

Article

Automatic Identification System (AIS)-Based Spatiotemporal Allocation of Catch and Fishing Effort for Purse Seine Fisheries in Korean Waters

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Abstract

This study proposes an Automatic Identification System (AIS)-based spatiotemporal allocation methodology to estimate catch distribution and fishing effort for large purse seine fisheries in Korean waters. AIS trajectory data from July 2019 to June 2022 were analyzed to identify fishing grounds, while carrier vessel port-entry records were used to estimate daily landings. These were allocated to specific fishing segments to derive spatially explicit catch quantities. Compared with periodic surveys or voluntary reports, the AIS-based approach significantly enhanced the accuracy of fishing ground identification and the reliability of catch estimation. The results showed that fishing activity peaked between November and February, with the highest catch densities observed south of Jeju Island and in adjacent East China Sea waters. Catch declined markedly from April to June due to the mackerel closed season. These findings demonstrate the method's potential for evaluating the effectiveness of Total Allowable Catch (TAC) regulations, supporting dynamic and adaptive management frameworks, and strengthening IUU fishing monitoring. Although the current analysis is limited to TAC-regulated species, AIS-equipped vessels, and a three-year dataset, future studies could expand the timeframe, integrate environmental data, and apply this methodology to other fisheries to improve sustainable resource management.

Keywords: Automatic Identification System (AIS); purse seine; fishing ground; catch estimation; Total Allowable Catch (TAC); fisheries management

Key Contribution: This study develops an AIS-based method to spatially allocate landing data to actual fishing segments, improving fishing ground identification and catch estimation for large purse seine fisheries in Korean waters.



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1. Introduction

Over recent decades, global marine ecosystems have been subjected to unprecedented levels of environmental stress, primarily driven by anthropogenic and climate change, escalating marine pollution, and unsustainable fishing practices [1,2]. Rising sea surface temperatures have altered oceanographic conditions, disrupting species' distribution ranges and leading to the displacement of traditional fishing grounds [3]. Overexploitation of fishery resources has resulted in significant declines in biomass for many commercially important species, thereby threatening the ecological integrity and economic viability of

global fisheries [4]. Recognizing the urgency of these challenges, the international community adopted the conservation and sustainable use of oceans, seas, and marine resources as Sustainable Development Goal (SDG 14) in 2015, with the commitment of more than 160 countries to implementing strategies aimed at reversing the decline in marine biodiversity and promoting sustainable fisheries [5]. Since then, individual nations have developed and enforced fisheries management policies and marine ecosystem conservation measures aligned with the objectives of SDG 14.

In South Korea, the legal framework for fisheries management is underpinned by Article 104 of the Fisheries Act, which mandates the Minister of Oceans and Fisheries to establish and maintain a comprehensive national fisheries database [6]. This database consolidates data on fishing operations, catch performance, and the spatial distribution of marine resources by fishery type and sea area, forming a critical foundation for resource assessment and policy development. The availability of such high-resolution datasets has facilitated numerous empirical studies, including analyses of spatiotemporal shifts in fishing groups [7–9] and assessments of fishing environments in response to environmental variability [10,11]. Marine resource assessment in South Korea currently relies on two principles approaches. The first involves direct onboard surveys conducted by government research vessels, providing standardized sampling of biological and environmental parameters. The second integrates fishing activity reports submitted by fishermen with catch data reported to local fisheries cooperatives [12]. Legally registered fishing vessels are obligated to report fishing dates, catch quantities, and operational locations either in written form or via the electronic reporting system operated by the National Center for Safe Fishing Operations. However, the comprehensiveness of these data is constrained by logistical limitations, including an insufficient number of survey vessels and personnel to achieve nationwide coverage. The accuracy of self-reported data is undermined by potential under-reporting or delayed submissions of catch volume, fishing effort, and operational locations, as fishermen may intentionally restrict the disclosure of precise fishing ground information to protect their proprietary knowledge [13]. Fish landing records compiled by National Federation of Fisheries Cooperatives (Suhyup) are widely used for estimating total catch volumes. Nonetheless, unreported or privately transacted landings, often referred to as non-cooperative landings, pose a persistent challenge to the accuracy of official statistics. The magnitude of this issue varies by species. For example, in the case of chub mackerel (*Scomber japonicus*), 1.1% of landings bypass cooperative reporting channels, with 98.9% processed through official cooperatives [14]. Purse seine vessels, which primarily harvest mackerel, report nearly 100% of their landings via cooperatives, rendering their catch data exceptionally reliable for scientific analyses and fisheries management purposes. Globally, studies that utilize fisheries resources data also rely on diverse sources such as catch surveys and sampling surveys to assess fishing performance, standardize CPUE, and evaluate fishery sustainability [15–18].

To regulate fishing pressure and promote sustainable exploitation of fishery resources, South Korea operates a Total Allowable Catch (TAC) system that allocates annual species-specific quotas to individual fishing vessels. Chub mackerel and horse mackerel (*Trachurus japonicus*), the primary target species of purse seine fisheries, are both managed under this TAC framework [13]. Although both chub mackerel and horse mackerel are subject to the TAC system, this study focused solely on chub mackerel, which accounts for more than 98% of purse-seine landings, whereas horse mackerel catches are minimal and irregular. Identifying the precise fishing grounds from which these species are harvested is a critical prerequisite for accurate resource assessment, spatiotemporal stock modeling, and ecosystem-based fisheries management. For vessel tracking, South Korea employs two systems: the V-Pass Vessel Monitoring System (VMS), which is mandatory for most

fishing vessels but not publicly accessible due to security constraints, and the Automatic Identification System (AIS), which is required for vessels exceeding 10 gross tons. AIS data, being publicly accessible and covering all purse seine vessels, provide an invaluable resource for monitoring fishing operations at a high spatial and temporal resolution, as the system automatically broadcasts each vessel's position, speed, and course in real time [19]. Against this backdrop, the present study leverages AIS-derived vessel trajectory data to analyze the operational characteristics of purse seine vessels, with a focus on the classification of net deployment and retrieval events. Landing site coordinates are used to identify the entry and exit points of carrier vessels, which are then temporally matched to TAC landing dates. This enables the spatial allocation of catch to the actual fishing grounds from which it originated. Accordingly, this study aims to develop a quantitative methodology that integrates Automatic Identification System (AIS) trajectory data with official landing records to estimate the spatiotemporal distribution of catches by coastal purse seine fisheries in Korean waters. The specific objectives are (1) to identify fishing and non-fishing activities using AIS trajectories, (2) to allocate cooperative landing data to the corresponding fishing segments, and (3) to examine seasonal and interannual variability in catch distribution to support fisheries management applications. By integrating these datasets, the study provides a robust methodological framework for estimating localized catch distributions, thereby enhancing the precision of resource assessments.

Purse seine fisheries in Korea typically operate as coordinated fleets consisting of one main vessel, two light vessels, and three carrier vessels, which enables continuous fishing–transport cycles. This cooperative structure, while highly efficient, creates challenges for directly linking landed catch to its fishing grounds—necessitating integrated analysis of AIS trajectories and landing records.

The remainder of this paper is structured as follows: Section 2 provides a detailed description of the fishing characteristics of purse seine vessels and introduces a classification scheme for identifying fishing grounds based on operational behavior. Section 3 outlines the methodology for estimating the spatiotemporal distribution of catch. Specifically, Section 3.1 details the extraction of AIS-based vessel trajectory data, while Section 3.2 describes the classification of fishing and non-fishing activity segments. Section 3.3 presents the procedures for identifying carrier vessel positions and determining landing dates, and Section 3.4 outlines the spatial allocation of estimated landings to identified fishing grounds. Section 4 reports the results of the catch distribution analysis, and Section 5 concludes with key findings, management implications, and recommendations for future research.

