Title: Trials for Efficient Electronic Monitoring of Fishing Operations in Gillnet Tuna Fisheries of Pakistan

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Abstract

The drift gillnet fisheries in the Northern Indian Ocean, particularly in Pakistan, play a crucial role in regional economies but pose significant management challenges due to the lack of comprehensive data on catch and bycatch. This study evaluates the feasibility and effectiveness of Electronic Monitoring Systems (EMS) in Pakistan's tuna gillnet fisheries. WWF-Pakistan initiated a phased crew-based observer program under the ABNJ Tuna Project to address data gaps, which evolved into a pilot project for electronic monitoring. The trials involved installing CCTV and Shellcatch technology on gillnet vessels to record fishing operations and bycatch events. The results showed that EMS could enhance data collection accuracy, verify crew-based observer data, and overcome the limitations of traditional onboard observer schemes. The study highlights the need for technological innovations, capacity building, and policy support to scale up EMS implementation for sustainable fisheries management in the Northern Indian Ocean. Key findings include the successful documentation of fishing activities, bycatch handling practices, and species composition, providing valuable insights for regional and global conservation efforts.

Keywords: Electronic Monitoring (EM), Gillnet Fisheries, Tuna, Bycatch Mitigation, Data Collection, Artisanal Fisheries, Observer Programs.

Introduction

The drift gillnet fisheries in the Northern Indian Ocean represent one of the key areas of management concern, particularly for the Indian Ocean Tuna Commission (IOTC) (Anderson et al.,2020), play a crucial role in regional economies, particularly in coastal communities where fishing is a primary livelihood.. It poses challenges for capacity building due to the complex nature of the fishery and the lack of comprehensive data (Temple et al., 2019). In the Indian Ocean, artisanal and semi-industrial fisheries account for more than half of all tuna catches, with principal species including skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) (Pillai & Satheeshkumar, 2012), with gillnets responsible for 40% of this total catch (Heidrich et al,. 2023). Many fundamental characteristics of gillnet fisheries in Indian Ocean coastal states are largely unknown, including unknown levels of reported bycatch of sharks, cetaceans, turtles, and seabirds (Anderson et al., 2020). Data on catch and effort are estimated, including based on declared landings and are considered amongst the most crucial data gaps in virtually all Indian Ocean tuna gillnet fisheries (Temple et al., 2019).

In the Northern Indian Ocean, artisanal and semi-industrial fisheries are significant contributors to the overall tuna catch. Pakistan is one of seven Indian Ocean coastal countries identified as major contributors to gillnet catches of tuna and tuna-like species. The other countries include India, Indonesia, the Islamic Republic of Iran, Oman, Sri Lanka, and Yemen(Anderson et al., 2020). To address the catch, effort and other data gaps, WWF-Pakistan initiated a phased, crew-based observer program under the ABNJ tuna Project. This was designed initially to pilot the collection of logbook- and observer-type data on fishing activities within the tuna gillnet fleet. It operates as a logbook or self-sampling scheme, where typically skippers participate voluntarily, providing information on catches, bycatch, effort, and fishing grounds; the pilot project achieved formal support from the Ministry of Maritime Affairs, Government of Pakistan and achieved ~15% coverage of Pakistan's gillnet fleet. Although this alone is a substantial feat and verification of proof-of-concept, the next phase is to pilot a system to verify and validate the crew-based data scheme. E-monitoring technology has been identified as a potential effective solution for data verification and monitoring purposes (Temple et al., 2019), (Brown et al., 2021).

Accurate and comprehensive data collection is essential for the effective management of fisheries. Reliable data on catch and effort are crucial for assessing the health of fish stocks, understanding fishing patterns, and identifying trends in bycatch. However, in the case of gillnet fisheries in the Indian Ocean, data collection faces numerous challenges. One of the primary challenges is the logistical difficulty of monitoring a large number of small-scale and artisanal fishing vessels. Traditional observer programs, which place human observers on vessels to collect data, are often impractical for small-scale fisheries due to the limited space onboard, safety concerns, and the high costs associated with deploying observers across a dispersed fleet. Additionally, the data that are collected are often incomplete or inaccurate, further complicating management efforts.

In addition, implementing a fully-fledged scientific observer scheme on small-scale vessels faces challenges such as ensuring adequate safety at sea, providing suitable working and living conditions onboard, and addressing the lack of human and financial resources needed to monitor often very large numbers of vessels and coordinate an observer scheme (Gilman et al., 2019). Thus, Electronic Monitoring (EM) offers a practical alternative to onboard observers for the collection of scientific and compliance data (Holah et al., 2022), (Rosa et al., 2021) (Wang et al., 2021), (Emery et al., 2019).

WWF-Pakistan's efforts also contribute to current initiatives of the Indian Ocean Tuna Commission (IOTC) in supporting Member States to implement a Regional Observer Scheme (ROS, IOTC Resolution 11/04). The stated aim of the ROS is for 5% coverage of fishing activity in artisanal (coastal) fleets (Sinan & Bailey, 2020). Additionally, these efforts align with Resolution 16/04, which involves a pilot trial to test the effectiveness of electronic monitoring in small-scale/coastal fisheries and the potential of electronic monitoring to collect observer data in accordance with IOTC data collection standards (Heidrich et al., 2023), (Sinan et al., 2022).

Challenges with the IOTC Regional Observer Scheme

Implementing the ROS in artisanal fisheries faces several challenges. One significant obstacle is the cumbersome process of data reporting and formatting. Currently, and despite requirements for submissions of editable, electronic data ROS data submissions continue to be made in paper, PDF, or Word document formats (IOTC, 2024), (Gilman et al., 2020). This places an appreciable burden on IOTC resources, as these formats are time-consuming to process into a database (IOTC, 2023). This inefficiency delays data analysis and decision-making, impacting the scheme's ability to provide timely insights into fishing activities(Ewell et al., 2020). These challenges are comfortably addressed by ER and EM systems(Brown et al., 2021), (IOTC, 2024).

Another critical challenge is the low coverage levels of the ROS. The difficulty in implementing on-board observer coverage for smaller vessels, characteristic of artisanal fisheries, contributes to this low coverage (IOTC, 2022). Additionally, while observer training programs exist, there is a need for an IOTC-accredited training program for observers to ensure consistent standards across member states, requiring an enormous scale of national observer scheme training and ongoing management (IOTC, 2023). Addressing these coverage gaps and standardizing observer training is essential for enhancing the scheme's effectiveness in data collection and analysis (IOTC, 2024).

Electronic Monitoring for the IOTC ROS

To address some of the limitations of the ROS, Electronic Monitoring Systems (EMS) present a promising solution. The aim of implementing EMS within the ROS framework is to support monitoring efforts in artisanal fisheries and complement existing port-sampling schemes. EMS offers several benefits, including collecting scientific data on smaller-sized vessels impractical for onboard observers. This ensures comprehensive coverage of fishing activities, enhancing the accuracy and reliability of data collected (IOTC, 2024), (Gilman et al., 2019).

Moreover, EMS results are verifiable and repeatable, providing a level of data consistency that may surpass traditional ROS trip reports. The technology's rapid development also holds promise for real-time data collection, enabling more timely insights into fishing activities (IOTC, 2023), (Helmond et al., 2019). While EMS implementation may incur high initial costs, the long-term benefits, such as reduced training costs and fewer required observers, justify the investment(IOTC, 2023), (Tseng & Kuo, 2020).

Feasibility Study for EMS in Artisanal Fisheries

Before widespread implementation, a feasibility study is necessary to assess the viability of EMS in artisanal fisheries. Several considerations must be addressed, including the high costs associated with equipment purchase, installation, and maintenance. Logistics present another challenge, as small vessels may have limited space for monitoring equipment alongside fishing gear and crew accommodations (IOTC, 2024). Furthermore, the acceptance of EMS by fishers and concerns regarding privacy must be carefully addressed to ensure successful implementation. Despite these challenges, EMS offers a complementary approach to onboard observers, particularly in fisheries where practical difficulties hinder observer placement. By addressing these considerations and leveraging the potential of EMS technology, the IOTC can enhance the effectiveness of its monitoring efforts and contribute to sustainable fisheries management in the region (EM4Fish, 2023).

Moving data from ship to shore is a key constraint facing EM, including SSFs, and a cost-effective solution is required if EM is to realise its full potential. The transaction and management costs for EM data transfer can be eliminated when transmitting wirelessly, e.g. over existing 4G or 5G wireless networks (Tassetti et al., 2022). However, because the necessary infrastructure did not exist for this trial, we relied on hard drives for physical data storage and transport (Helmond et al., 2019). This study does not address the study's data management and transfer aspects in detail because the advantages of wireless data transfer are well established. The case for eliminating physical drives does not need to be made again. EM systems should be designed to transfer EM data over a mobile network infrastructure, especially given the short trip lengths and thus small image file sizes. Data transfer logistics and costs are highly impactful on the final feasibility of EM in small-scale fisheries (Gilman et al., 2020).

Objectives of the EMS Trails

The primary objective of this study is to evaluate the feasibility and effectiveness of Electronic Monitoring Systems (EMS) in the tuna gillnet fisheries of Pakistan. This involves assessing the capability of EMS to enhance data collection accuracy, verify crew-based observer data, and overcome the limitations associated with traditional onboard observer schemes. By leveraging EMS technology, this study aims to contribute to the sustainable management of gillnet fisheries in the Northern Indian Ocean and support regional and global conservation efforts.

Characterization of the Fishing Fleet and Operations

In Pakistan, approximately 700 gillnet vessels catch tunas on the continental shelf and in offshore waters (FAO, 2023). The fleet comprises locally made wooden boats., Most boats operating from Karachi (Sindh) range from 15 to 25 meters in length, while those from Balochistan range from 10 to 15 meters. Approximately 65 large boats, ranging from 20 to 30 meters, embark on fishing trips lasting more than two months in deeper waters, and these vessels are equipped with onboard freezing facilities (FAO, 2023).

Tuna gillnetters are outfitted with hydraulic net hauling devices and navigation equipment, such as GPS and fish finders, though the smaller vessels may not have these features. Fish are stored on ice in insulated compartments, each with about 1 to 1.5 tonnes capacity. In most tuna fishing vessels, the fleet uses surface multifilament nylon gillnets with a stretched mesh size of 13-17 cm (mean 15 cm). These multifilament nylon nets are utilized for catching longtail tuna (*Thunnus tonggol*), kawakawa (*Euthynnus affinis*), striped bonito (*Sarda orientalis*), yellowfin tuna (*Thunnus albacares*), and skipjack tuna (*Katsuwonus pelamis*) in offshore waters (Moazzam, 2021). Nets range in length from 5-12 km and are ~14 meters wide. Some larger fishing boats operate from Karachi and Gwadar. There are variations in the length and specifications of the nets, depending on the target species. Generally, tuna gillnets are set in the evening and hauled in the early morning. Fishing boats engaged in tuna fisheries are primarily based in Karachi and Gwadar. Boats based in Karachi have a wide area of operation, with some venturing up to 400 miles from the base station. Larger fishing boats also operate on high seas, beyond Pakistan's Exclusive Economic Zone. Previously, about 150 to 200 large boats, mainly based in Karachi, Gwadar, and Jiwani, fished for tuna

Methodology

In 2012, WWF-Pakistan initiated a crew-based observer programme to collect information using a standardized data sheet to record the quantity and species of fish caught about catches of tuna and tuna-like species as well as of the bycatch non-target species in the tuna gillnet fisheries of Pakistan (Razzaque et al., 2020). One of these observers was taken onboard by the pilots of the CCTV camera on his fishing boat from January to February 2018. The same observer was on board for the trails of the Shellcatch Technology from August to September 2019.

Based on the fishing operations of the tuna gillnet vessel, the criteria prepared to understand the feasibility of installing the EMS of CCTV and Shellcatch operations are given in Table 1. The configuration of the CCTV camera and Shellcatch technology used on the tuna fishing vessels, which differ in their configuration and technology are provided in Table 1.

Table 1. Criteria for Gillnet Tuna Fisheries of Pakistan for Implementing Electronic Monitoring Systems (EMS)

Criteria	**Description**
Target Field Site Locations	The EMS should cover areas of EEZ of Pakistan, with Karachi city serving as the primary hub for installation on tuna gillnet vessels.
Equipment Placement during Trials	EMS equipment should remain on vessels during the trial period, except during the offseason for fishing (May-August), when removal may be necessary to prevent damage or when there is no fishing season.
Onboard Power Requirements	The EMS equipment requires a separate power source, such as a separate power battery or solar power, to ensure continuous operation, considering that when the net is set, the vessel engine is turned off, potentially deactivating the camera.

GPS Antenna Installation	Each vessel is equipped with its GPS, eliminating the need for a remote GPS antenna for the EMS unit.
Operation Mode during Trials	The EMS should be capable of multi-day recording, covering the period from setting the net to hauling. Alternatively, it must remain functional during the net haul if continuous recording is not possible.
Target Recording Time per Day	The EMS should record for a minimum of 15 hours per day.
Fishing Trip Length	Fishing trips typically last between 15 to 20 days per vessel. The equipment should be able to complexly cover the fishing days of one trip. Each vessel typically undertakes 1 to 2 fishing trips per month, depending on the catch.
Duration of Initial Trial Period	The initial trial period for EMS implementation should last between 6 to 8 months.
On-board Equipment Requirements	The supplier will provide the necessary equipment, including image-capturing devices, location sensors (GPS), and tamper-proof hardware. The system should record fishing operations, including catch loading, sorting, and discard, with the ability to capture high-resolution images and video footage.
Data Transmission and Security	Data should be encrypted and may be transferred through Wi-Fi, satellite communication, or removable, secure hard drives. Near-real-time information should include date, time, position, and system status.
Information during Searching Activities	EMS should store GPS positions at regular intervals to monitor search activities effectively.
Location and Time of Gear Set and Haul	EMS should record the date, set time, and location of fishing operations using GPS, sensors, and cameras.
Estimation of Catch and Discards	EMS should provide estimates/records of total catch, species composition, and size distribution, as well as discard of target tunas and bycatch of large and small individuals.
Vessel and Fishing Characteristics	Vessels targeted for EMS installation should be approximately 20 meters in length, equipped with gillnets for tuna fishing, and target various tropical tunas, neritic tunas, billfish, and seerfish.
Trial Period and Coverage	The EMS should be installed on a minimum of three to four vessels for the trial period, with a focus on a low-cost, compact, and portable system.

