it is particularly crucial to understand the impacts of tourism on threatened marine species and ecosystems (Vaz et al. 2017).

We did not find any influence of tide or tidal flow (rising or receding tides) on guitarfish abundance. Numerous studies have found that tidal flow does affect the movement of elasmobranchs, where species such as sandbar sharks (*Carcharhinus plumbeus*), mangrove whiprays (*Urogymnus granulatus*) and freshwater sawfish (*Pristis microdon*) move predominantly in the direction of the tide (Whitty et al. 2009; Schlaff et al. 2014; Martins et al. 2020). This may be due to increased availability of foraging area during high tide as well as to reduce energy expenditure especially for juveniles (Schlaff et al. 2014). Anecdotal evidence suggests that such tide-related movements by guitarfish may occur in deeper waters but may not be apparent in extremely shallow waters, especially where guitarfish get stranded on the beach. It is well known that the moon's illumination influences marine ecosystems including sharks and rays. For example, white sharks (*Carcharodon carcharias*) and blue sharks (*Prionace glauca*) show deeper movements with an increase in the moon's illumination. Conversely, bull sharks (*Carcharhinus leucas*) and largetooth sawfish (*P. microdon*) show shallower movements with an increase in illumination (Andrzejaczek et al. 2025). These movements may be linked to predation strategies, as full moon nights can assist predators in locating prey (Andrzejaczek et al. 2025). In our study, we did not find any influence of moon phases on guitarfish abundance. This could be due to several factors, such as constant prey availability irrespective of moon phase or that guitarfish do not depend solely on visual cues for successful predation (Murie et al. 2024; Andrzejaczek et al. 2025), or because we observed only juveniles in a potential nursery ground from which lunar-influenced migration is unlikely.

We observed that in extremely shallow waters, the number of guitarfish was the highest at the presunrise diel period, followed by the postsunset period. This could be explained by nektobenthic diel vertical migration (Humphries et al. 2017). This is a type of inshore–offshore movement of benthic predators along the seabed rather than in the water column, usually occupying shallower waters at night and deeper waters during the day to ensure feeding, reproduction and predator avoidance (Humphries et al. 2017). This type of movement has been described before in four species of skates in the Western English Channel, and among giant shovelnose rays (*Glaucostegus typus*), all of which come to shallow nearshore habitat at night (Vaudo and Heithaus 2012; Humphries et al. 2017). Intertidal sand flats, where we observed widenose guitarfish, could be an important feeding area where crustaceans and fish such as anchovies are found. In fact, gut content analysis on guitarfish (*Glaucostegus* sp.) collected from a shallow estuarine bay in Goa revealed that smaller individuals (< 40 cm) generally feed on prawns, shrimp small crabs and fish such as anchovies (Yogi et al. 2022). Such diel migrations of these guitarfish could also be due to behavioural thermoregulation, where they hunt in shallow warmer waters and digest their food in deeper cooler waters (Humphries et al. 2017).

4.2 | Potential Nursery Ground

An area can be classified as a nursery site, if it meets three criteria: (1) Newborns are encountered more commonly compared to other areas, (2) newborns remain or return to this area for extended periods and (3) they use this habitat across several years (Martins et al. 2018). We suggest Galgibaga Beach as a potential nursery site for widenose guitarfish because we found significantly higher absolute and relative abundance of guitarfish in Galgibaga compared with the other study sites, thereby meeting Criterion 1. Furthermore, we found consistently higher proportions of neonates compared with adults throughout our study duration within this site, fulfilling Criterion 2. However, our data do not cover multiple years, making it difficult to understand Criterion 3. Therefore, long-term monitoring is essential to gain robust data to confirm Galgibaga Beach as a nursery site. Preliminary data on relative abundances from this study contributed to the identification of Galgibaga Beach, along with the adjacent Talpona Beach, as an Important Shark and Ray Area (ISRA) (IUCN SSC 2023; Kyne et al. 2023). Patnem and Agonda beaches also exhibit high abundance estimates for juvenile guitarfish; however, Agonda Beach is almost twice as long as Galgibaga Beach, whereas Patnem Beach is shorter. Based on evidence from Local Ecological Knowledge (LEK), we selected Galgibaga Beach as the focus site for our seasonal monitoring surveys. Long-term monitoring is therefore essential to understand whether neonates use Galgibaga for extended periods to confirm that it is a nursery site and to identify other potential nursery grounds.