2. Fishing Characteristics of Purse Seine Vessels

Purse seine fishing is one of the most important commercial fisheries in Korea, contributing nearly 18% of national coastal and offshore production [8,14]. The operational sequence of a purse seine fleet can be divided into three phases: fish school detection and aggregation, net setting, and hauling (Figure 1). Each purse seine fleet consists of one main vessel, two light vessels, and three carrier vessels. This functional division of roles allows for continuous fishing transport cycles, as the main vessel focuses on encircling and hauling fish, light vessels aggregate fish using illumination, and carrier vessels alternately transport catches to port. During setting, the main vessel encircles the school at 8–10 knots, assisted by light and carrier vessels. The coordinated operation enables continuous fishing cycles but complicates the direct attribution of landed catch to specific fishing grounds.

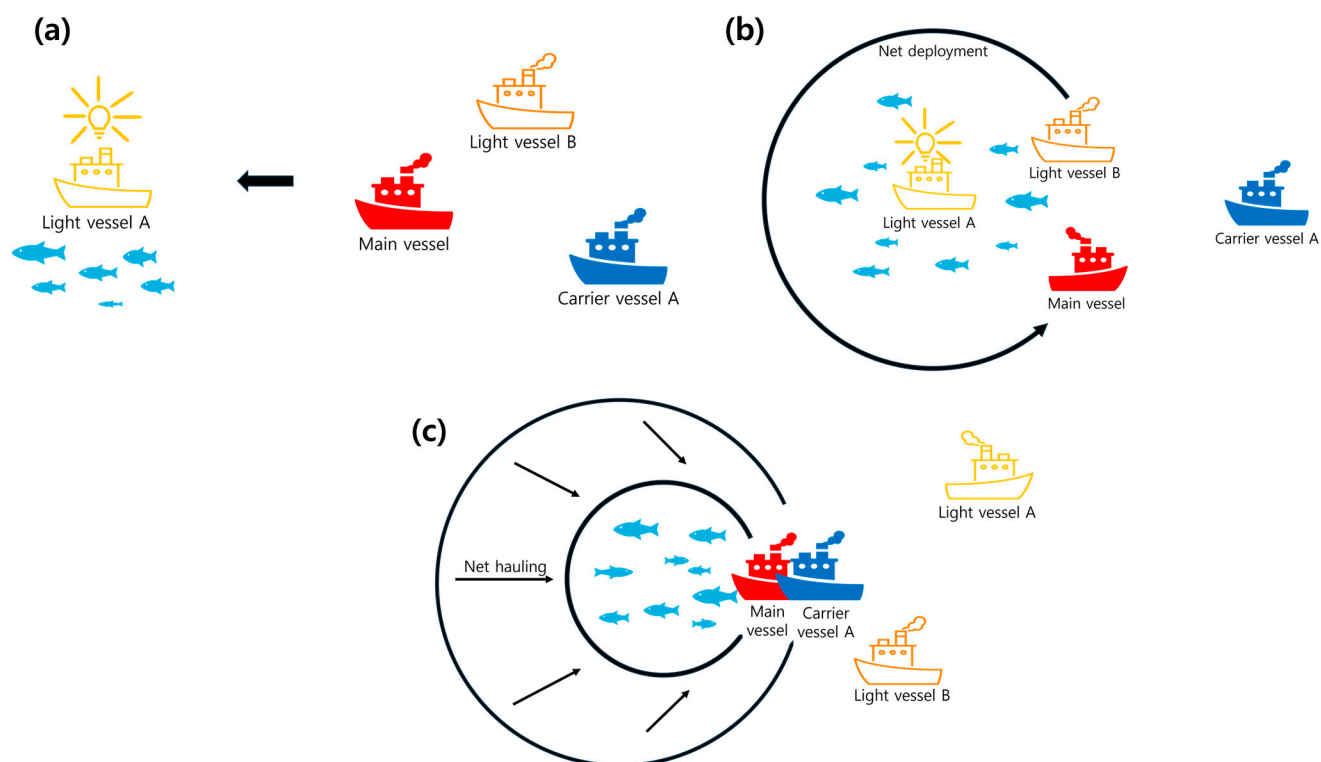


Figure 1. Purse seine vessel group operation process. (a) Fish school detection and aggregation: light vessel A attracts fish using lights while the main vessel, light vessel B, and carrier vessel A approach the school; (b) net setting: the main vessel deploys the net in a circular pattern to encircle the fish, while light vessel B holds the net and carrier vessel A remains nearby; (c) hauling: the main vessel tightens the net and hauls the catch, assisted by carrier vessel A, while light vessels A and B monitor or move to search for the next fishing ground.

In the first phase (Figure 1a), the fleet is engaged in detecting and aggregating fish schools. Fish location is achieved through the combined use of advanced acoustic instruments such as sonar and radar, operated primarily from the main vessel and occasionally from the light vessels [20]. The light vessels are crucial in this phase, as one of them (Light Vessel A) typically deploys powerful illumination to aggregate pelagic fish into dense schools by exploiting their phototactic behavior. Once a school is aggregated, the main purse seiner, accompanied by the second light vessel (Light Vessel B) and one of the carrier vessels (Carrier Vessel A), approaches the illuminated area. Meanwhile, the other two carrier vessels are engaged in logistical operations, either transporting previously caught fish to port, unloading at a landing site, or returning from port to rejoin the main vessel for the next fishing cycle. The second phase (Figure 1b) begins once the main vessel identifies a suitable fish aggregation and initiates net deployment. The purse seine net, which can exceed several hundred meters in length, is rapidly set in a circular path around the school, with deployment speeds typically ranging between 8 and 10 knots. The setting process is rapid, generally lasting only 5–10 min [8]. During this maneuver, Light Vessel B secures one end of the net to ensure proper enclosure, while Carrier Vessel A positions itself nearby in anticipation of the hauling process.

Following net deployment, the operation enters the hauling phase (Figure 1c). The lower portion of the net is tightened, or “pursed”, to prevent the escape of encircled fish. At this stage, Light Vessel A, which has previously aggregated the school, either reduces its activity or relocates to search for subsequent fishing opportunities. Meanwhile, the main vessel initiates the hauling process, gradually concentrating the fish into a smaller enclosure. Carrier Vessel A then actively participates by transferring the catch directly from

the seine into its hold. Once hauling is completed, the main vessel resumes its search for a new fishing ground, while Carrier Vessel A either continues with the fleet for another operation or departs for port if its storage capacity is reached. To maintain operational continuity, Carrier Vessel B will depart from port to replace Carrier Vessel A and rejoin the fishing group [8]. This sequential rotation of carrier vessels ensures that fishing operations can continue uninterrupted, even as landings are being transported to shore. However, this continuous fishing–transport cycle complicates the direct attribution of landed catch to its original fishing grounds, as fishing and transport occur simultaneously, creating a temporal and spatial lag between capture and landing that renders simple logbook-based associations unreliable. This structural characteristic of the purse seine fleet underscores the methodological challenge of linking cooperative landing statistics with spatially explicit fishing grounds, as fishing and transport are decoupled in time and space due to the continuous rotation of carrier vessels.

To address this challenge, the present study adopts a data-integration approach by combining Automatic Identification System (AIS) trajectories with cooperative landing records, where AIS provides detailed vessel positions and timing of operations, and landing data supply verified catch quantities and dates, enabling the spatial linkage of landings to their corresponding fishing grounds. The AIS data provide high-resolution positional information that enables the identification of spatial and temporal associations among vessels within each purse-seine fleet [19]. By reconstructing fleet dynamics and identifying which carrier vessel conducted a particular landing event, it becomes possible to match TAC-reported landed weights with the fishing activities of the corresponding purse seiner. In practice, this entails detecting the operational zones of the main vessel, classifying fishing activity segments, and linking those with carrier vessel arrivals and departures at port. Through this reconstruction, the study estimates the catch amount attributable to specific fishing grounds, thereby enhancing the spatial precision of catch allocation under Korea's TAC system.