EMS Trials to Monitor Fishing Operations

Implementing Solar-Powered CCTV

A comprehensive unit of CCTV consisting of two cameras was installed on a gillnetter to monitor fishing operations. The system features a robust solar energy setup, consisting of a 150-watt poly-crystalline solar EV panel paired with a 10-amp charge controller, operating at approximately 24V. The energy generated is stored in a 150 Ah, 12V liquid battery, ensuring continuous power to the CCTV unit even during periods of low sunlight. The solar panel structure is designed to withstand the harsh marine environment, providing durability and reliability.

The CCTV monitoring system utilizes a Star Tech DVR system with four-channel ports to record video footage. Two Star Tech CCTV cameras are strategically placed on the vessel to capture detailed footage of fishing operations. A 2 TB hard disk is integrated into the DVR system, supporting extensive data storage. To ensure continuous operation during power disruptions, an Uninterruptible Power Supply (UPS) is included in the system.

The solar-powered CCTV monitoring system offers several operational benefits. It provides an eco-friendly and cost-effective power solution, reducing dependency on traditional fuel sources and minimizing environmental impact. Additionally, it enhances transparency and accountability in fishing practices, aiding in the accurate documentation and verification of catches.

The configuration of the CCTV unit includes the following components:

- 150W solar panel (poly-crystalline) ~24 V (1 Qty)
- 10-ampere charge controller (1 Qty)
- 150 Ah, 12V liquid battery (1 Qty)
- Panel structure (1 Qty)
- Peripheries (switches, cables, etc.) as required
- Star Tech DVR system (4 Channels ports) (1 unit)
- Star Tech CCTV Camera (2 units)
- 2 TB hard disk (1 unit)
- UPS (1 unit)

Implementing Shellcatch Technology

A comprehensive EMS using Shellcatch Technology was also installed on a gillnetter. The Shellcatch camera system is designed to provide detailed monitoring and data collection. The camera unit has dimensions of 58 x 121 x 203 mm and weighs 714g. It features a 13000 mAh battery and operates with an input voltage range of 7 - 24 V. The camera captures images at a resolution of 8 MP (3280 x 2464 px) and supports video in H.264 format. Connectivity options include WiFi, GPS, 2G/3G/NBIoT, and Iridium Satellite, ensuring robust data transmission capabilities.

The energy source for the camera is flexible, being powered either by a solar energy system or connected directly to the boat's energy source. This ensures continuous operation even during extended fishing trips. The Shellcatch system leverages advanced AI algorithms built on an open-source framework for constructing, training, and deploying object detection models. These algorithms significantly enhance the accuracy of species identification and catch reporting.

An integrated web platform processes and stores video data, providing tools for video review, event registration, and statistical analysis. This platform facilitates the detailed examination of fishing activities and helps generate comprehensive reports. Additionally, a mobile app is available for configuring the monitoring unit and uploading data to the cloud platform when within 3G-4G network or WiFi range, making data management seamless and efficient.

The Shellcatch system records video and GPS data, capturing the sets and hauls of fishing gear, measuring vessel speed, and autonomously managing energy consumption. This comprehensive data collection ensures a detailed and accurate record of fishing operations. Video and GPS data are processed by a WiFi data link unit, which uploads the information to the Shellcatch cloud platform for real-time analysis. This real-time capability allows for prompt response and management of fishing practices.

The Shellcatch camera system offers high-resolution images and videos, ensuring detailed documentation of fishing activities. Its robust connectivity options, including WiFi and various satellite networks, allow for real-time data transmission and remote monitoring. The system reduces dependency on human observers, making it a cost-effective solution, particularly beneficial in remote and resource-scarce areas.

The configuration of the Shellcatch camera includes:

- Dimensions: 58 x 121 x 203 mm
- Weight: 714g
- Battery: 13000 mAh
- Input Voltage: 7 - 24 V
- Picture Resolution: 8 MP (3280 x 2464 px)
- Picture Format: JPEG
- Video Format: H.264
- Connectivity Options: WiFi + GPS, 2G / 3G / NBIoT / Iridium Satellite

The implementation of Shellcatch Technology has been successful on over 500 small-scale fishing vessels in the Eastern Pacific. The camera units are designed for easy installation on vessels of all sizes, ensuring broad applicability. The implementation involved partnerships with national governments, NGOs, and the scientific community to monitor and verify bycatch data, promoting sustainable fishing practices.

The methodology involves accurate reporting of bycatch and fishing practices, contributing to more reliable data for fisheries management. Continuous monitoring through video and GPS tracking, combined with automated detection and analysis using AI algorithms, provides comprehensive oversight of fishing operations. By promoting good release practices and certifying fishing operations as bycatch-free, the system supports sustainable fishing initiatives and enhances marketability.

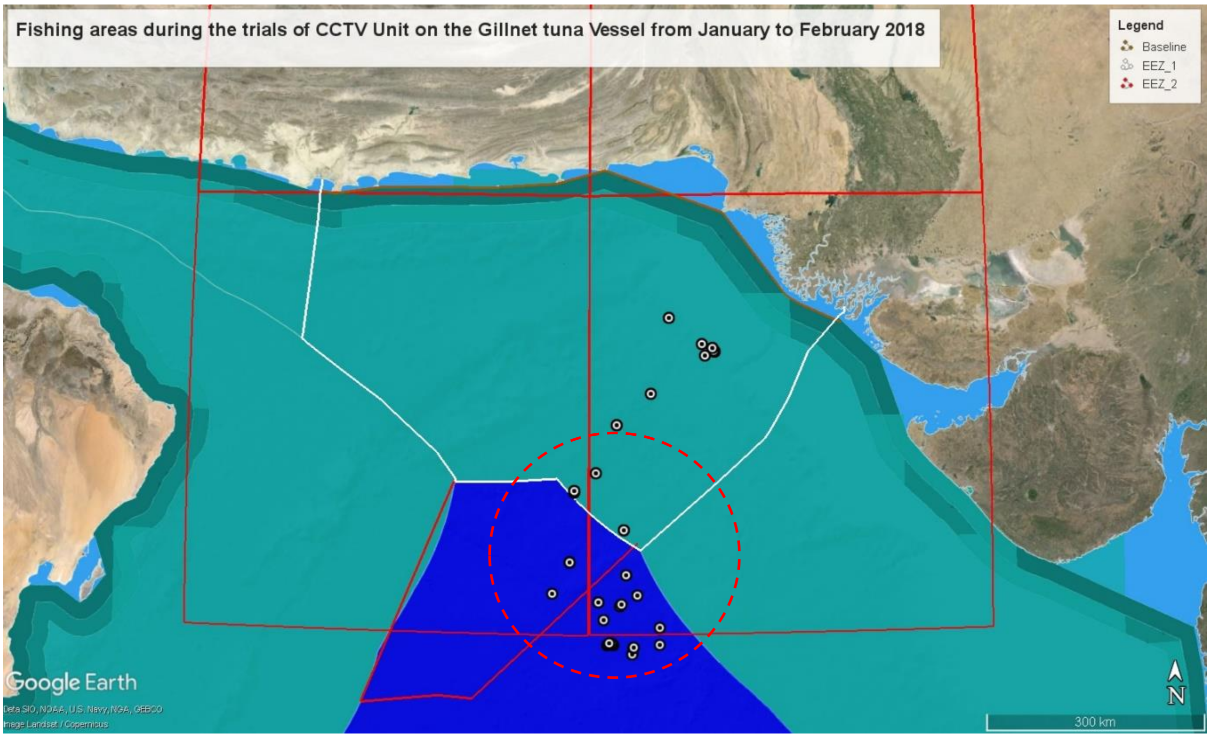
The Shellcatch system offers several advantages, including reducing the dependency on human observers and providing near-real-time data on bycatch. Improved connectivity supports data transmission over various networks, ensuring reliable data flow. Ongoing improvements in hardware, AI algorithms, and web platform functionality ensure that the Shellcatch system remains at the forefront of fisheries monitoring technology. The success of Shellcatch Technology in the Eastern Pacific sets the stage for global expansion, promoting sustainable fisheries management worldwide through collaborative partnerships.

The preliminary analysis of the recorded information of the observer on the prescribed datasheet was analysed for the specific composition of tuna and tuna-like species and the bycatch events and handling of the bycatch megafauna species from the respective trips. All the recorded data collected on the datasheet by the observer were translated into the Excel database. The database contains different fields ranging from administration data, fishing operation, species composition, sampling of the caught species, interaction, treatment, and the fate of the tuna and tuna-like species including status and releases of the megafauna bycatch species – meeting the minimum requirement of the data collection of IOTC from tuna fisheries. The recorded photos from the CCTV camera unit were downloaded after each fishing trip and the recorded images by the Shellcatch Cameras were transmitted and uploaded to the cloud for review and analysis on the web platform of Shellcatch Technology.

Results and Discussion

Implementing CCTV Camera Unit

Data collection during these trials was recorded on a prescribed datasheet, documenting the fish catches, including tuna species, tuna-like species, and bycatch megafauna species. During the CCTV unit trials, the observer participated in two fishing trips: the first lasted 24 days and the second 13 days, totalling 34 fishing days and 4 travel days. Each fishing day was documented as one datasheet or dataset. The fishing operations used subsurface gear setting, starting in the evening between 1700 and 1800 hours to set the net and hauling it back in the early morning between 0300 and 0400 hours. This allowed a soak time, typically 12 hours under normal conditions. The net was then fully hauled back, and the fish catch was handled and sorted on deck, usually concluding between 0700 and 0900 hours, depending on the catch size and the entanglement and release of bycatch. During these two trips, a gillnet 12 km in length and 5 meters in width was used in offshore waters (Map 1).



Map 1: Geographical locations of fishing activities during the trials of a CCTV unit on a gillnet tuna vessel in the northern Arabian Sea from January to February September 2018, highlighting the EEZ boundaries and specific fishing locations. The gillnet vessel had a CCTV unit showing fishing operations on the map consisting of the different zones of the EEZ and plotted on a 5x5 reporting grid. Various fishing locations are marked with black dots, indicating where the gillnet tuna vessel operated during the trial period.

During this period, the recorded fish catches included approximately 14 species. The length frequency of three individuals from each species or category was also documented onboard. All the recorded fish catches were categorized into groups for easier understanding: tuna, tuna-like species, sharks, unidentified species, and reptiles. the primary target species of the fishery. The "Tuna Type" category, which likely includes various species of tuna or closely related species, represents 20.88% of the catch, making it the second most prevalent category. Sharks constitute 14.84% of the catch, indicating a significant amount of bycatch in the gillnet tuna fishery. Reptiles, such as sea turtles, make up the smallest portion at 2.75%. This data underscores the composition of the catch, with a predominance of tuna and notable bycatch of sharks and minimal capture of reptiles (Graph 1).

Yellowfin tuna is the predominant species, making up 18.68% of the total catch, followed by Skipjack and Bullet/Frigate with 14.84% and 12.64% respectively. Dolphinfish accounts for 11.54%, while Trash Fish represents 10.44% of the catch. Notably, different shark species collectively form a significant portion of the catch at 9.34%, indicating a substantial presence of non-target species. Marlin and Mako species contribute 8.79% and 4.40% respectively, while turtles are captured at a rate of 2.75%. Other species such as Kawakawa, Striped Bonito, and Whale Shark each account for 2.20% of the total catch.

The least represented species, including Swordfish, Longtail, and Thresher species, each make up 0.55%. This graph underscores the composition of the catch, dominated by various tuna species, while also highlighting significant bycatch, including sharks and turtles (Graph 2).

The recorded length frequency data for three individuals from each fish species or category where Yellowfin tuna are predominantly found in the 40-60 cm range, with a peak frequency of around 50 cm. Skipjack and Dolphinfish also exhibit similar length distributions, primarily within the 40-70 cm range in individual 1 length frequency, Yellowfin tuna are predominantly found in the 40-60 cm range, with a peak frequency around 50 cm. Both Skipjack and Dolphinfish exhibit similar length distributions, mainly within the 40-70 cm range. Shark species display a broad range of lengths, with significant frequencies around 50-60 cm and another peak at 150 cm, indicating the presence of both juvenile and mature individuals. Marlin species show varied lengths, with notable frequencies at both smaller lengths (around 50 cm) and larger lengths (150-200 cm), and Yellowfin Tuna is predominantly found in the 70-90 cm range, with a peak frequency of around 80 cm. Skipjack and Dolphinfish both species exhibit similar length distributions, mainly within the 60-90 cm range in individual 3, respectively (Graphs 3,4 and 5).

For the status of alive and dead captures. Only a few species are captured alive, including whale shark and Turtle Spp., with the counts for these species ranging from approximately 1 to 6. In contrast, the dead category encompasses a wide array of species, with total counts reaching nearly 175 for some species. The species composition in the dead category includes Bullet/Frigate, Dolphinfish, Kawakawa, Longtail, Mako Spp., Marlin Spp., Shark Spp., Skipjack, Striped Bonito, Swordfish, Thresher Spp., Trash Fish, and Yellowfin (Graph 6).

The status at the release of species in the alive category includes Turtle Spp. and Whale Shark, with counts under 10, indicating that these species are more likely to survive after capture. The dead category includes species such as trash Fish., with counts ranging from 10 to 40, suggesting discards. The none (not released) category, which encompasses a wide variety of species, shows the highest counts, reaching up to 140 for some species. This category includes Bullet/Frigate, Dolphinfish, Kawakawa, Longtail, Mako Spp., Marlin Spp., Shark Spp., Skipjack, Striped Bonito, Swordfish, Thresher Spp., and Yellowfin (Graph 7).