Our results show a higher abundance of juvenile widenose guitarfish in shallow water during November and December, which are commonly considered winter months. Guitarfish aggregations in shallow waters have been reported in different parts of the world (Farrugia et al. 2011; Chaikin et al. 2020; Anderson et al. 2021; Azrieli et al. 2024). Along the coast of Israel, Azrieli et al. (2024) reported similar behaviour of juvenile blackchin guitarfish (*Glaucostegus cemiculus*) stranded on the beach with higher abundances from August to September (summer season) with a decline in November and December (winter season). Chaikin et al. (2020) observed mature blackchin guitarfish observations along the Israeli coast decreasing when water temperature exceeded 28°C or dropped below 19°C. Similarly, Farrugia et al. (2011) also reported that shovelnose guitarfish (*Rhinobatos productus*) had higher activity rates and were found more in warmer water temperatures ranging from 20°C to 24°C with a peak at 22°C. Unlike these studies, we found the highest abundances of widenose guitarfish in the winter months. This may be due to the overall higher water temperatures in coastal Goa, where the sea surface temperature generally ranges between 26°C and 31°C throughout the year. These differences could also be attributed to being a different species, having different geographical ranges and potential adaptations to local conditions. High proportions of neonates (< 25 cm) during November and December suggest that these months may be a pupping season for widenose guitarfish in Goa. However, LEK from Goa suggests pupping of guitarfish in the months of August and September and low guitarfish abundance in shallow waters during April and May (Gupta et al. 2023). The present study has limited or no data for those months. We need more robust ecological data across all seasons and over a longer term to identify pupping seasons and better understand the seasonal behaviour of guitarfish in Goa.

4.3 | Population Estimation

We employed a novel method (N-mixture models) to estimate the abundance of guitarfish, which, to our knowledge, has not been used on any guitarfish species before. Using this, we measured the absolute abundance of juvenile widenose guitarfish in extremely shallow waters as 538 individuals across 25 km of the coastline. We found that the two explanatory variables we chose, i.e., visibility and rock cover, did not significantly explain our data. The variability of the visibility index was not high enough to affect detection probability to a significant degree during the study period. However, water visibility may decline during the monsoon season, which was not surveyed by our study, and this may affect detection probability. Among the beaches chosen for this study, those with high rock cover, e.g., Cola Beach, had no evidence of guitarfish. Although this may suggest that these species do not prefer rocky shores, we would need more data to confirm, especially due to our low sample size.

The walking transect surveys, along with N-mixture modelling, emerged as a useful method to study species like guitarfish. Methods such as satellite tagging, acoustic tagging and baited remote underwater video (BRUV) surveys are among the most commonly used approaches to study marine species ecology, which can be associated with high costs and the need for technical expertise (Wearmouth and Sims 2009; Hammerschlag et al. 2017; Alghozali et al. 2023). As part of the present study, we also conducted BRUV surveys during both day and night to understand the diel movements of juvenile guitarfish. However, the surveys did not yield any guitarfish, likely due to the type of bait used and poor visibility in the coastal waters of Goa. In contrast, the walking transect surveys require minimum equipment and expertise and very low costs and can easily be used to collect data and better direct conservation efforts. This method shows promise as a standard method for monitoring guitarfish and other coastal batoids, especially in tropical, developing countries where similar species behaviour may be present and resources for other methods are limited.

4.4 | Limitations

Although the walking transect surveys and N-mixture models have several advantages, they also have certain limitations. The N-mixture models require that the population be demographically and geographically closed (Kidwai et al. 2019; Royle 2004). We conducted the surveys at each site on consecutive days so that we could meet the assumption of a closed population. This assumption can be tested through methods like mark-recapture and investigating their movement ecology, which would be the next step in understanding these elusive species. For our N-mixture models, the non-significance of the two explanatory variables could be due to the low sample size and could be tackled by increasing the number of sites and the number of surveys per site. Other potentially important variables such as prey availability and anthropogenic disturbances should also be included in the model to get more robust estimates. During the walking transect surveys, we were unlikely to double-count individuals based on their behaviour and our walking speed; however, this may not be true for all contexts.