3. Spatiotemporal Estimation of Catch

In this study, the daily fish landing data of purse seine vessels were systematically allocated to the corresponding fishing segments where active operations were conducted, thereby enabling the estimation of the spatiotemporal distribution of catch. This analytical workflow, illustrated in Figure 2, was designed to integrate vessel activity records with fishery-dependent data, thereby producing a high-resolution representation of the spatial and temporal dynamics of purse seine fisheries. Such integration is critical for evaluating fishing effort, quantifying catch per unit effort (CPUE), and supporting ecosystem-based fisheries management [19,21].

The first stage of the workflow involved linking Automatic Identification System (AIS) data with the national vessel registry to isolate the trajectories of purse seine vessels. AIS trajectories were reconstructed by processing sequential latitude and longitude coordinates of identified vessels, producing continuous movement tracks for analysis. To discriminate fishing activity from non-fishing operations, behavioral indicators characteristic of purse seine deployment were applied to the trajectory data. Specifically, fishing events were inferred from distinctive operational signatures such as short-duration, high-speed circular movements associated with net setting and retrieval [22,23]. This classification step ensured that only the segments corresponding to effective fishing effort were retained for catch allocation.

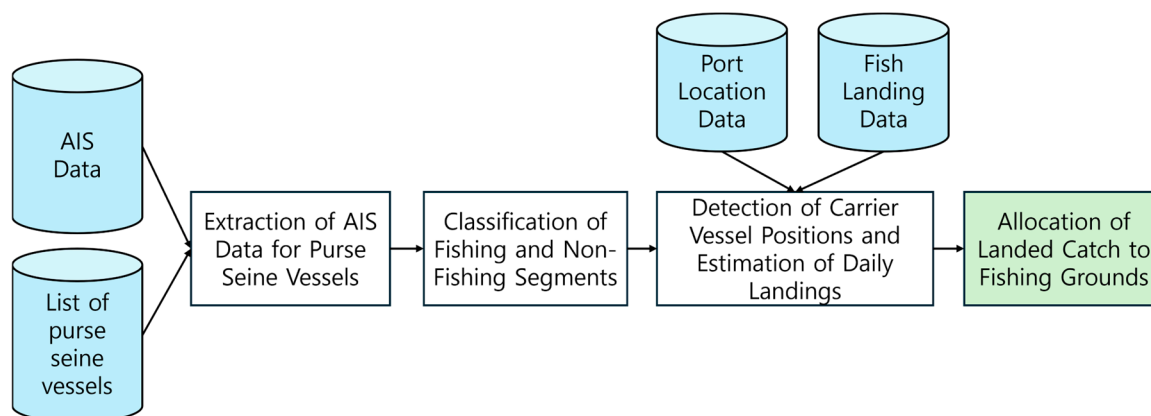


Figure 2. Workflow for estimating spatiotemporal catch distribution using AIS data and landing records: AIS data and the vessel registry were used to extract purse seine vessel trajectories. Fishing segments were identified based on movement patterns, and landing events were determined using port location data. Landed weight was then allocated to the corresponding fishing segments.

An essential component of purse seine operations involves the use of carrier vessels, which transport catches to designated landing sites. AIS data from carrier vessels were therefore analyzed to detect landing events. A landing was operationally defined as an event where a carrier vessel entered the spatial boundary of a port or designated landing site and remained within that boundary for a minimum threshold duration. When such conditions were met, the vessel was considered to have discharged catch at that site on the corresponding date. The associated fish landing weights recorded in the fishery dataset were subsequently matched to the most recent fishing operation, defined as the contiguous set of main vessel hauling segments that loaded the carrier immediately prior to its return leg to port (identified by a final rendezvous within ~1 nm with carrier speed < 3 knots for ≥ 10 min, followed by a sustained >5 knots transit toward port for ≥ 30 min), rather than to an entire calendar day of fishing. This methodological linkage allowed landed catches to be retroactively assigned to specific fishing grounds, thereby permitting the spatiotemporal allocation of catch data across the fishing grounds [24].

3.1. Extraction of AIS Trajectories of Purse Seine Vessels

3.1.1. AIS Data Collection

The use of AIS in fisheries research is underpinned by international regulations. The International Maritime Organization (IMO), under the Safety of Life at Sea (SOLAS) Convention, mandates AIS installation for all commercial vessels over 300 gross tons engaged in international voyages, vessels over 500 gross tons not engaged in international voyages, and all passenger vessels regardless of size. Furthermore, the IMO recommends AIS installation for fishing vessels exceeding 300 gross tons or measuring longer than 15 m [25]. In South Korea, these requirements are more stringent, with AIS installation being compulsory for all fishing vessels exceeding 10 tons operating in coastal waters, as required by the Ministry of Oceans and Fisheries under the Ship Safety Act (Article 30) and the Ship Equipment Standards (Article 108-5). This regulatory framework ensures comprehensive AIS coverage across the Korean purse seine fleet, thereby enhancing the reliability of spatiotemporal analyses in this study.

To capture AIS transmissions from purse seine vessels, receivers were strategically installed at Jeju National University, the Jeju Fisheries Research Institute in Pyoseon-myeon (Seogwipo City), and Busan Port. The geographic distribution of these stations, depicted in Figure 3, ensured robust signal coverage of key fishing grounds and transit corridors. AIS transmissions typically include vessel identifiers such as name, Maritime Mobile

Service Identity (MMSI), and call sign, as well as navigational attributes including position, speed, and course over ground [26]. The physical installations of these AIS receivers at Baengnokdam and Witse Oreum on Mt. Hallasan are shown in Figure 4, highlighting the infrastructure supporting the acquisition of high-resolution vessel tracking data.