The status of fish catch (fate) species in the discarded category primarily include Bullet/Frigate and Trash Fish, with counts ranging from 10 to 40 events, indicating these species are frequently caught but not retained. The released category includes Turtle Spp. and Whale Shark, with relatively low counts under 10, suggesting that these species are more likely to be released alive after capture, reflecting an effort to mitigate bycatch impact on these protected species. The retained category shows the highest counts, encompassing a diverse array of species such as Dolphinfish, Kawakawa, Longtail, Mako Spp., Marlin Spp., Shark Spp., Skipjack, Swordfish, Thresher Spp., and Yellowfin, with counts reaching up to nearly 140 for some species. This indicates that the majority of the catch is retained, underscoring the economic importance of these species (Graph 8).

The recorded videos from the CCTV were meticulously reviewed to validate the fishing activities. The footage confirmed that fishermen employed the sub-surface gear setting for the gillnets. The recorded clips clearly show fishermen pulling the mainline, from which branch lines extend, each with pairs of floaters attached. Additionally, the handling of sailfish specimens was documented, including the beheading of billfish and their subsequent measurement, ensuring accurate recording of catch details.

In the operation area, the handling and sorting of other tuna and tuna-like species were also closely monitored. The footage captured the discarding of certain species, such as bullet and frigate tuna, highlighting the selectivity of the fishing practices employed.

The recorded videos provided substantial evidence of the fishing techniques and handling of species, particularly endangered, threatened, and protected (ETP) species like marine turtles. The fishermen demonstrated improved practices, showing special care in handling marine turtles compared to their previous methods. The turtles were carefully managed by holding the edges of their shells and releasing them into the sea from the opposite side of the boat, minimizing stress and potential injury to these sensitive creatures.

However, it is important to note that not all recorded videos from both trips were not completely reviewed due to technical issues related to the CCTV format. The 24-hour-long videos presented challenges in extracting information, limiting the comprehensive analysis of the entire footage. Despite these limitations, the reviewed segments provided valuable insights into fishing operations and species-handling practices.

Experiences of Installing and Operating CCTV Camera Units on Fishing Boats for Monitoring Fishing Operations

The use of CCTV camera technology on fishing boats presents an affordable and easily deployable solution for monitoring fishing operations and fish species composition. This technology is readily available, low cost and includes sophisticated operations, design, durability, and data transfer capabilities. Below is a detailed overview of the experiences and challenges encountered during the installation and operation of these systems.

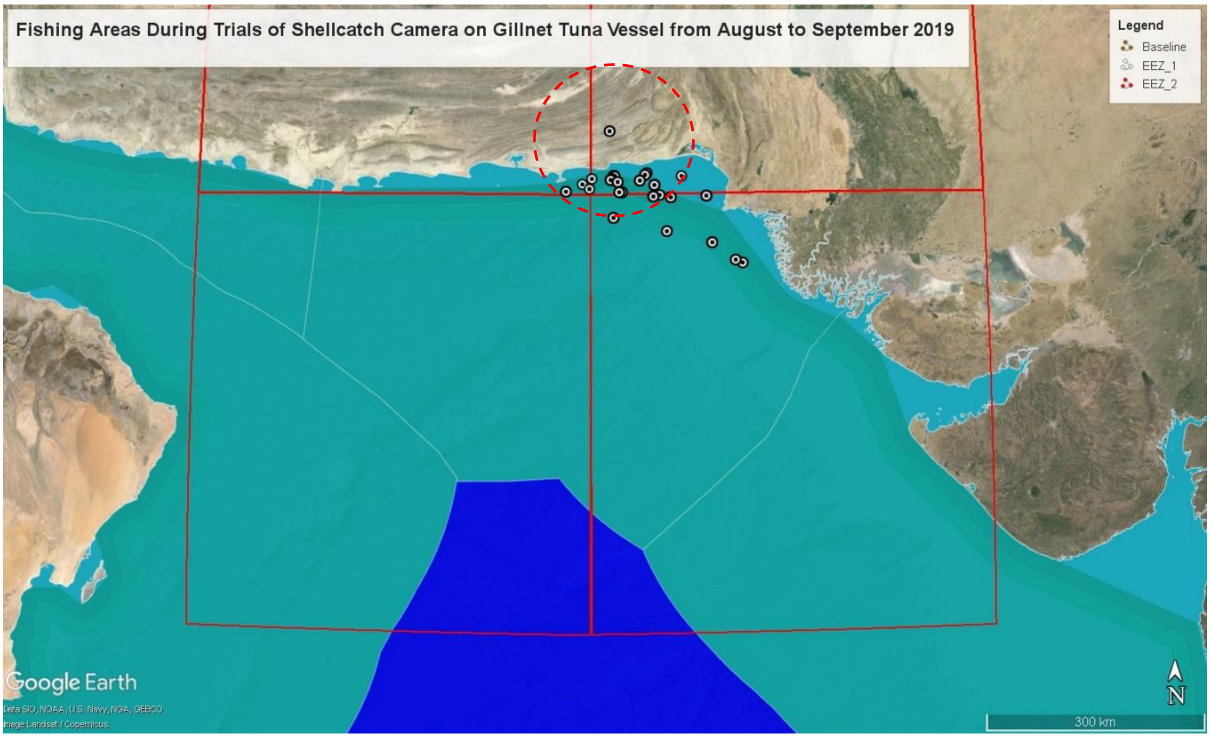
- **Ease of Installation:** The CCTV camera units were straightforward to install on the fishing boats. The configuration included a solar-powered system with a DVR, cameras, and necessary peripherals. Despite being a conventional technology, the cameras featured night vision capabilities, allowing for 24-hour monitoring of fishing activities. This ensured that fishing operations, including the handling of different species by the fishermen, could be recorded and reviewed comprehensively.
- **Power Supply:** The installation of CCTV camera units on fishing boats is straightforward, making it accessible for small-scale fishers. The system configuration includes two-night vision cameras, a DVR system, a 2 TB hard disk, and a UPS unit, all powered by a dedicated 150W poly-crystalline solar panel. The solar panel is crucial as it ensures a continuous power supply of 24V, independent of the boat's engine, thus maintaining the system's operation even during power interruptions.
- **Operational Setup:** The cameras were designed for easy deployment on their mounted areas during fishing trips and could be detached when not in use. However, the maritime environment posed some challenges. The vibration of the boat often caused the cameras to shift, leading to recording issues such as upside-down frames. To mitigate this, a dedicated fisherman had to regularly clean and adjust the cameras during each fishing operation, ensuring clear and accurate recordings.
- **Maintenance and Replacement of Cameras:** Maintaining the CCTV camera units is crucial to ensure their longevity and functionality. Regular maintenance involves routine cleaning, as marine environments can cause salt and grime buildup on the camera lenses, impairing visibility. The assigned crew member must wipe down the cameras after every fishing operation to ensure clear footage. In addition to cleaning, it is essential to inspect the cameras for any physical damage or wear and tear caused by constant exposure to harsh marine conditions. The mounting brackets and connections should be checked regularly to ensure they are secure and not corroded. Any signs of corrosion or damage should be addressed immediately to prevent equipment failure. When it comes to replacements, the ease of sourcing these cameras from local markets means that faulty units can be quickly replaced without significant downtime. However, it is important to have spare units and parts on hand

to facilitate rapid replacement and minimize disruptions to the monitoring process. The installation of new cameras should follow the same meticulous alignment and operational checks to maintain data consistency and reliability.

- **Camera Angle and Monitoring:** One significant limitation was the inability of the fishermen to view the recordings and camera angles in real-time unless a dedicated LCD was connected to the DVR unit onboard. This lack of immediate feedback sometimes resulted in suboptimal camera angles, affecting the quality of the footage captured.
- **Data Transfer Process:** At the end of each fishing trip, which typically lasted several days, the fishermen would stay back for one to two days to prepare for the next trip. During this period, the DVR unit was brought back to the office for data transfer. This process involved transferring data from the DVR's external hard drive to a separate database, a task that could take up to an entire day depending on computer performance. To ensure continuity and functionality, a dedicated person from WWF-Pakistan was responsible for checking and adjusting the cameras before the fishermen embarked on their next trip.
- **Video Playback and Analysis:** Monitoring and analyzing the recorded video posed significant challenges. The videos, encoded in H.264 format, required long hours to review, and the playback software did not support efficient rewinding or fast-forwarding. This limitation made it time-consuming to locate and review specific events within the footage.
- **Alternative Solutions:** To address these issues, an alternative method was adopted. The recorded videos were played and a new video was created via screen recording. This screen-recorded video was then trimmed to extract the desired moments. Although this method allowed for more targeted analysis, it was still labour-intensive and less than ideal.
- **Need for Dedicated Software:** The need for dedicated video playback software became apparent. Such software would facilitate the extraction of specific events along with timestamps, significantly easing the monitoring process. Without it, the original format of the recorded video remains cumbersome to analyze, highlighting a critical area for improvement.

Implementing Shellcatch Camera Tech

Data collection during these trials was recorded on a prescribed datasheet, documenting the fish catches, including tuna species, tuna-like species, and bycatch megafauna species. During the Shellcatch trials from August to September 2019, the observer participated in fishing trips that lasted 27 days, totalling 23 fishing days and 4 travel days. Each fishing day was documented as one datasheet or dataset. The fishing operations used subsurface gear setting, starting in the evening between 1700 and 1800 hours to set the net and hauling it back in the early morning between 0300 and 0400 hours. This allowed a soak time, typically 12 hours under normal conditions. The net was then fully hauled back, and the fish catch was handled and sorted on deck, usually concluding between 0700 and 0900 hours, depending on the catch size and the entanglement and release of bycatch. During these two trips, a gillnet 12 km in length and 5 meters in width was used in offshore waters (Map 2).



Map 2: Geographical locations of fishing activities during the trials of a Shellcatch camera on a gillnet tuna vessel in the northern Arabian Sea from August to September 2019, highlighting the EEZ boundaries and specific fishing locations. The gillnet vessel had a Shellcatch Camera showing fishing operations on the map consisting of the different zones of the EEZ and plotted on a 5x5 reporting grid. Various fishing locations are marked with black dots, indicating where the gillnet tuna vessel operated during the trial period.

During this period, the recorded fish catches included approximately 18 species. The length frequency of three individuals from each species or category was also documented onboard. All the recorded fish catches were categorized into groups for easier understanding: tuna, tuna-like species, sharks, unidentified species, and reptiles. the primary target species of the fishery. the "Tuna Type" category constitutes the highest percentage of the total catch, making up 45.37%, followed closely by the "Tuna" category at 41.67%. This indicates that the majority of the catch consists of tuna and tuna-like species, reflecting the primary target of the gillnet fishery. The "Unidentified" category represents 11.11% of the catch, highlighting a portion of the catch that could not be precisely identified. The presence of reptiles and sharks is minimal, each making up 0.93% of the total catch. (Graph 9).

Yellowfin constitutes the highest percentage of the total catch at 12.04%, reflecting its prominence in the gillnet tuna fishery. Unidentified species, Longtail, Queenfish Spp., and Spanish Mackerel each account for 11.11% of the catch, indicating a significant presence but also underscoring challenges in accurate species identification. Bullet/Frigate makes up 10.19% of the catch, followed by Kawakawa at 7.41%. Catfish Spp. and Marlin Spp. each contribute 4.63% to the catch. Pomfret Spp., Dolphinfish, Skipjack, and Barracuda Spp. each represents 3.70%, while Trash Fish and Leatherjackets Spp. each account for 2.78% of the total catch. Grunt, Turtle Spp., Thresher Spp., Snapper Spp., and Trevally Spp. each make up 0.93%, highlighting their relatively lower occurrence in the catch (Graph 10).

The recorded length frequency data for three individuals from each fish species or category where Yellowfin tuna are found within the 50-75 cm range, with significant frequencies around 60 cm. Similarly, Queenfish species are primarily observed in the 50-75 cm range, with notable frequencies around 55 cm. The unidentified category shows a broad distribution, particularly concentrated around the 25-50 cm range. Bullet/Frigate, Longtail, Spanish Mackerel, and Kawakawa species also have notable occurrences in the 50-75 cm range, reflecting their common capture sizes. Dolphinfish are observed within the 50-75 cm range, while Turtle species appear in the 75-100 cm range. Other species, including Pomfret Spp., Leatherjackets Spp., Barracuda Spp., Snapper Spp., Catfish Spp., Thresher Spp., Marlin Spp., Grunt, Skipjack, Trash Fish, and Trevally Spp., display varied length distributions with fewer occurrences. In individual length 1 of species, The data indicates that Yellowfin tuna is found within the 70-80 cm range, with a peak frequency of 4. Queenfish species are primarily observed in the 50-70 cm range, with notable frequencies around 60 cm. The unidentified category shows a broad distribution, particularly concentrated around the 10-40 cm range. Longtail 60-80 cm range, Spanish Mackerel 80- 90 cm range, and Kawakawa species also have notable occurrences in the 50-70 cm range, reflecting their common capture sizes. Dolphinfish are observed within the 50-70 cm range. Marlin Spp., observer in 100 cm range. Other species, including Pomfret Spp., Leatherjackets Spp., Barracuda Spp., Snapper Spp., Catfish Spp., Thresher Spp., Grunt, Skipjack, Trash Fish, and Trevally Spp., display varied length distributions with fewer occurrences for the individual length 2 of species, and Grunt species are predominantly found within the 0-10 cm range, with a peak frequency of 4. Unidentified species show a broad distribution, particularly concentrated around the 10-50 cm range. Yellowfin tuna are mostly observed within the 70-100 cm range, with notable frequencies around 75 cm and 100 cm, respectively (Graphs 11, 12, and 13)

For the status at capture, stark contrast between the numbers of alive and dead captures. Only a small number of Turtle species, with a count of just under 10, indicate they survive the capture process. In contrast, the dead category shows a high frequency of multiple species, with counts exceeding 100 for several species. The species composition in the dead category is diverse, including Barracuda Spp., Bullet/Frigate, Catfish Spp., Dolphinfish, Grunt, Kawakawa, Leatherjackets Spp., Longtail, Marlin Spp., Queenfish Spp., Skipjack, Snapper Spp., Spanish Mackerel, Thresher Spp., Trash Fish, Trevally Spp., Unidentified, Yellowfin, and Pomfret Spp. (Graph 14).