4.5 | Conservation Implications

Identification of Galgibaga Beach as a potential nursery site is a crucial step in the conservation of the Critically Endangered widenose guitarfish. Conservation efforts can be directed towards this site, and long-term monitoring can help better understand its use as a nursery ground for young guitarfish. As a turtle nesting site, Galgibaga already has certain regulations on fishing and tourism activities, such as restrictions on beach lights, the development of tourist shacks, and beach activities at night (Dakshin Foundation 2021). Similar regulations can be implemented for guitarfish, focusing on critical habitats and pupping seasons, incorporating them into existing measures for marine turtles. The ISRA notification can play a pivotal role here. Although the ISRA is currently a scientific process with no direct policy and management links, recognising sites like Galgibaga as an ISRA can be a valuable tool in guiding sustainable development, tourism and fisheries management in this region. It is vital that any regulations are developed and implemented in partnership with the local community for ethical and effective outcomes (Gupta et al. 2020; Nazareth et al. 2022).

Within India, getting fisheries-independent data for a Critically Endangered elasmobranch species is rare. The walking transect survey method can be of great conservation significance because of its simplicity and cost-effectiveness and can help monitor guitarfish populations and identify important critical habitats across the coast of Goa and other regions. Our study estimated the abundance of juvenile widenose guitarfish for the first time, creating a much-needed baseline for the population of this species. Such data can contribute to monitoring progress towards different conservation targets, as well as facilitating communication with policymakers (Callaghan et al. 2024). Additionally, training of local community members and government officials to use walking transects can build local capacity and establish the long-term monitoring of guitarfish in Goa.

Although international trade has been identified as a major driver of guitarfish declines (Sherman et al. 2023), we find that local fisheries seem to be the main threat to guitarfishes in Goa. Therefore, we propose local fisheries policy changes, such as restricting benthic nets (such as bottom set gill nets or shore seines) during the pupping season to complement the existing protections for the widenose guitarfish under India's Wildlife (Protection) Amendment Act (2022). Identifying critical habitats like nursery grounds is an important step, as spatiotemporal restrictions on fishing and tourism can be directed to these sites. Additionally, like the community-based incentives for live release for whale sharks, promoted by the Forest Department in Goa (Malkarnekar 2025), we propose a similar incentive scheme for the live release of guitarfish. Live release interventions have been successful for guitarfish in other parts of the world (Wosnick et al. 2020), and previous research from India has shown that fishers would participate in such initiatives, even without a significant financial incentive (Gupta et al. 2020, 2023).

Our work is the first of its kind in India, providing valuable insights into the ecology, habitat use and nursery grounds for a Critically Endangered and extremely understudied species, while also providing fisheries-independent abundance estimates. We are only beginning to understand how these species use these nearshore waters, and further research is necessary to inform conservation and management plans.

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Ethics Statement

All necessary permits were obtained from the Goa Forest Department. (Permit No. 2-66-WL-RESEARCH PERMISSION-FD-Vol.VI/1174 and Permit No. 2-66-WL-RESEARCH PERMISSION-FD-2023-24-Vol.VIII/5363).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The full dataset is not publicly available because additional analyses and publications are planned. Data will be made available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Visibility index. **Table S2:** Model selection results based on corrected Akaike information criterion (AICc) for negative binomial generalised linear models (GLMs) used in seasonal monitoring surveys. **Table S3:** Best-fitting model output from generalised linear model (GLM) with a negative binomial distribution. **Table S4:** Model selection results based on corrected Akaike information criterion (AICc) for N-mixture models used in population estimation. **Figure S1:** Post hoc pairwise comparison for differences between sites (top) and between different diel periods (bottom). The *** indicates a significant difference between the pairs.