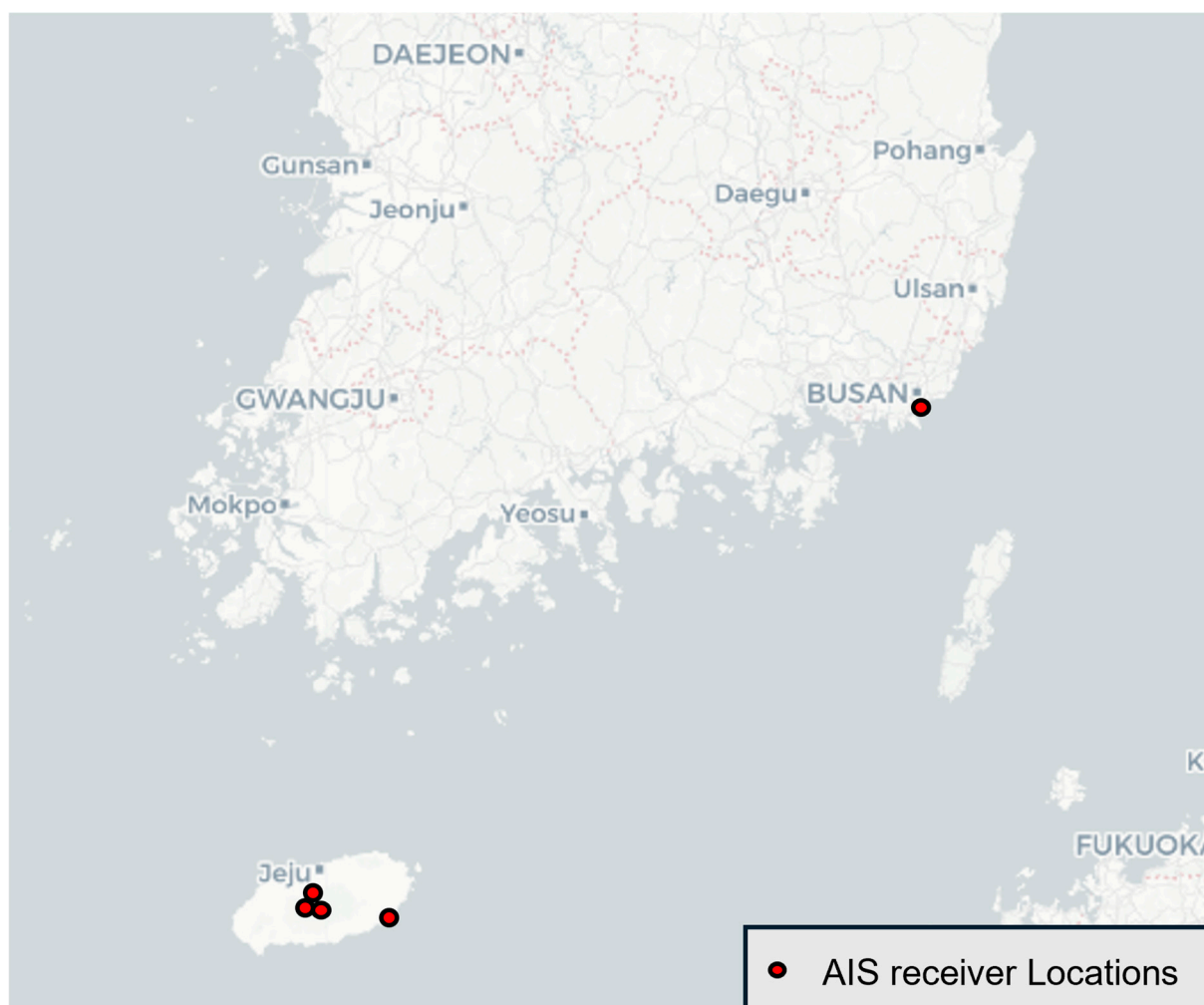


Figure 3. Locations of installed AIS receivers (red circles) at Jeju National University, Baengnokdam and Witse Oreum on Mt. Hallasan, Busan Port, and Jeju Fisheries Research Institute. Red markers indicate AIS receiving stations operated by the Ministry of Oceans and Fisheries, as used for data collection in this study.

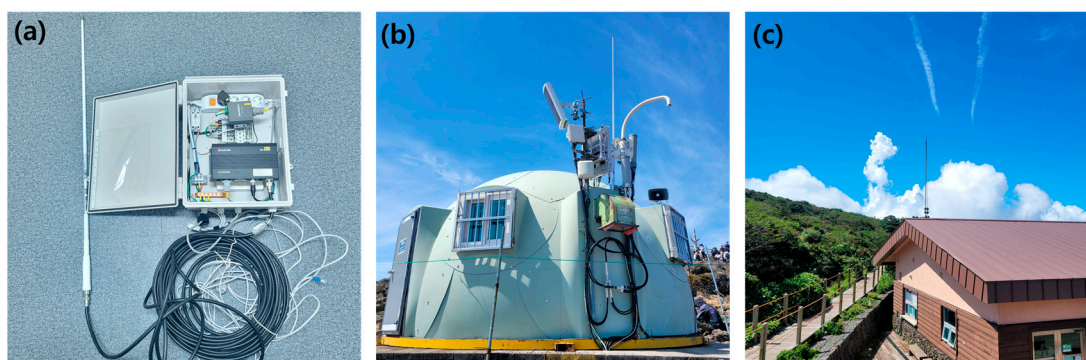


Figure 4. AIS receivers used in this study: (a) AIS receiver unit; (b) AIS receiver installed at Baengnokdam, Mt. Hallasan; (c) AIS receiver installed at Witse Oreum, Mt. Hallasan.

3.1.2. Vessel Identification and AIS Matching

Given that purse seine fisheries operate cooperatively in fleets, it was necessary to identify the membership and roles of vessels within each fleet. A comprehensive list of purse seine vessels was obtained directly from the Korea Purse Seine Fishery Association, which included vessel names, call signs, registration numbers, and operational roles, comprising a total of 110 vessels organized into 18 fleet groups (including both fishing and carrier vessels) before filtering and verification. Since MMSI numbers serve as globally unique identifiers for vessels, the vessel list was cross-referenced against AIS data to extract fleet-specific trajectories. This process required manual verification to resolve inconsistencies in vessel identifiers, ultimately yielding a curated dataset containing vessel name, MMSI number, gross tonnage, call sign, registration number, fleet membership, and assigned operational role. The operational roles (e.g., main vessel or carrier vessel) were obtained from the Korea Purse Seine Fishery Association and subsequently validated using AIS trajectory patterns including port-entry frequency, movement range, and average speed (Table 1).

Table 1. List of Purse Seine Vessels (all vessels belong to the same fleet).

Role	Vessel Name	MMSI	Call Sign	Registration No.
Main vessel	No.105 K*****	440***290	360**	1806002-*****
Light vessel	No.107 K*****	440***140	340**	9412007-*****
Light vessel	No.111 K*****	440***650	342**	9508121-*****
Carrier vessel	No.118 K*****	440***320	318**	0605004-*****
Carrier vessel	No.128 K*****	440***510	338**	1506001-*****
Carrier vessel	No.203 K*****	440***240	359**	1706002-*****

Note: The asterisks (*) indicate intentionally masked digits for confidentiality.

A large volume of AIS position records collected between July 2019 and June 2022 was analyzed in this study. The dataset comprised 110 purse seine vessels organized into 18 fleets registered under the Korea Purse Seine Fishery Association. Subsequently, AIS records were filtered to retain only those corresponding to the MMSI numbers listed in Table 1. Out of the 18 fleets, 10 fleets were included in the present analysis due to limitations in AIS data availability. After data cleaning and filtering, representative fishing trajectories were derived for each vessel, providing a comprehensive depiction of the spatial and temporal extent of purse seine fishing operations in Korean coastal waters.

Subsequently, AIS records were filtered to retain only those corresponding to the MMSI numbers listed in Table 1. Out of the 18 purse seine fleets officially registered with the association, only 10 fleets were included in the present analysis due to limitations in AIS data availability.

3.2. Classification of Fishing and Non-Fishing Activities

For each vessel, AIS records were sorted chronologically by timestamp to allow sequential analysis of positional and speed dynamics. These ordered records were visualized using the Folium library in Python (Python 3.11.4), whereby georeferenced points were connected into polylines to depict vessel trajectories, based on AIS position reports recorded at an average interval of approximately 1 min, providing high temporal resolution for trajectory reconstruction, as illustrated in Figure 5. The resulting spatiotemporal reconstructions provided the basis for linking landing data with fishing activity, thereby producing an empirical estimate of the spatial distribution of purse seine catches across the study domain.