For the status at release, the species captured alive are exclusively Turtle species, with counts just under 10, indicating a very small number of fish survive the capture process. The dead category includes unidentified, trash fish, and Bullet/ Frigate with counts around 20, suggesting these species did not survive the capture. The none category, which represents species for which the status at release was not recorded or applicable, shows the highest counts, with a wide variety of species such as Barracuda Spp., Catfish Spp., Dolphinfish, Grunt, Kawakawa, Leatherjackets Spp., Longtail, Marlin Spp., Queenfish Spp., Skipjack, Snapper Spp., Spanish Mackerel, Thresher Spp., Trash Fish, Trevally Spp., Yellowfin, and Pomfret Spp., with some species counts exceeding 80 (Graph 15).

For the discarded, released alive, and retained catches, the discarded category includes species such as unidentified, trash fish, and Bullet/ Frigate., with counts around 20, indicating that these species were captured but subsequently discarded. The released category shows that Turtle species were exclusively released, with counts just under 10, suggesting targeted conservation efforts to release this vulnerable species. The retained category exhibits the highest counts, with a diverse composition of species including Barracuda Spp., Bullet/Frigate, Catfish Spp., Dolphinfish, Grunt, Kawakawa, Leatherjackets Spp., Longtail, Marlin Spp., Queenfish Spp., Skipjack, Snapper Spp., Spanish Mackerel, Thresher Spp., Trevally Spp., Yellowfin, and Pomfret Spp., with some species counts exceeding 80 (Graph 16)

The videos recorded 38 by Shellcatch Camera were downloaded to the web portal. the camera successfully recorded other activities aboard the fishing vessel, such as meal breaks, fixing and repairing fishing gear, using handline hooks, prayers, and communication with other fishing boats. This camera model is suitable for small-scale fishing boats with limited space for mounting equipment and whose operations primarily take place during the day. However, during this trial, the version of the Shellcatch camera used in the trials was unable to record the fishing operations of tuna gillnet fisheries, primarily because these operations occur at night, and this camera model lacks night vision or infrared technology.

To effectively trial electronic monitoring in gillnet tuna fisheries, especially for nighttime operations, more resources are needed to acquire the latest Shellcatch technology. This advanced technology includes features such as night vision capabilities, ensuring comprehensive monitoring of all fishing activities. Additionally, Shellcatch offers sophisticated services, including secure cloud data storage, monitoring and analysis of recorded videos to identify target and bycatch species, and training on the web portal for efficient video analysis using integrated algorithms for bycatch detection. These enhancements would streamline the data collection and reporting processes of national and regional fisheries management organizations.

Advancements and System Improvements

To address the limitations observed during the initial deployment, Shellcatch has developed an upgraded version of its technology, incorporating several key improvements:

- Enhanced Night Vision: The new Shellcatch cameras are equipped with advanced night vision capabilities, including infrared technology, enabling effective recording of fishing operations during nighttime.
- Higher Frame Rates: The upgraded cameras offer higher frame rates, ensuring smoother and more detailed video capture of all fishing activities. This enhancement is crucial for accurately monitoring and analyzing rapid movements during fishing operations.
- Improved Compression: With higher compression technology, the new system efficiently manages video data, reducing file sizes without compromising quality. This improvement facilitates easier storage and faster transmission of recorded footage.
- Better Web Management Platform: The updated web management platform provides a more intuitive and user-friendly interface. It allows for streamlined video analysis, enhanced reporting capabilities, and seamless integration with existing fisheries management systems.
- Easier Maintenance: The new Shellcatch system is designed for easier maintenance, minimizing downtime and ensuring consistent performance. Enhanced durability and simplified troubleshooting processes contribute to the system's reliability.
- Greater Connectivity Options: To accommodate areas with varying levels of internet access, the upgraded system offers multiple connectivity options, including GSM, direct internet, and intermediated data upload. This flexibility ensures continuous data transmission and reporting, even in remote locations without reliable internet connectivity.
- Seamless Integration with Electronic Reporting: The upgraded Shellcatch system seamlessly connects to electronic reporting capabilities via the app. This integration simplifies data entry and reporting processes, enabling real-time submission of catch data to regulatory authorities.
- Market Connection Applications: In addition to electronic reporting, the Shellcatch system offers integration with market connection applications. This feature facilitates direct connections between fishermen and potential buyers, streamlining the sales process and promoting fair trade practices.

The Power of Web Cam Versus CCTV Technology

Shellcatch employs advanced webcam technology rather than traditional CCTV cameras for several reasons:

- Versatility: Webcams are typically more versatile and adaptable to different environments and mounting configurations. This adaptability is essential for small-scale fishing boats with limited space.
- Higher Resolution: Modern webcams offer high-resolution video capture, providing clearer and more detailed footage compared to standard CCTV cameras. This clarity is vital for accurately identifying species and monitoring fishing activities.
- Cost-Effectiveness: Webcams are generally more cost-effective than CCTV cameras, making them a practical choice for widespread deployment in the fishing industry. The lower cost allows for more extensive coverage and better resource allocation.
- Integration Capabilities: Webcams are designed to easily integrate with digital platforms and cloud-based systems. This integration simplifies data management, analysis, and reporting, enhancing the overall efficiency of fisheries management operations.

The upgraded Shellcatch system addresses the limitations of previous versions and offers a comprehensive solution for monitoring gillnet tuna fisheries. With enhanced night vision, higher frame rates, improved compression, a better web management platform, easier maintenance, and greater connectivity options, Shellcatch continues to advance sustainable fishing practices and regulatory compliance. The use of webcam technology further amplifies the system's effectiveness, providing clear, high-resolution footage and seamless integration with modern digital platforms.

Future Directions and Recommendations

Based on the findings and implications of this study, several future directions and recommendations can be made:

- Expansion of EM Programs: Scaling up the implementation of EM systems across a larger portion of the gillnet fleet in Pakistan and other Indian Ocean countries can provide more comprehensive data coverage and support regional fisheries management efforts.
- Technological Innovations: Continued research and development of EM technology, including advancements in camera resolution, data storage, and real-time data transmission, can enhance the effectiveness and efficiency of EM systems.
- Capacity Building: Training and capacity-building programs for fishers, observers, and analysts are essential to ensure the successful implementation and operation of EM systems. This includes training on data collection protocols, equipment maintenance, and data analysis techniques.
- Policy and Regulatory Support: Strengthening policy and regulatory frameworks to support the adoption of EM technology is crucial. This includes developing guidelines for EM implementation, establishing data standards, and ensuring compliance with international fisheries management agreements.
- Collaborative Efforts: Promoting collaboration among stakeholders, including government agencies, non-governmental organizations, fishers, and international bodies such as the IOTC, can enhance the effectiveness of EM programs and support sustainable fisheries management.
- Ongoing Monitoring and Evaluation: Regular monitoring and evaluation of EM programs are necessary to assess their effectiveness, identify challenges, and make necessary adjustments. This iterative process ensures that EM systems continue to provide valuable data and support sustainable fisheries management.

The implementation of Electronic Monitoring systems in Pakistan's gillnet fisheries has demonstrated the potential to scale up EM trails for data collection, support sustainable fisheries management, and address critical challenges and knowledge gaps along with transparency and traceability in the region.

Building on these findings and recommendations, further advancements in EM technology and its application can contribute to the long-term sustainability of fisheries in the Indian Ocean.

Acknowledgements

We extend our heartfelt gratitude to the ABNJ Tuna Project and the Shark Conservation Fund for their generous financial assistance, which made it possible to conduct the trials of the CCTV and Shellcatch technology on tuna gillnet vessels. We also wish to express our sincere appreciation to Shah Zameen for his cooperation and willingness to install the EMS units on his boat, playing a crucial role in the success of these trials. Special thanks go to Summaiya Abid and Syed Muhammad Mawahid for their diligent efforts in data acquisition and maintaining the database, ensuring the accuracy and integrity of our research data.

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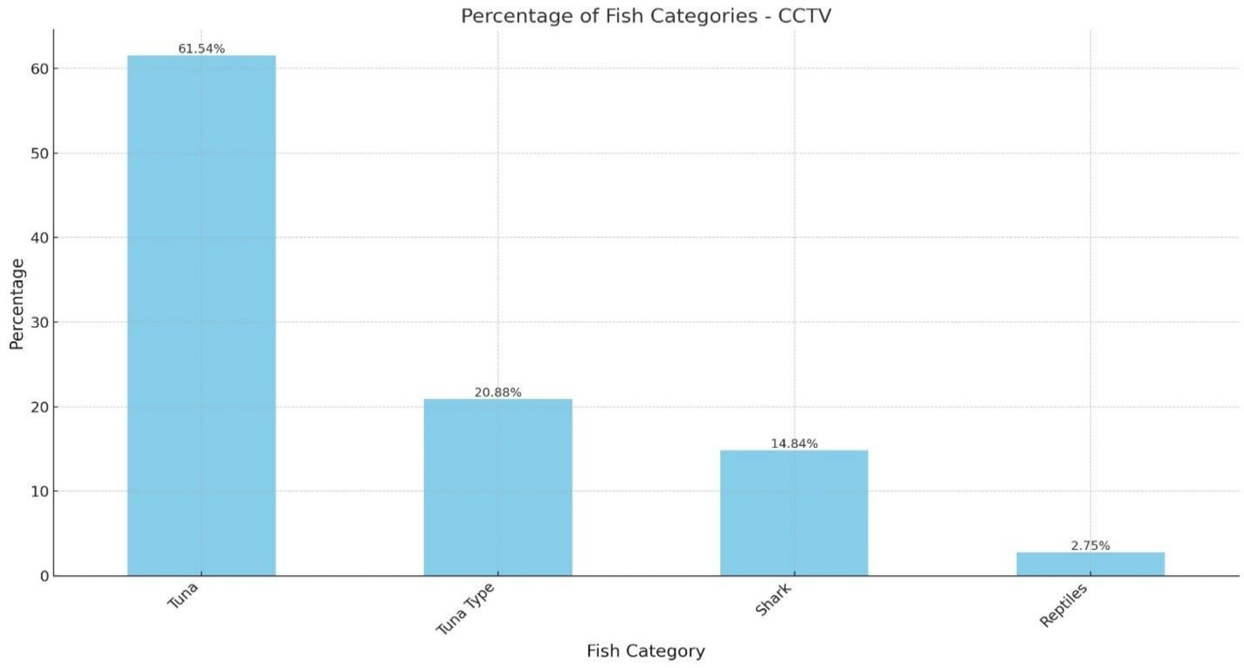
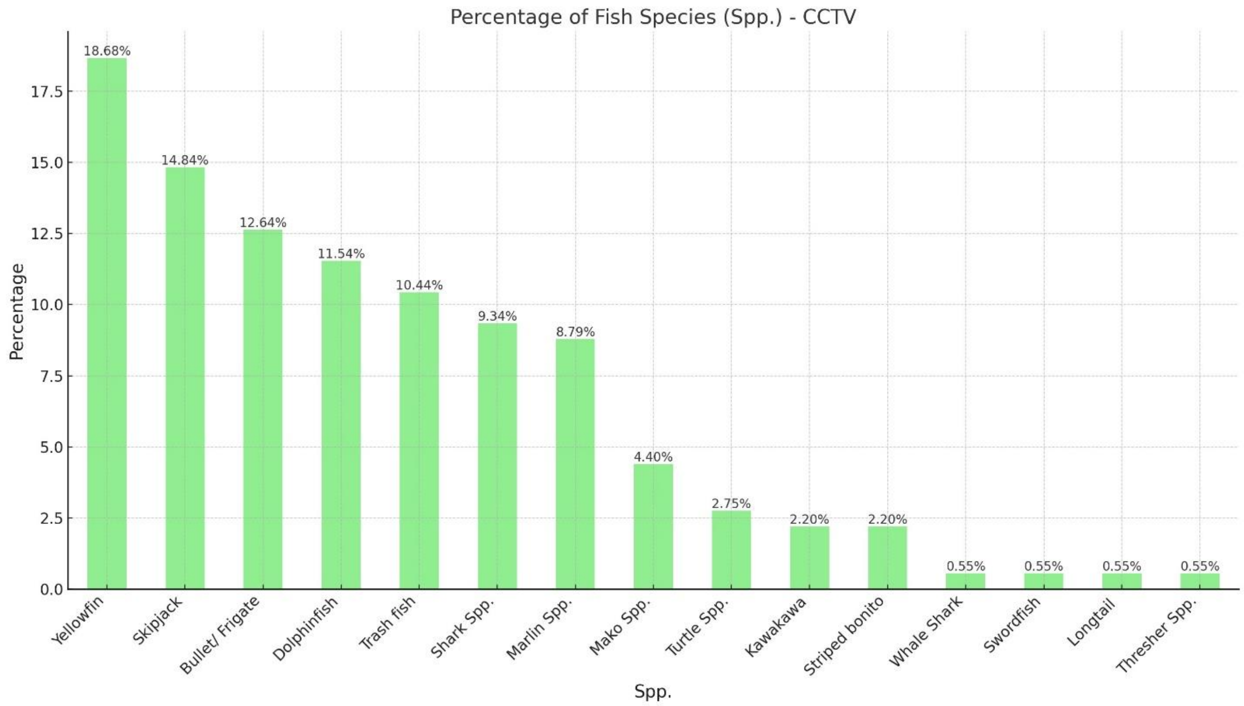
Annexure – 1

Graphs of the preliminary analysis of the fish catch composition and fate recording during the CCTV trials.



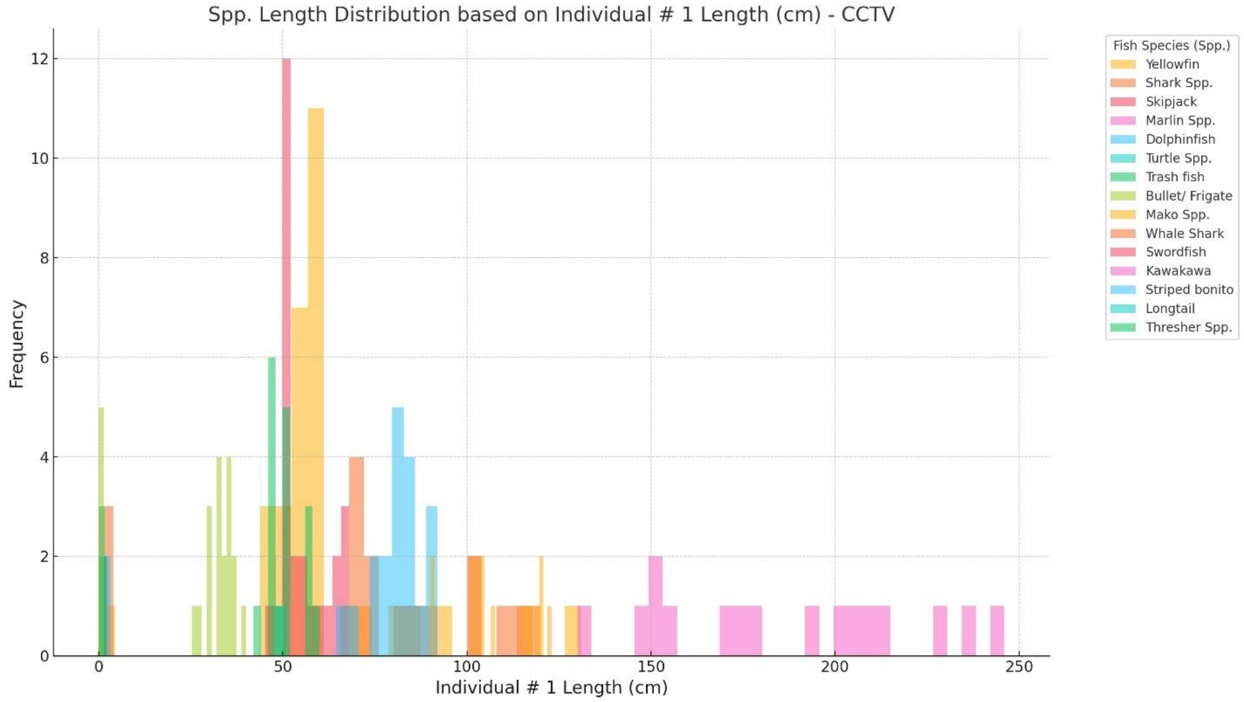
Graph 1: Distribution of fish categories recorded, showing percentages of Tuna (61.54%), Tuna Type (20.88%), Shark (14.84%), and Reptiles (2.75%). The graph reveals that the majority of the catch consists of tuna, which accounts for 61.54% of the total recorded catch.

This highlights the primary target species of the fishery. The "Tuna Type" category, which likely includes various species of tuna or closely related species, represents 20.88% of the catch, making it the second most prevalent category. Sharks constitute 14.84% of the catch, indicating a significant amount of bycatch in the gillnet tuna fishery. Reptiles, such as sea turtles, make up the smallest portion at 2.75%. This data underscores the composition of the catch, with a predominance of tuna and notable bycatch of sharks and minimal capture of reptiles.



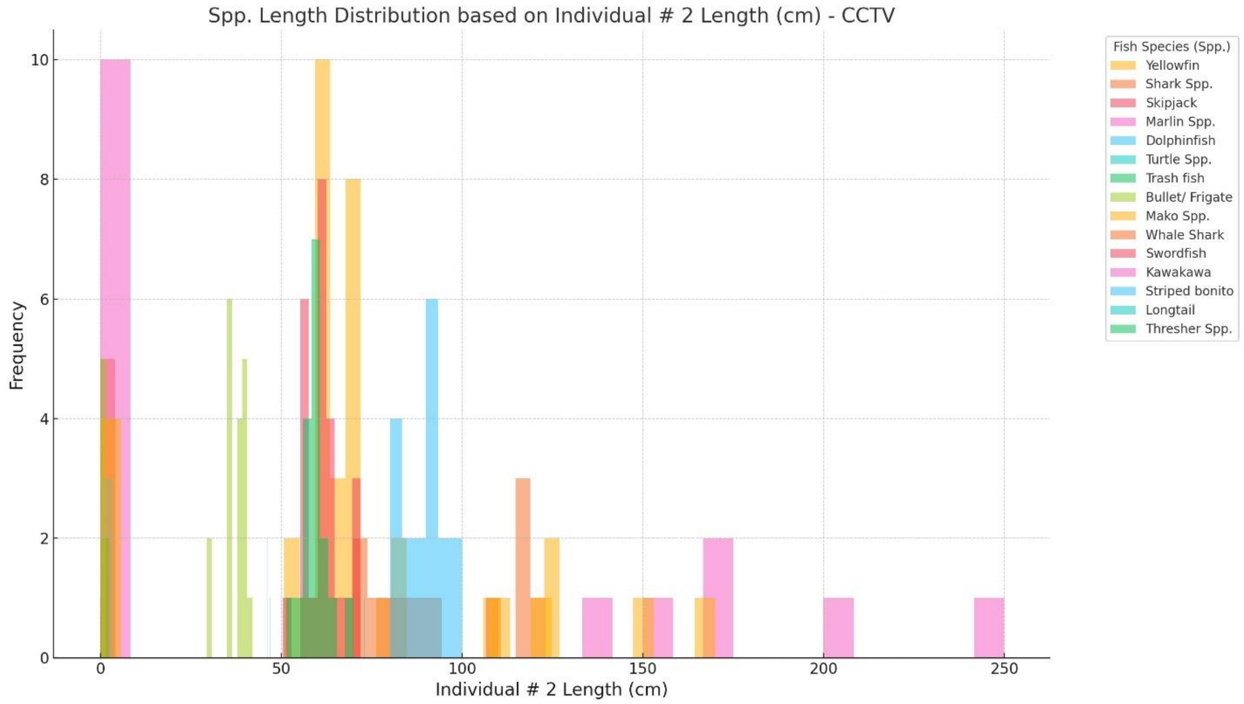
Graph 2: Distribution of fish species recorded, showing percentages for Yellowfin (18.68%), Skipjack (14.84%), Bullet/Frigate (12.64%), Dolphinfish (11.54%), Trash Fish (10.44%), Shark Spp. (9.34%), Marlin Spp. (8.79%), Mako Spp. (4.40%), Turtle Spp. (2.75%), Kawakawa (2.20%), Striped Bonito (2.20%), Whale Shark (2.20%), Swordfish (0.55%), Longtail (0.55%), and Thresher Spp. (0.55%).

Yellowfin tuna is the predominant species, making up 18.68% of the total catch, followed by Skipjack and Bullet/Frigate with 14.84% and 12.64% respectively. Dolphinfish accounts for 11.54%, while Trash Fish represents 10.44% of the catch. Notably, different shark species collectively form a significant portion of the catch at 9.34%, indicating a substantial presence of non-target species. Marlin and Mako species contribute 8.79% and 4.40% respectively, while turtles are captured at a rate of 2.75%. Other species such as Kawakawa, Striped Bonito, and Whale Shark each account for 2.20% of the total catch. The least represented species, including Swordfish, Longtail, and Thresher species, each make up 0.55%. This graph underscores the composition of the catch, dominated by various tuna species, while also highlighting significant bycatch, including sharks and turtles



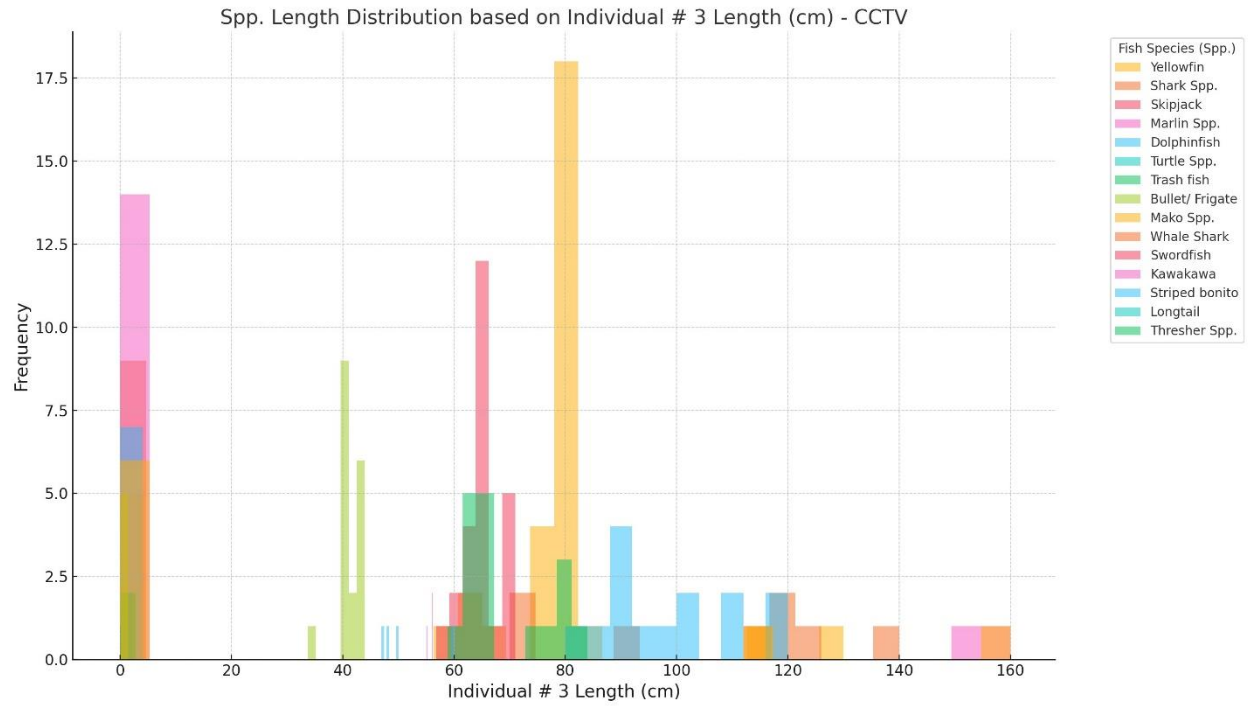
Graph 3: Length distribution of various fish species recorded, showing frequency of different lengths for Yellowfin, Shark Spp., Skipjack, Marlin Spp., Dolphinfish, Turtle Spp., Trash Fish, and other species.

The data shows that Yellowfin tuna are predominantly found in the 40-60 cm range, with a peak frequency at around 50 cm. Skipjack and Dolphinfish also exhibit similar length distributions, primarily within the 40-70 cm range. Shark species display a broader range of lengths, with significant frequencies around 50-60 cm and another smaller peak at 150-200 cm. Marlin species have varied lengths, with notable frequencies at both smaller (50 cm) and larger lengths (150-200 cm). Trash Fish, an unspecified category, shows frequencies across a wide range, peaking at 50 cm and 100 cm. Other species like Turtle Spp40-60 cm.., Bullet/Frigate, Mako Spp., and Whale Shark display varied length distributions with fewer occurrences.



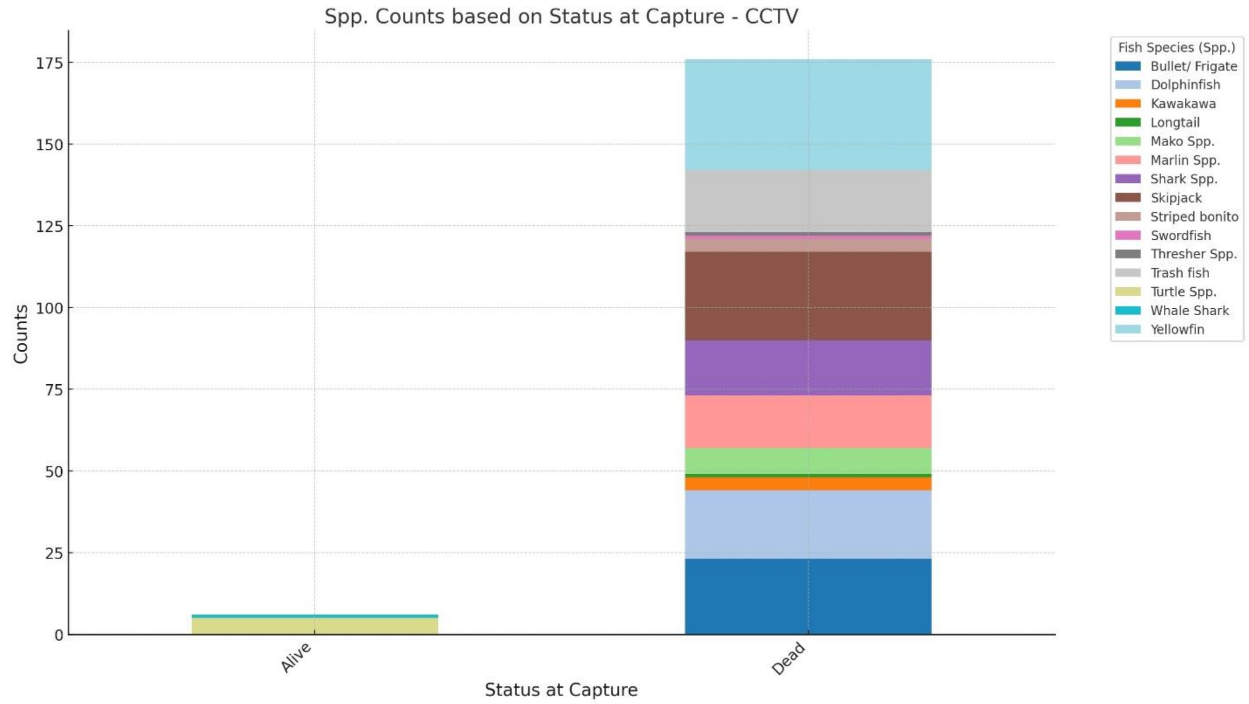
Graph 4: Length distribution of various fish species recorded, showing frequency of different lengths for Yellowfin, Shark Spp., Skipjack, Marlin Spp., Dolphinfish, Turtle Spp., Trash Fish, and other species.

The data highlights that Yellowfin tuna are predominantly found in the 40-60 cm range, peaking around 50 cm. Skipjack and Dolphinfish exhibit similar length distributions, mainly within the 40-70 cm range. Shark species display a broad range of lengths, with significant frequencies around 50-60 cm and another peak at 150 cm. Marlin species have varied lengths, with notable frequencies at both smaller (50 cm) and larger lengths (150-200 cm). Trash Fish, an unspecified category, shows frequencies across a wide range, peaking at 50 cm and 100 cm.