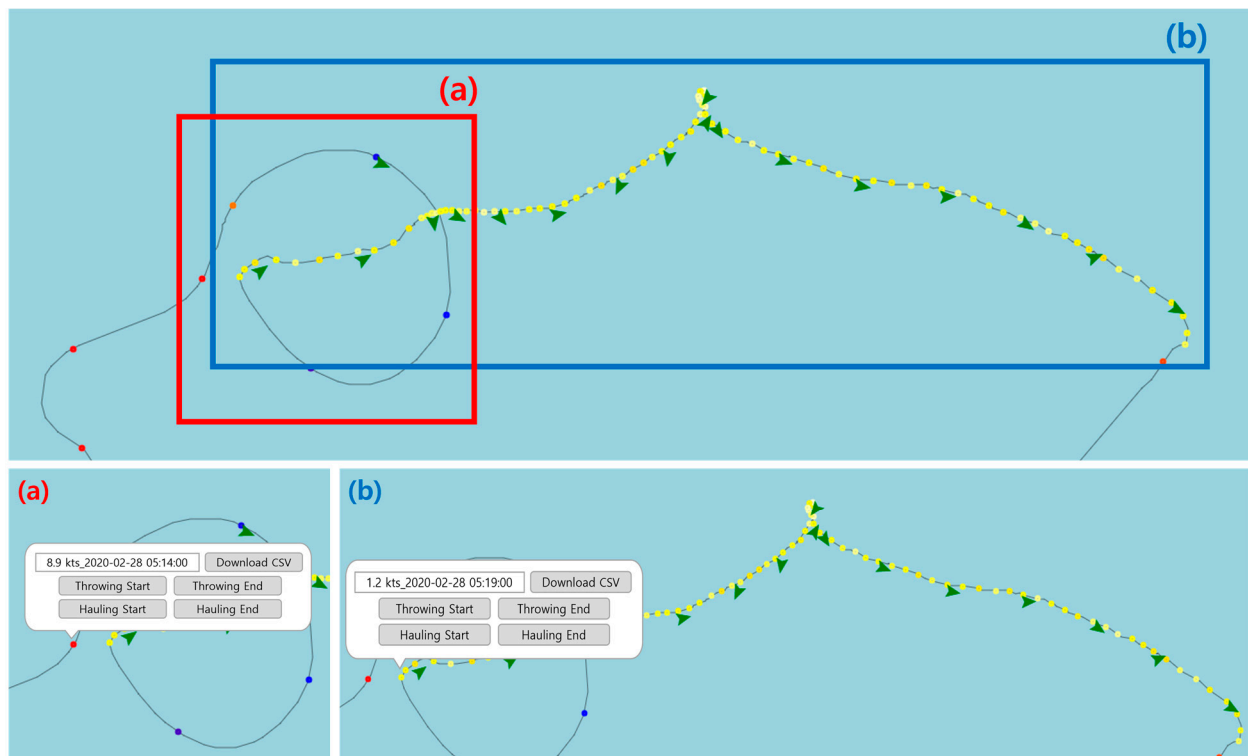


Figure 5. (a) Trajectory of the main purse seine vessel during the purse deployment phase. The vessel accelerates to 8–10 knots and draws a circular pattern during net deployment. Deployment is considered to start at the onset of circular motion and end when the vessel slows down; (b) trajectory during the hauling phase. After deployment, the vessel decelerates to under 3 knots to begin hauling and resumes speed when hauling is complete. The bottom of each panel shows the interface used to manually classify fishing states using selected trajectory points, speed, and AIS timestamps. Colored dots represent the vessel speed during operation, with color transitions indicating changes in velocity along the trajectory.

The trajectory analysis of purse seine vessels provides critical insights into the operational dynamics of fishing activities, particularly during the distinct phases of net deployment and hauling. As illustrated in Figure 5a, the trajectory of a representative main purse seine vessel during the purse deployment phase exhibited a characteristic circular motion. Upon arrival at the fishing ground, the vessel accelerated to a speed ranging between 8 and 10 knots, consistent with documented purse seine operational practices [8]. This rapid maneuvering was undertaken to encircle the targeted fish aggregation effectively, thereby ensuring maximal catch efficiency. The initiation of the deployment phase was operationally defined as the point at which the vessel first exhibited circular movement, whereas the termination of this phase was delineated by the cessation of such motion and the subsequent reduction in vessel speed. These behavioral markers were critical in distinguishing active net setting from pre-deployment search and post-deployment activities.

In contrast, the trajectory in Figure 5b corresponds to the hauling phase, identified when the 3 min rolling-mean speed was <3 knots for ≥ 10 min and concluding when the rolling mean speed rose above 5 knots for ≥ 5 min; we did not apply an explicit acceleration/deceleration threshold, relying instead on a duration-based filter to avoid transient slowdowns. This phase, which is inherently labor-intensive and time-consuming, was defined as beginning at the point of deceleration and concluding when the vessel resumed higher speeds to depart for the next fishing ground. Such reduced-speed patterns are consistent with observations from prior analyses of purse seine fleet behavior, where hauling has been reliably associated with low vessel velocity and stationary or semi-

stationary movement patterns [27]. These trajectory- and speed-based patterns formed the basis for our systematic classification of fishing activity in the AIS dataset (July 2019–June 2022). All trajectory segments used in the analysis were manually annotated independently, with disagreements resolved by consensus. We supervised the protocol and reviewed the methodology and threshold choices. Validation involved direct consultations with three experienced purse-seine operators, who reviewed representative speed–time and track excerpts and confirmed the operational realism of the speed/duration thresholds used for phase detection, thereby integrating expert knowledge into the framework and reducing misclassification risk compared with automated approaches alone [22].

As of 2023, the Korea Coastal Purse Seine Cooperative registered 18 active fleets, comprising a total of 110 vessels: 18 main vessels, 36 auxiliary vessels (light boats), and 56 carrier or transport vessels. This complex and coordinated fleet structure reflects the scale and industrial organization of the fishery, with multiple vessels contributing to distinct yet interdependent operational roles. However, due to the partial availability of high-resolution AIS trajectory data, the present study analyzed fishing activity from only 10 fleets. Despite this limitation, the selected sample encompassed sufficient operational variability to support robust inference on fishing behavior.

To facilitate precise identification of fishing phases, an interactive user interface was developed to assist in classifying fishing sections. The interface, presented in Figure 5, enabled us to select trajectory points suspected to correspond with the initiation or termination of specific fishing activities. For each selected point, the system displayed relevant timestamps, speed values, and geographic coordinates. Analysts could then annotate these points with operational states such as “Throwing Start,” “Throwing End,” “Hauling Start,” or “Hauling End.” These annotated data were systematically recorded, and the compiled dataset—encompassing time, vessel speed, and spatial coordinates—formed the foundation of the fishing activity dataset, as summarized in Table 2. This integrative framework ensured both transparency and reproducibility in the classification process, thereby enhancing the scientific rigor of subsequent analyses on fishing effort and catch standardization.

Table 2. Results of Fishing Operation Section Classification.

MMSI	Throwing_Start	Throwing_End	Hauling_Start	Hauling_End
440*****	2019-12-28 1:54	2019-12-28 1:57	2019-12-28 1:59	2019-12-28 3:24
440*****	2019-12-28 3:34	2019-12-28 3:38	2019-12-28 3:39	2019-12-28 4:53
440*****	2019-12-28 5:46	2019-12-28 5:50	2019-12-28 5:51	2019-12-28 7:12
440*****	2019-12-28 7:21	2019-12-28 7:25	2019-12-28 7:26	2019-12-28 8:42

The asterisks (*) indicate intentionally masked digits for confidentiality.

3.3. Detection of Carrier Vessel Positions and Estimation of Daily Landed Catch

3.3.1. Method for Identifying Carrier Vessel Positions

The methodological framework for identifying carrier vessel locations and extracting daily landing information is depicted in Figure 6. To achieve this, AIS trajectories of carrier vessels associated with the purse seine fleet were systematically extracted from the fleet-level dataset and analyzed to determine their positional dynamics. Each trajectory was intersected with predefined geospatial boundaries representing recognized landing ports. A vessel was classified as having arrived at port when its trajectory crossed into the boundary, while its departure was identified when the trajectory exited this spatial domain. This spatiotemporal classification is consistent with established approaches in fisheries science that utilize AIS data to infer vessel activities [22,28].

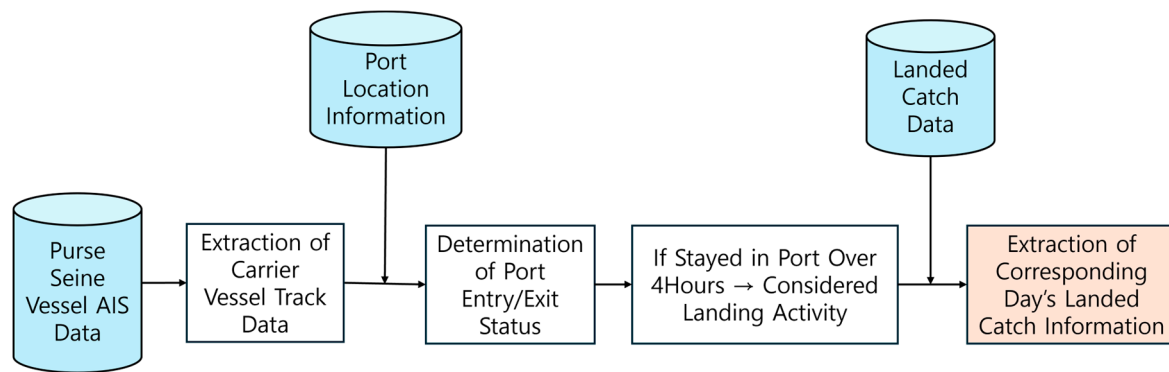


Figure 6. Carrier vessel location identification and estimation of daily landed catch.