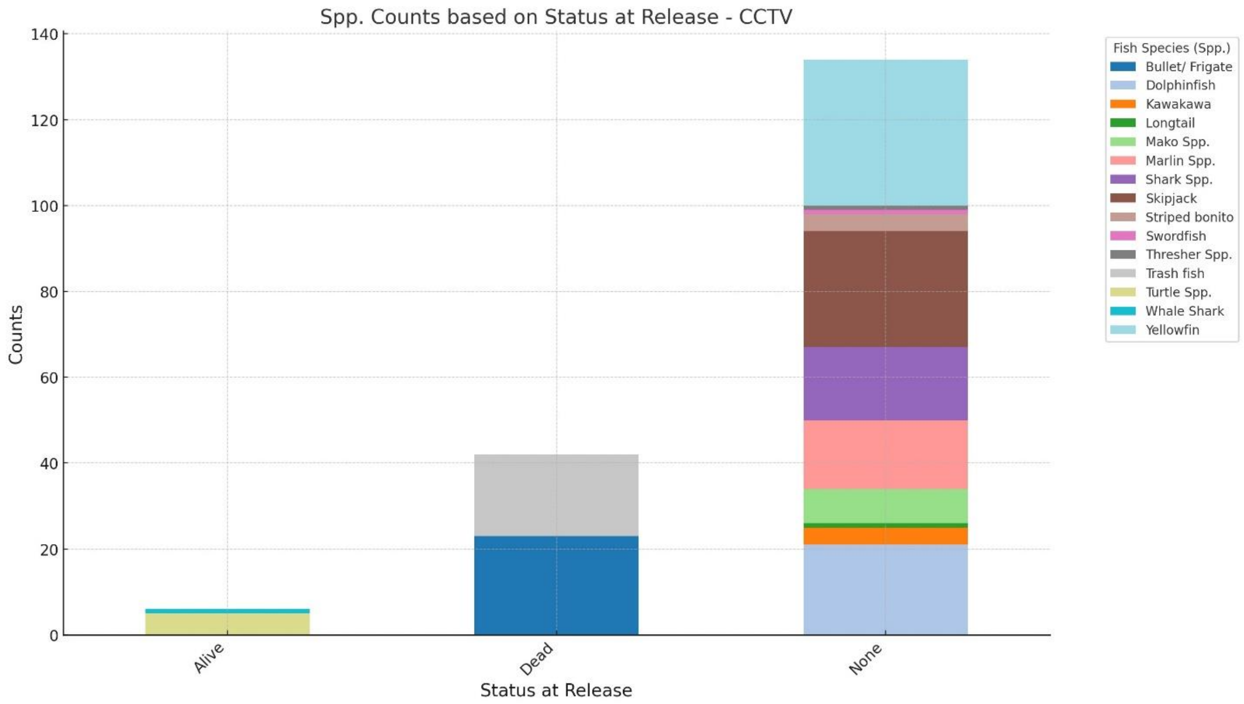
Graph 5: Length distribution of various fish species recorded, showing frequency of different lengths for Shark Spp., Yellowfin, Skipjack, Dolphinfish, Trash Fish, Bullet/Frigate, and other species.

The data indicates that Shark species are predominantly found in the 70-80 cm range, with a peak frequency around 80 cm, making them one of the most frequently observed length categories. Yellowfin tuna are commonly observed within the 40-60 cm range, peaking around 50 cm. Skipjack tuna are mostly seen within the 50-70 cm range, with a peak frequency around 60 cm. Dolphinfish frequencies are concentrated in the 50-70 cm range, while Trash Fish, an unspecified category, show a broad range with a peak around 70 cm. Bullet/Frigate species also exhibit significant frequencies peaking at around 80 cm.



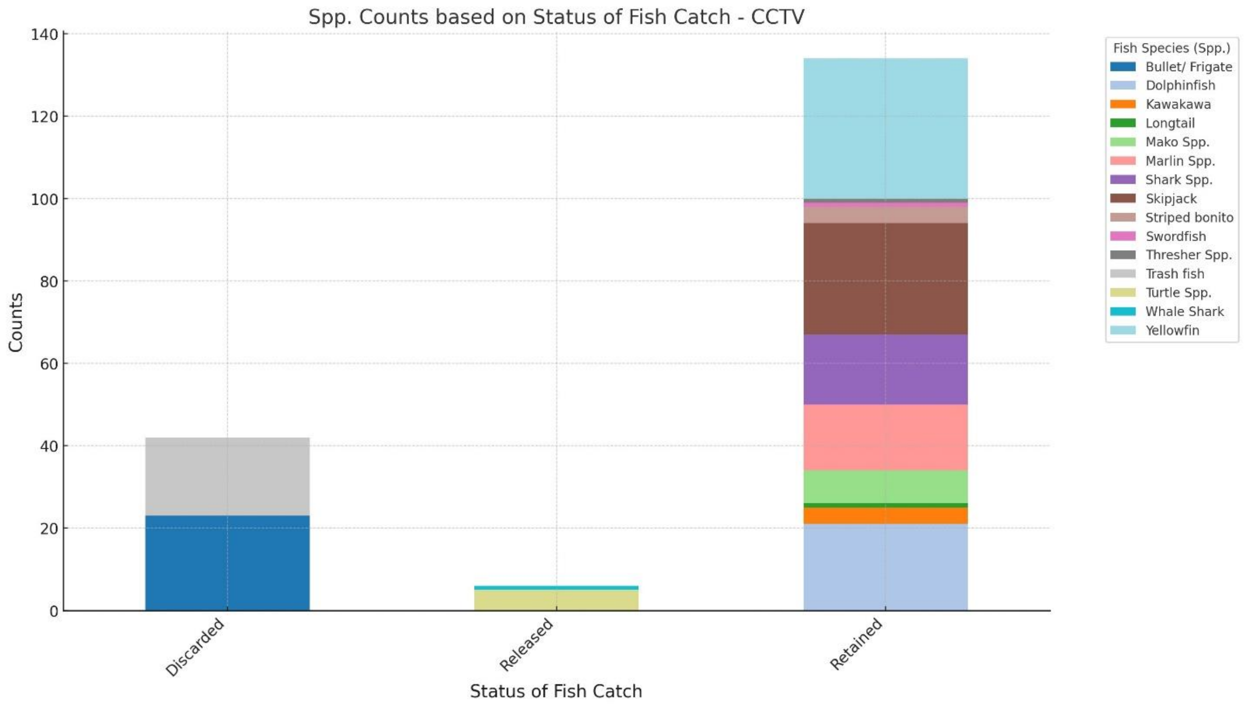
Graph 6: Counts of various fish species recorded, categorized by their status at capture (Alive or Dead), showing the predominance of dead captures across multiple species.

The data reveals a significant contrast between the counts of alive and dead captures. Only a few species are captured alive, including whale shark and Turtle Spp., with the counts for these species ranging from approximately 1 to 6. In contrast, the dead category encompasses a wide array of species, with total counts reaching nearly 175 for some species. The species composition in the dead category includes Bullet/Frigate, Dolphinfish, Kawakawa, Longtail, Mako Spp., Marlin Spp., Shark Spp., Skipjack, Striped Bonito, Swordfish, Thresher Spp., Trash Fish, and Yellowfin.



Graph 7: Counts of various fish species recorded, categorized by their status at release (Alive, Dead, None), highlighting the presence of Turtle Spp., and Whale Shark in the alive category, and a diverse composition of species in the none category.

The data reveals that species in the alive category include Turtle Spp. and Whale Shark, with counts under 10, indicating that these species are more likely to survive after capture. The dead category includes species such as trash Fish., with counts ranging from 10 to 40, suggesting discards. The none (not released) category, which encompasses a wide variety of species, shows the highest counts, reaching up to 140 for some species. This category includes Bullet/Frigate, Dolphinfish, Kawakawa, Longtail, Mako Spp., Marlin Spp., Shark Spp., Skipjack, Striped Bonito, Swordfish, Thresher Spp., and Yellowfin.

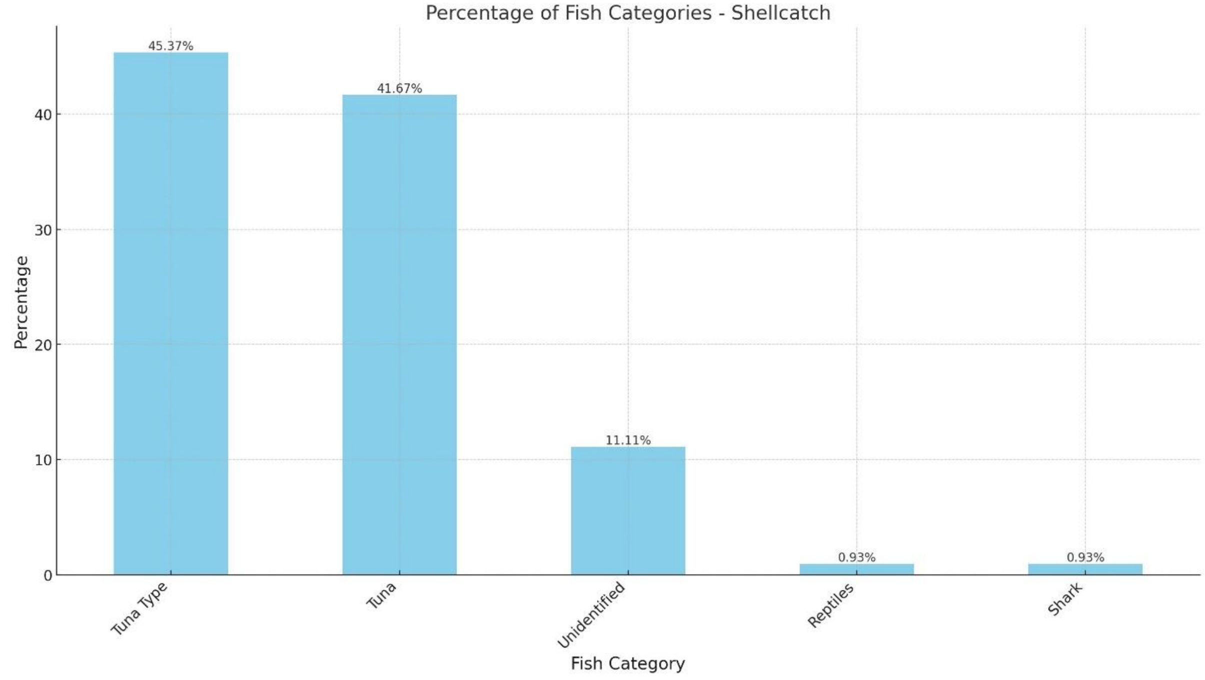


Graph 8: Counts of various fish species recorded, categorized by their status of fish catch (Discarded, Released, Retained), highlighting the predominance of retained species and the relatively low counts of released species including Turtle Spp. and Whale Shark.

The data reveals that species in the discarded category primarily include Bullet/Frigate and Trash Fish, with counts ranging from 10 to 40 events, indicating these species are frequently caught but not retained. The released category includes Turtle Spp. and Whale Shark, with relatively low counts under 10, suggesting that these species are more likely to be released alive after capture, reflecting an effort to mitigate bycatch impact on these protected species. The retained category shows the highest counts, encompassing a diverse array of species such as Dolphinfish, Kawakawa, Longtail, Mako Spp., Marlin Spp., Shark Spp., Skipjack, Striped Bonito, Swordfish, Thresher Spp., Trash Fish, and Yellowfin, with counts reaching up to nearly 140 for some species. This indicates that the majority of the catch is retained, underscoring the economic importance of these species.

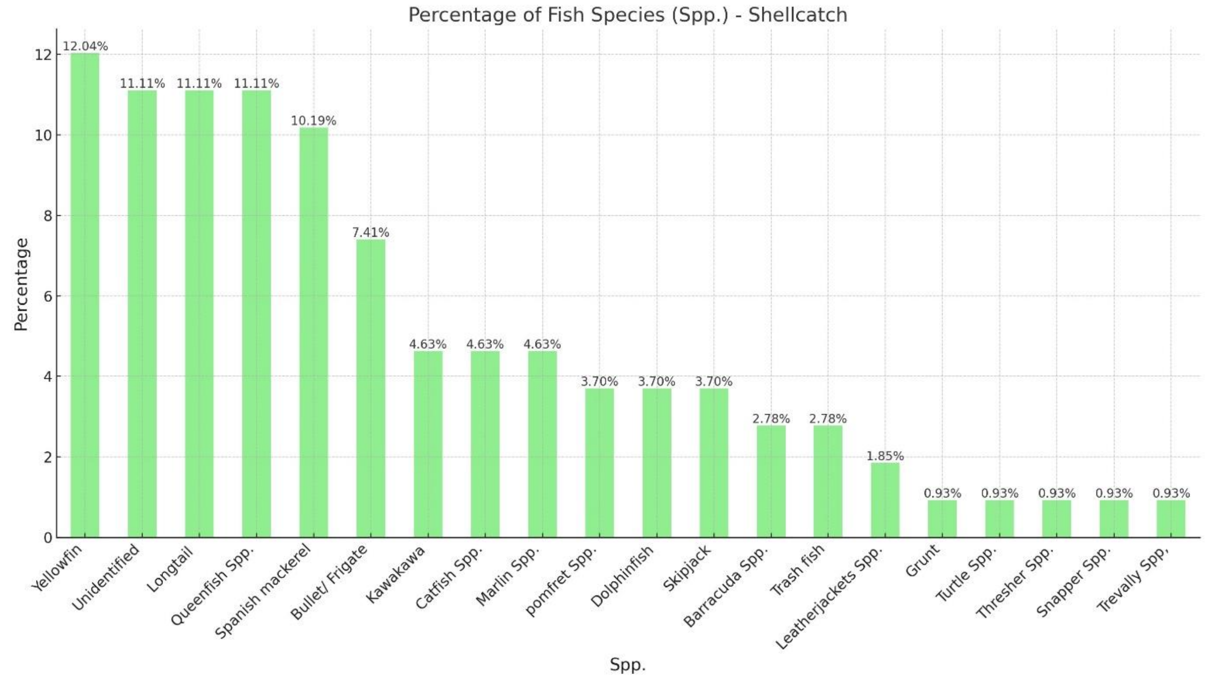
Annexure – 2

Graphs of the preliminary analysis of the fish catch composition and fate recording during the Shellcatch Camera trials.