It is important to note that port calls by carrier vessels do not always equate to landing events. Vessels may enter ports for multiple reasons including transit, crew exchanges, or logistical resupply, and such calls may not involve unloading of catch. To distinguish genuine landings, we integrated dockside field observations and fleet operator knowledge into the analysis. Specifically, three experienced purse seine operators (captain/boatswain roles) were consulted, and their feedback together with the authors' field observations at major purse seine ports confirmed the operational characteristics used to designate definitive landing events. This operational threshold provided a reliable filter for excluding non-landing port visits, a methodological refinement similar to that applied in recent AIS-based fisheries studies [19,29]. Linkage between vessel movement data and official landing records was established by aligning the port entry dates with documented landing dates. The geographic boundaries of the major landing ports used for identifying port entry and exit of carrier vessels are summarized in Table 3. Through this comparative matching, daily landed catch was extracted and assigned to corresponding fishing operations, thereby ensuring consistency between observed trajectories and verified catch data. This integrative approach significantly enhanced the reliability of effort–catch associations, which are often subject to uncertainty when based solely on logbook or landing data [30,31].

Table 3. Location Information on Landing Ports. This table shows the geographic boundaries (latitude and longitude ranges) for major landing ports such as Jeju-si, Chuja-do, Hallim, and Busan-si, used to determine port entry and exit of carrier vessels based on AIS data.

Port_Name	Lat_Start	Lat_End	Lon_Start	Lon_End
jeju-si	33.51	33.54	126.52	126.57
chuja-do	33.92	33.98	126.24	126.38
hanlim	33.41	33.43	126.25	126.27
busan-si	35.04	35.11	128.98	129.12
busan-si	35.11	35.18	129.11	129.13

Figure 7 illustrates the spatial distribution of carrier vessels during hauling operations in coastal purse seine fisheries. Within each fleet, three carrier vessels typically operate in a rotational system: one vessel hauls catches alongside the main purse seine vessel, another proceeds to port for landing once its hold reaches capacity, and the third returns from port to resume hauling after unloading operations. This rotational structure minimizes downtime and maximizes fishing efficiency, reflecting an optimized logistical strategy within the purse seine industry [32]. A carrier vessel approaching the main vessel generally undertakes between three to five hauling operations before its storage hold reaches full capacity, after which it proceeds to port for landing. This cyclical operational dynamic is

visualized in Figure 8, which displays the AIS trajectories of multiple carrier vessels functioning in sequence. For instance, the light-blue trajectory represents a vessel conducting four hauling operations (labeled 1 through 4) before navigating toward port to discharge its load. Meanwhile, the blue vessel, which had been waiting in proximity, assumes responsibility for the subsequent hauling operations. This pattern ensures a continuous flow of fishing and landing activities, sustaining fleet efficiency and preventing interruptions in fishing operations.

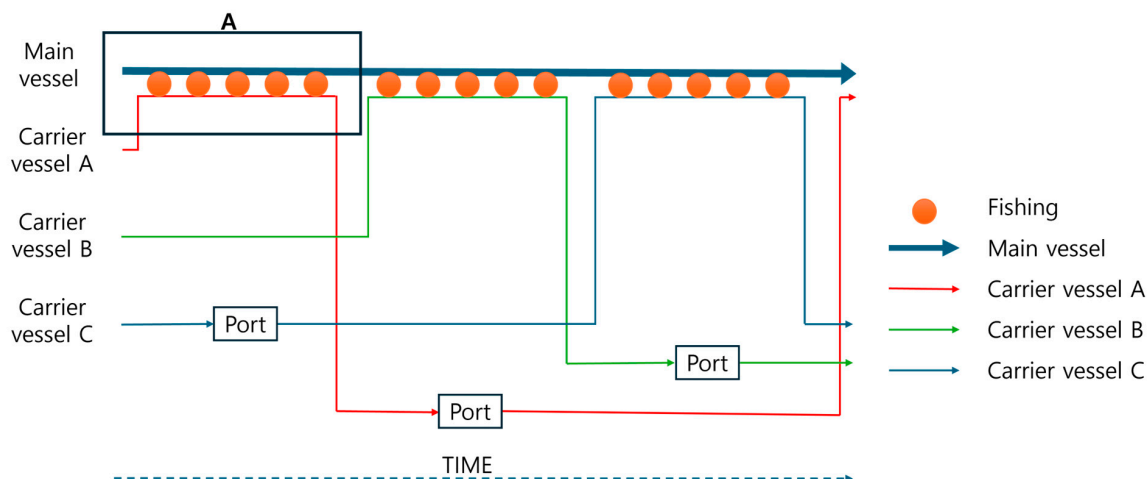


Figure 7. Carrier vessel positions during fishing operations.

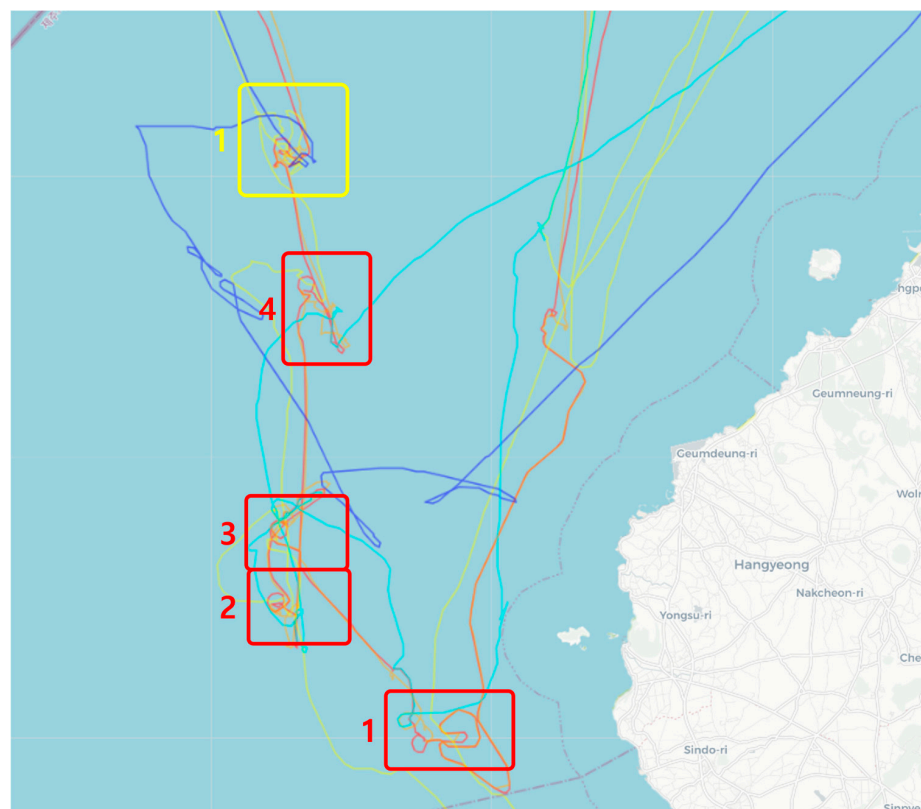


Figure 8. Actual AIS trajectories of carrier vessels showing alternating hauling operations. The light blue vessel conducted four hauls (boxes 1–4) before returning to port, followed by the blue vessel which continued the operation. The yellow box marks the first hauling position shared by the second carrier vessel and the main vessel, showing their sequential operation in that area. Colored lines denote vessel types: red—main vessel; orange and yellow—light vessels; light-blue and blue—carrier vessels.

3.3.2. Catch Data from Landing Ports

Among the mackerel landed by large purse seine fisheries, approximately 98.9% are marketed through the National Federation of Fisheries Cooperatives (Suhyup) auction system, where comprehensive landing records are maintained [33]. This institutionalized marketing channel ensures a high level of accuracy and reliability in reported landings, providing a robust foundation for quantitative assessments of catch and fishing effort. For the present study, mackerel landing records were utilized as a primary data source to derive unbiased and standardized estimates of catch quantities, thereby minimizing potential uncertainties associated with underreporting or incomplete records in non-cooperative channels.

To estimate the landed catch of coastal large purse seine vessels, detailed daily landing records by auction market were obtained from the Korea Fisheries Resources Agency (FIRA), based on total allowable catch (TAC)-target species reporting requirements. These datasets include key attributes such as landing date, vessel identification, fishery type, auction market, landed weight, and corresponding fishing grounds [33]. A summary of the TAC landing dataset used in this study is presented in Table 4. Unlike auction-based landings, which typically occur in the early morning hours to align with wholesale market operations, carrier vessels associated with purse seine fleets enter ports immediately after their storage capacity is reached. This operational difference necessitated the integration of AIS trajectory data with official landing records in order to validate the correspondence between port entry and actual auction landing dates.

Table 4. Landing Data of Mackerel from Purse Seine Fisheries.

Month	Day	Species	Fishing Type	Registration No.	Catch (kg)	Grid Code
7	23	Mackerel	Purse seine	0907001-*****	108	113
7	24	Mackerel	Purse seine	0402002-*****	17,424	-
7	24	Mackerel	Purse seine	0107003-*****	3942	232
7	24	Mackerel	Purse seine	1807001-*****	23,148	113
7	25	Mackerel	Purse seine	0402002-*****	15,642	110

Note: The asterisk (*) indicate masked digits in vessel registration numbers to protect vessel privacy.

The comparative analysis revealed that, in the majority of cases, the official landing (auction) date occurred on the day following the vessel's port entry. This discrepancy can be attributed to the temporal gap between physical offloading and formalized auction reporting. To resolve this misalignment, the landed catch recorded on the day after port entry was consistently used as the benchmark for estimating the total catch accumulated through purse seine operations prior to the carrier vessel's arrival at port. This methodological refinement ensured temporal accuracy in linking fishing activity with corresponding landings [34,35].

3.4. Spatiotemporal Estimation of Catch Amount

The spatial distribution of purse seine fishing activities was analyzed using gridded spatial aggregation of AIS-derived fishing segments. The study area extended from 124° E to 132° E and 30° N to 36° N, covering Korean coastal and offshore waters surrounding Jeju Island and the southern part of the East Sea. The analyzed region was divided into 0.25° × 0.25° grid cells, within which the number of fishing events and the corresponding allocated catch amounts were aggregated. While the methodology section already described the use of 0.25° × 0.25° grid cells, we have now explicitly added a clarification that each grid cell was assigned a unique grid code for spatial aggregation and tabular

reference. Spatial maps were generated using Python (v3.11) using Matplotlib (v3.7.1), and all coordinates were referenced to the WGS-84 geographic coordinate system. This grid-based approach enabled a consistent comparison of both seasonal and interannual variations in catch distribution.

Building on these standardized landing estimates, Figure 9 illustrates the conceptual framework employed to allocate daily landed catch (derived in Section 3.3) to individual fishing segments executed by coastal purse seine vessels. In Section 3.2, AIS data of main vessels within the purse seine fleets were manually examined to identify the temporal boundaries of net setting and hauling activities, consistent with the operational dynamics of purse seine fishing. These fishing events were categorized according to the classification scheme presented in Table 2.

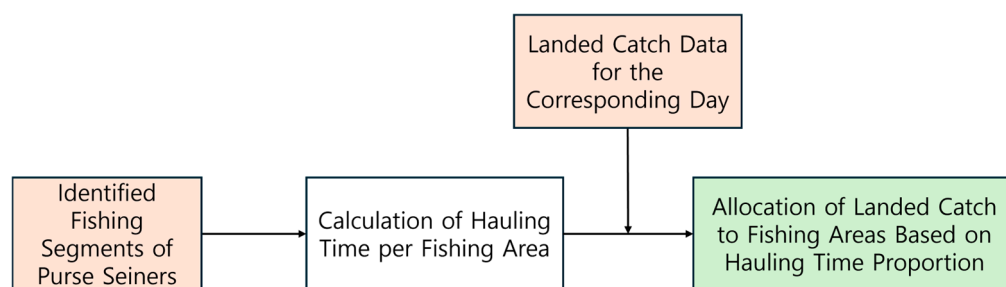


Figure 9. Spatiotemporal estimation of catch amount.

The allocation of catch to individual fishing operations was guided by the assumption that hauling duration serves as a proxy for catch magnitude, given that longer hauling times are generally associated with larger fish schools and greater net loads [36]. Thus, for each identified fishing segment, the hauling duration was calculated using the start and end times derived from AIS trajectories. The total landed catch estimated in Section 3.3 was then proportionally distributed across fishing segments based on each segment's relative contribution to the cumulative hauling time.

This spatiotemporal allocation process allowed for the estimation of catch at the scale of individual fishing grounds. As shown in Figure 10, the methodology apportioned daily landing weights to fishing locations in proportion to net hauling duration, thereby linking aggregate landings with fine-scale fishing effort. Figure 11 further demonstrates the application of this approach to actual fishing trajectories, highlighting the spatial heterogeneity of catch distribution. The mathematical formulation of the allocation procedure is expressed in Equation (1), where Catch Amount denotes the landed catch allocated to the segment; Landing Weight is the total landed catch for the corresponding landing event; and hauling time ratio is the duration of the given hauling segment divided by the cumulative hauling time across all segments associated with that landing.

$$\text{Catch Amount} = \frac{\text{Landing Weight}}{\text{Hauling Time Ratio}} \quad (1)$$

where the landing weight refers to the total landed catch assigned to the carrier vessel, and the hauling time ratio denotes the relative contribution of each fishing segment's hauling duration to the total. In this framework, the hauling time ratio represents the proportion of each identified hauling segment's duration relative to the total hauling time accumulated by the fleet before a corresponding landing event. This ratio was used as a weighting factor under the assumption that longer hauling durations generally indicate larger catches, as confirmed through consultations with experienced purse-seine operators and consistency with prior studies [36]. Thus, for a given carrier vessel's landing, the total landed weight was distributed across all preceding hauling events in proportion to each segment's hauling

time. This equation provided a standardized framework for estimating catch per fishing ground, enabling integration of landings with effort metrics and advancing the accuracy of spatiotemporal CPUE estimations.

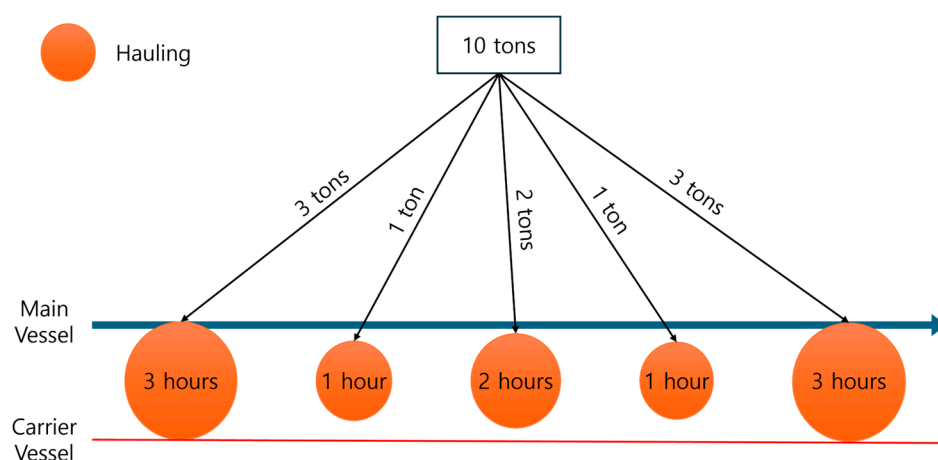


Figure 10. Example of catch allocation based on hauling duration. The total catch reported at the landing site is proportionally distributed to each fishing section according to the duration of hauling operations.