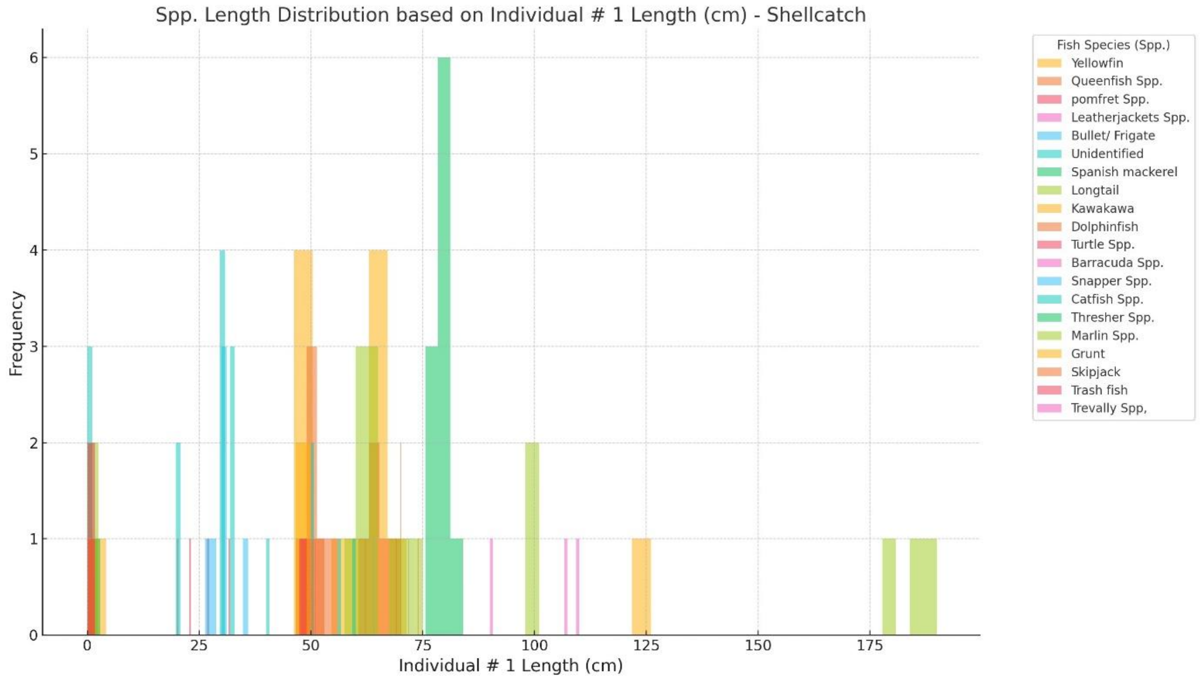
Graph 9: Percentage distribution of various fish categories recorded, showing Tuna Type (45.37%), Tuna (41.67%), Unidentified (11.11%), Reptiles (0.93%), and Shark (0.93%).

The data reveals that the "Tuna Type" category constitutes the highest percentage of the total catch, making up 45.37%, followed closely by the "Tuna" category at 41.67%. This indicates that the majority of the catch consists of tuna and tuna-like species, reflecting the primary target of the gillnet fishery. The "Unidentified" category represents 11.11% of the catch, highlighting a portion of the catch that could not be precisely identified. The presence of reptiles and sharks is minimal, each making up 0.93% of the total catch.



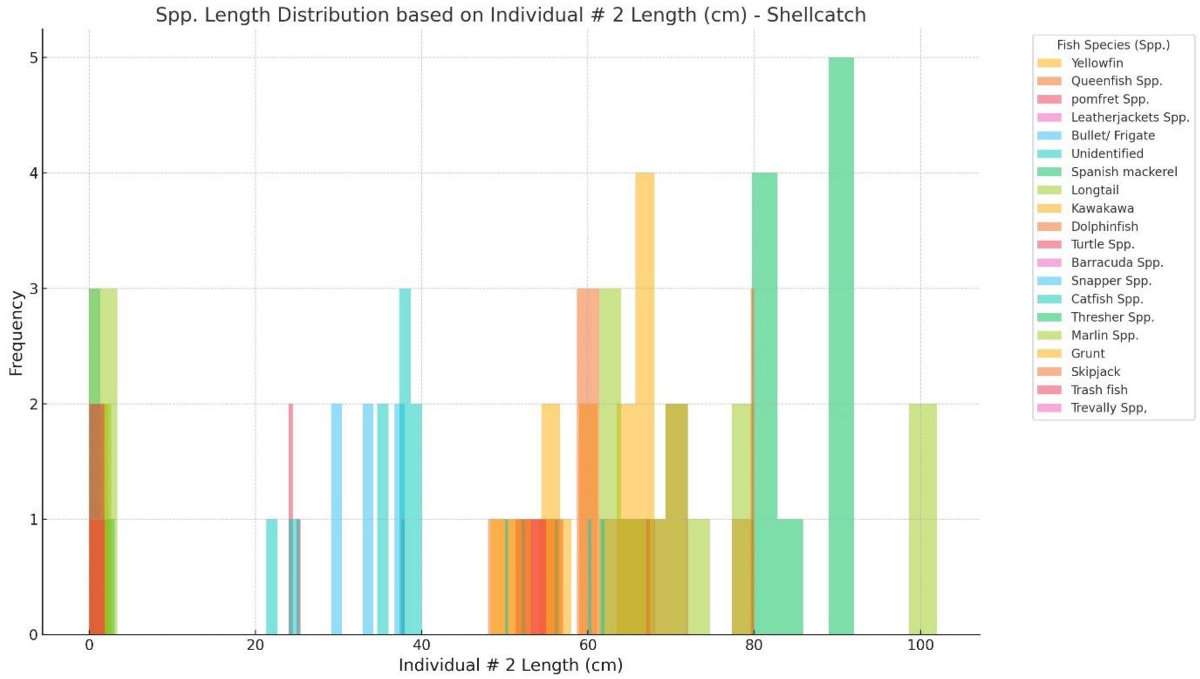
Graph 10: Percentage distribution of various fish species recorded, showing the highest percentage for Yellowfin (12.04%), followed by Unidentified, Longtail, Queenfish Spp., and Spanish Mackerel (each 11.11%), and a diverse array of other species.

The data reveals that Yellowfin constitutes the highest percentage of the total catch at 12.04%, reflecting its prominence in the gillnet tuna fishery. Unidentified species, Longtail, Queenfish Spp., and Spanish Mackerel each account for 11.11% of the catch, indicating a significant presence but also underscoring challenges in accurate species identification. Bullet/Frigate makes up 10.19% of the catch, followed by Kawakawa at 7.41%. Catfish Spp. and Marlin Spp. each contribute 4.63% to the catch. Pomfret Spp., Dolphinfish, Skipjack, and Barracuda Spp. each represents 3.70%, while Trash Fish and Leatherjackets Spp. each account for 2.78% of the total catch. Grunt, Turtle Spp., Thresher Spp., Snapper Spp., and Trevally Spp. each make up 0.93%, highlighting their relatively lower occurrence in the catch.



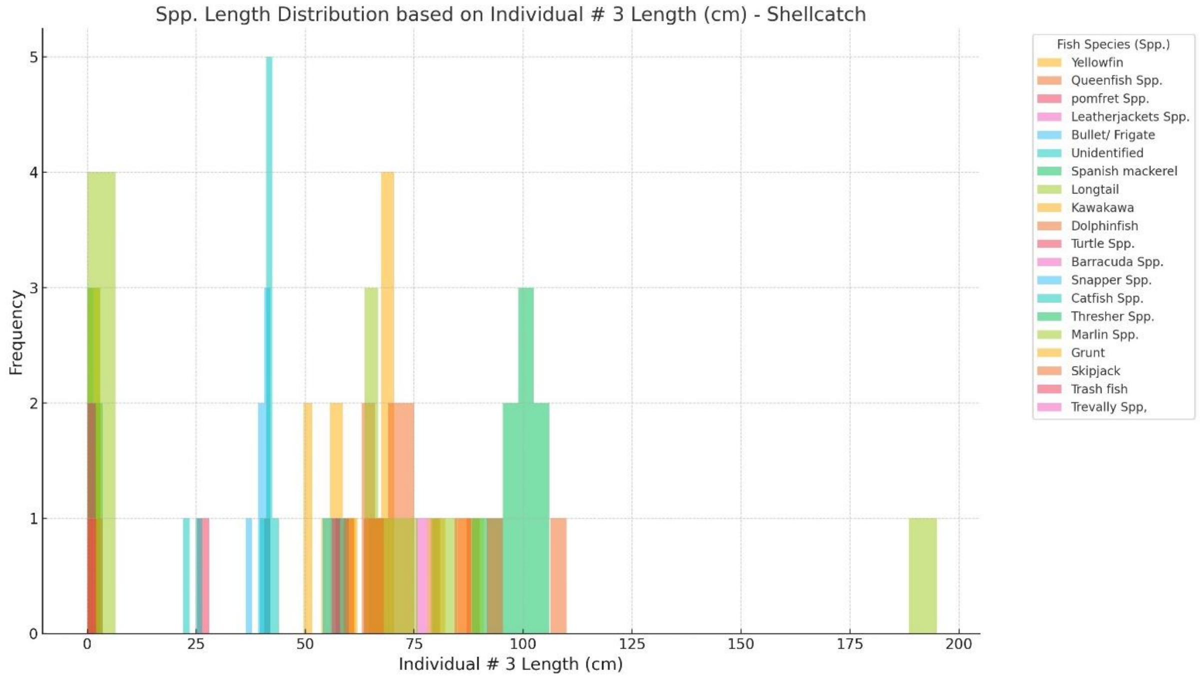
Graph 11: Length distribution of various fish species recorded, showing frequencies of different lengths for Yellowfin, Queenfish Spp., Unidentified, Bullet/Frigate, Longtail, Spanish Mackerel, Kawakawa, Dolphinfish, Turtle Spp., and other species.

The data indicates that Yellowfin tuna are predominantly found within the 50-75 cm range, with significant frequencies around 60 cm. Similarly, Queenfish species are primarily observed in the 50-75 cm range, with notable frequencies around 55 cm. The unidentified category shows a broad distribution, particularly concentrated around the 25-50 cm range. Bullet/Frigate, Longtail, Spanish Mackerel, and Kawakawa species also have notable occurrences in the 50-75 cm range, reflecting their common capture sizes. Dolphinfish are observed within the 50-75 cm range, while Turtle species appear in the 25-50 cm and 75-100 cm ranges, indicating variability in their capture sizes. Other species, including Pomfret Spp., Leatherjackets Spp., Barracuda Spp., Snapper Spp., Catfish Spp., Thresher Spp., Marlin Spp., Grunt, Skipjack, Trash Fish, and Trevally Spp., display varied length distributions with fewer occurrences.



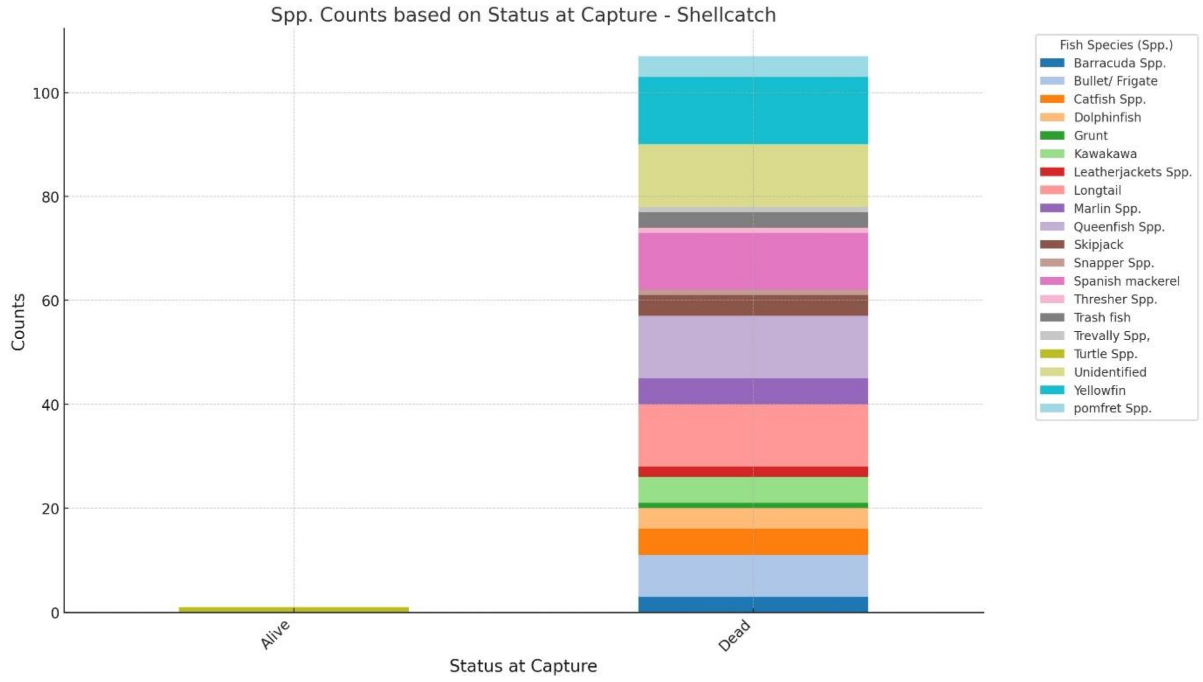
Graph 12: Length distribution of various fish species, showing frequencies of different lengths for Yellowfin, Queenfish Spp., Unidentified, Bullet/Frigate, Longtail, Spanish Mackerel, Kawakawa, Dolphinfish, Turtle Spp., and other species.

The data indicates that Yellowfin tuna are predominantly found within the 70-80 cm range, with a peak frequency of 4. Queenfish species are primarily observed in the 50-70 cm range, with notable frequencies around 60 cm. The unidentified category shows a broad distribution, particularly concentrated around the 10-40 cm range. Bullet/Frigate, Longtail, Spanish Mackerel, and Kawakawa species also have notable occurrences in the 50-70 cm range, reflecting their common capture sizes. Dolphinfish are observed within the 50-70 cm range. Other species, including Pomfret Spp., Leatherjackets Spp., Barracuda Spp., Snapper Spp., Catfish Spp., Thresher Spp., Marlin Spp., Grunt, Skipjack, Trash Fish, and Trevally Spp., display varied length distributions with fewer occurrences.



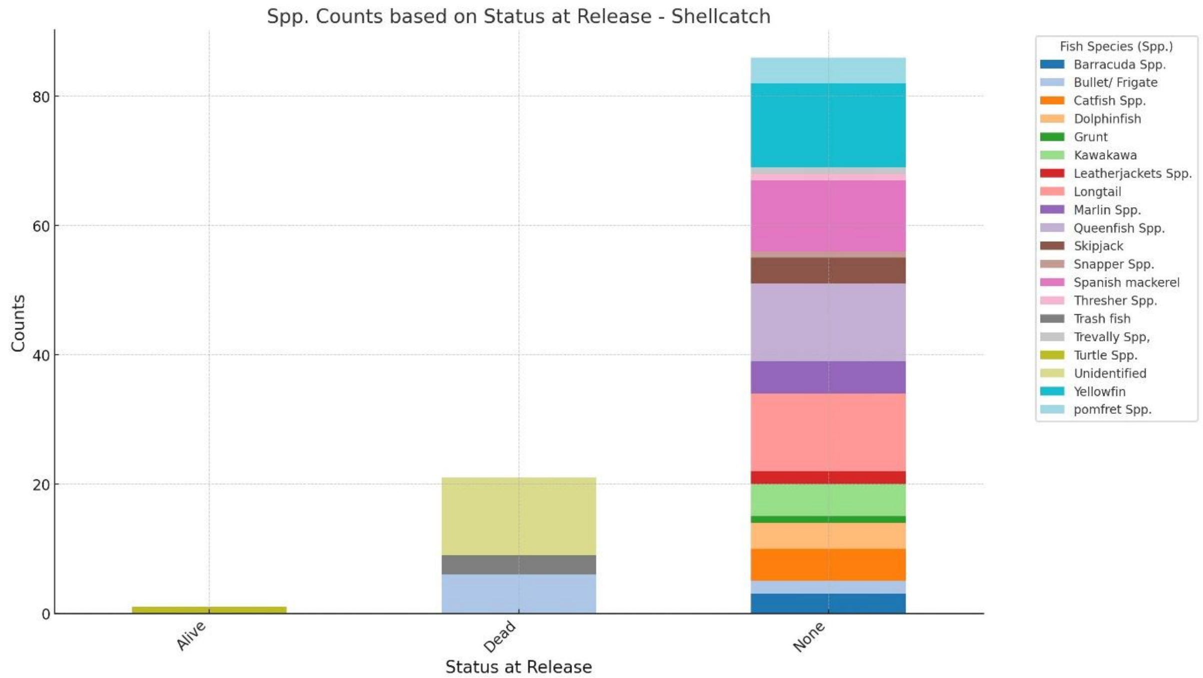
Graph 13: Length distribution of various fish species recorded, showing frequencies of different lengths for Grunt, Unidentified, Yellowfin, Bullet/Frigate, Longtail, Spanish Mackerel, Kawakawa, Dolphinfish, Turtle Spp., and other species.

The data indicates that Grunt species are predominantly found within the 0-10 cm range, with a peak frequency of 4. Unidentified species show a broad distribution, particularly concentrated around the 10-50 cm range. Yellowfin tuna are mostly observed within the 70-100 cm range, with notable frequencies around 75 cm and 100 cm. Bullet/Frigate, Longtail, Spanish Mackerel, and Kawakawa species have significant occurrences in the 50-75 cm range, reflecting their common capture sizes. Dolphinfish are also observed within the 50-75 cm range.



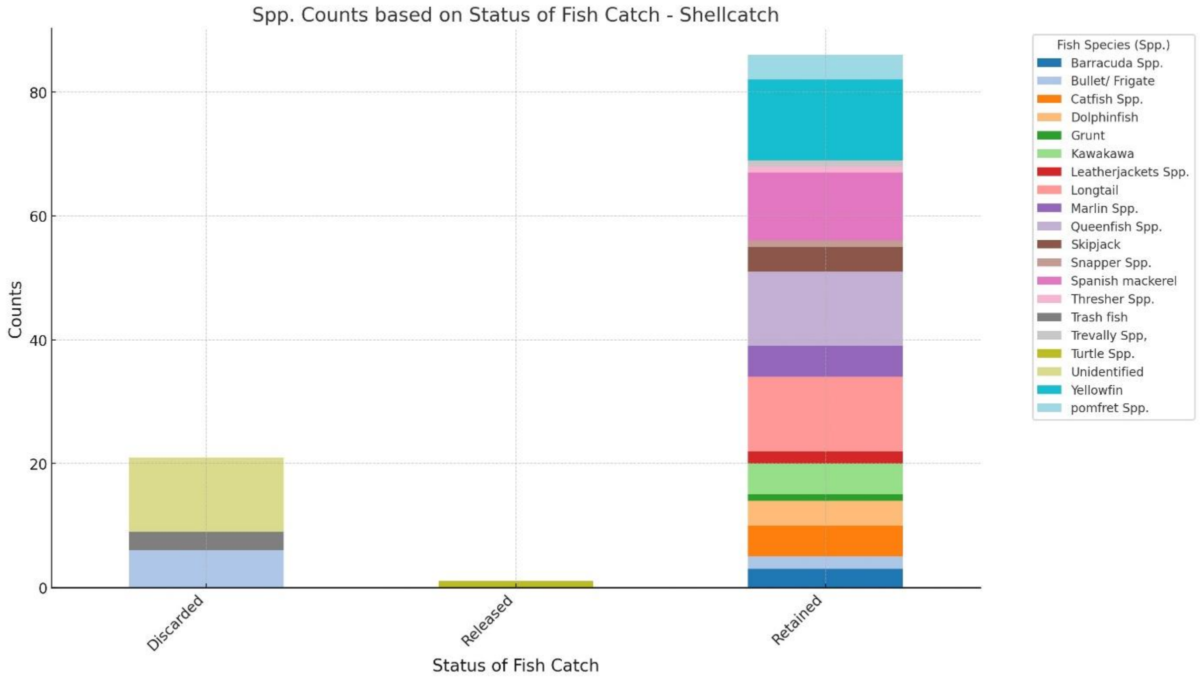
Graph 14: Counts of various fish species, categorized by their status at capture (Alive or Dead), highlighting the predominance of dead captures across multiple species and the relatively low counts of alive captures, primarily Turtle Spp.

The data reveals a stark contrast between the numbers of alive and dead captures. Only a small number of Turtle species, with a count of just under 10, indicate the survive the capture process. In contrast, the dead category shows a high frequency of multiple species, with counts exceeding 100 for several species. The species composition in the dead category is diverse, including Barracuda Spp., Bullet/Frigate, Catfish Spp., Dolphinfish, Grunt, Kawakawa, Leatherjackets Spp., Longtail, Marlin Spp., Queenfish Spp., Skipjack, Snapper Spp., Spanish Mackerel, Thresher Spp., Trash Fish, Trevally Spp., Unidentified, Yellowfin, and Pomfret Spp.



Graph 15: Counts of various fish species recorded by Shellcatch cameras on a gillnet tuna vessel, categorized by their status at release (Alive, Dead, None), highlighting the predominance of 'None' status captures across multiple species and the relatively low counts of 'Alive' captures, primarily Turtle Spp.

The data reveals that the species captured alive are exclusively Turtle species, with counts just under 10, indicating a very small number of fish survive the capture process. The dead category includes unidentified, trash fish, and Bullet/ Frigate with counts around 20, suggesting these species did not survive the capture. The none category, which represents species for which the status at release was not recorded or applicable, shows the highest counts, with a wide variety of species such as Barracuda Spp., Catfish Spp., Dolphinfish, Grunt, Kawakawa, Leatherjackets Spp., Longtail, Marlin Spp., Queenfish Spp., Skipjack, Snapper Spp., Spanish Mackerel, Thresher Spp., Trash Fish, Trevally Spp., Yellowfin, and Pomfret Spp., with some species counts exceeding 80.



Graph 16: Counts of various fish species recorded by Shellcatch cameras on a gillnet tuna vessel, categorized by their status of fish catch (Discarded, Released, Retained), highlighting the predominance of 'Retained' status captures across multiple species and the relatively low counts of 'Released' and 'Discarded' captures.

The data reveals that the discarded category includes species such as unidentified, trash fish, and Bullet/ Frigate., with counts around 20, indicating that these species were captured but subsequently discarded. The released category shows that Turtle species were exclusively released, with counts just under 10, suggesting targeted conservation efforts to release this vulnerable species. The retained category exhibits the highest counts, with a diverse composition of species including Barracuda Spp., Bullet/Frigate, Catfish Spp., Dolphinfish, Grunt, Kawakawa, Leatherjackets Spp., Longtail, Marlin Spp., Queenfish Spp., Skipjack, Snapper Spp., Spanish Mackerel, Thresher Spp., Trevally Spp., Yellowfin, and Pomfret Spp., with some species counts exceeding 80.

Annexure- 3
Comparison of Using CCTV Cameras with Shellcatch Technology for Electronic Monitoring of Fishing Operations

Category	**CCTV camera unit**	**Shellcatch Technology.**
Functionality	CCTV cameras are widely used for visual monitoring of fishing operations. They provide continuous video footage, which is crucial for verifying compliance with fisheries regulations and monitoring bycatch. Equipped with night vision capabilities, these cameras can record activities in low-light conditions, ensuring 24/7 surveillance. However, they primarily offer raw video data without integrated analytical capabilities.	Shellcatch technology offers a more integrated approach to electronic monitoring. In addition to video recording, Shellcatch includes GPS tracking, sensors, and advanced software for automatic catch documentation. The system can identify species, log catch quantities, and record fishing locations. This comprehensive functionality provides a detailed and accurate record of fishing activities, facilitating better management and reporting. It can record data at already set per frame for 40 days is supported by its internal battery and is powered by solar panel.
Ease of Installation	CCTV systems are relatively straightforward to install. The typical setup involves: Mounting the cameras in strategic locations on the vessel. Connecting the cameras to a DVR system for video storage. Ensuring a stable power supply, often achieved through a combination of a solar panel and UPS. The simplicity of installation makes CCTV cameras accessible for small-scale and artisanal fishers. However, ongoing maintenance, such as cleaning lenses and adjusting camera angles, is necessary to ensure optimal performance. The straightforward installation process makes CCTV systems accessible for small-scale fishers. However, cameras need regular maintenance, such as cleaning lenses and adjusting angles due to boat vibrations and environmental conditions.	Installing Shellcatch technology is more complex due to the integration of multiple components: Cameras and sensors must be precisely positioned to capture relevant data. Built-in GPS units need to be installed and calibrated by the service provider before installation. The system requires configuration to ensure synchronization of all components. While the initial setup is more involved and requires technical expertise, once installed, Shellcatch systems are relatively low-maintenance and provide more automated functionality. Despite the initial complexity, once installed, Shellcatch systems require minimal manual intervention and offer automated functionality.

Cost	CCTV systems are generally more affordable, with lower upfront costs. The primary expenses include: Cameras and DVR system. Storage devices, such as hard drives. Solar panels and UPS for power supply. However, there are ongoing costs related to maintenance, data retrieval, and manual analysis of the footage. The low upfront cost makes CCTV systems attractive for small-scale and artisanal fishers. However, the need for regular maintenance and manual data management can incur additional operational expenses over time.	Shellcatch technology has higher upfront costs due to its advanced features and comprehensive monitoring capabilities. Costs include: Cameras with integrated sensors. GPS units and software for data logging and analysis. Installation and configuration services. Despite the higher initial investment, Shellcatch can offer long-term savings by reducing labor costs associated with data processing and increasing the accuracy of catch documentation. In addition to the initial investment, Shellcatch offers subscription services for data management, software updates, and technical support. These subscription services provide ongoing access to cloud-based platforms, automated data analysis, and regular system maintenance, which can result in long-term savings by reducing labour costs associated with manual data processing.
Data Management	Data management for CCTV systems involves several manual steps: Retrieving the DVR unit at the end of each fishing trip. Transferring video footage to a database, which can take a full day depending on the volume of data. Manually reviewing and analyzing footage, which is time-consuming and labor-intensive. The primary challenge is the lack of an efficient video player for H264 encoded videos, requiring alternative methods such as screen recording to extract relevant moments.	Shellcatch offers automated data management, enhancing efficiency and accuracy: The system automatically logs catch data and uploads it to a cloud-based platform. Remote access to data allows for near-real-time monitoring and analysis. Advanced software tools facilitate the extraction of specific events and timestamps, reducing the need for manual review. This automation streamlines the entire process, making it faster and more reliable. Subscription services enhance data management efficiency, providing users with seamless access to analysis tools and cloud storage, thereby reducing the time and effort needed for manual data processing.

Maintenance and Replacement	Regular maintenance is essential for CCTV systems: Routine cleaning of lenses to prevent salt and grime buildup. Inspecting for physical damage and corrosion, especially in marine environments. Ensuring secure mounting and connections to prevent disruptions. Replacement of faulty units is straightforward due to the availability of components in local markets. Keeping spare units and parts on hand is advisable to minimize downtime and ensure continuous monitoring.	Shellcatch systems require less frequent manual intervention but still need regular checks: Periodic inspection of sensors and GPS units to ensure proper functioning. Software updates and calibration checks to maintain accuracy. Technical support may be needed for more complex maintenance tasks. Replacement parts may be more specialized and costly, but the overall system is designed to be robust and durable. Subscription services often include maintenance support, software updates, and technical assistance, ensuring the system remains operational and up-to-date.