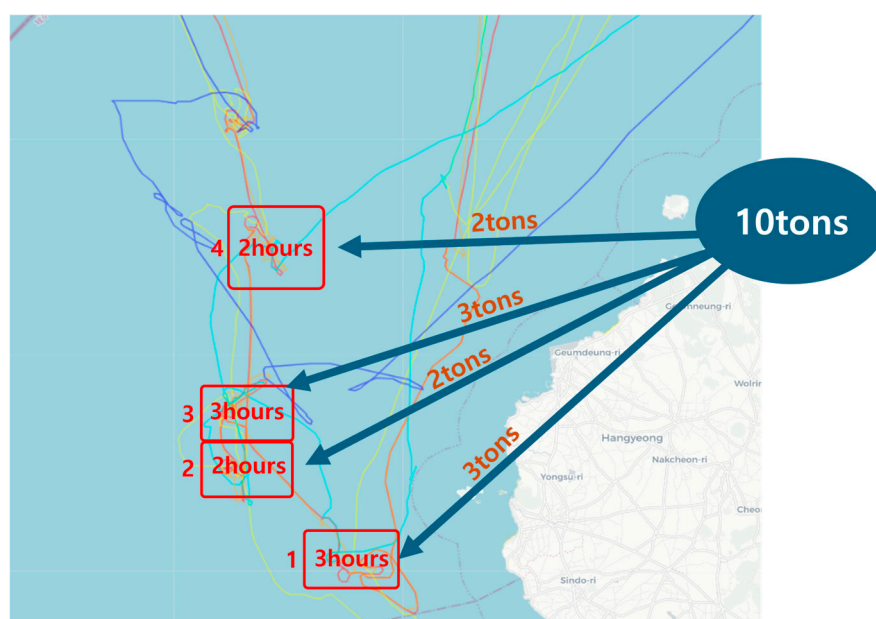


Figure 11. An example of allocating daily landing weight to actual fishing grounds based on net hauling time derived from AIS data. Colored lines denote vessel types: red—main vessel; orange and yellow—light vessels; light-blue and blue—carrier vessels.

4. Results

The spatial and temporal dynamics of mackerel catches by coastal purse seine vessels from July 2019 to June 2022, reconstructed from AIS-based effort and proportional allocation of landed catches, are illustrated in Figures 12–14. Figures 12–14 present the annual catch distributions for 2019–2020, 2020–2021, and 2021–2022, respectively. All figures share a common color scale and layout, enabling direct visual comparison of interannual changes in spatial distribution. Each figure presents the monthly distribution of estimated catch over a 0.25° spatial grid with pixel intensity reflecting the relative magnitude of estimated catch in each cell, as derived from AIS-based effort and the landings allocation procedure. Together,

these maps reveal higher median cell level estimated catch intensities during November to February than during April to June, accompanied by a southward displacement of the intensity centroid toward the waters south of Jeju.

During the first observation year (July 2019–June 2020; Figure 12), fishing activity was highly concentrated from August to December, with particularly elevated catch densities in offshore waters adjacent to Jeju Island and extending northwestward into the Yellow Sea. The peak in fishing intensity was observed in October and December 2019, corresponding to the seasonal aggregation of mackerel in these areas. Notably, Compared with April to June, the active grid's latitudinal and longitudinal extents were larger during November to February, and the convex hull area of non-empty cells increased, indicating wider fleet dispersion to exploit dispersed fish schools. By contrast, catches during the spring months of April to June 2020 were minimal, reflecting a clear seasonal contraction in fishing activity as mackerel availability in coastal waters declined.

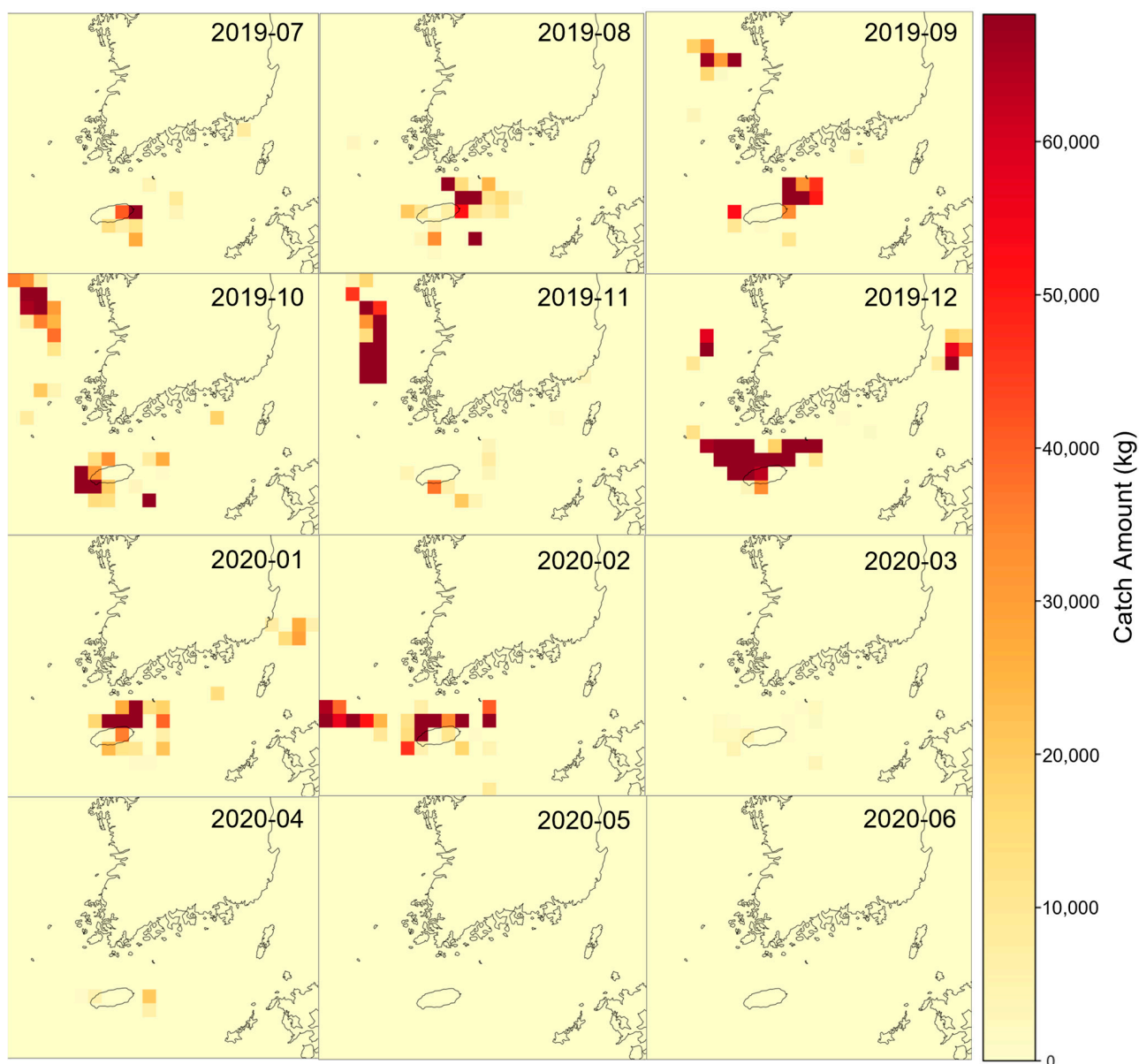


Figure 12. Spatial distribution of estimated monthly catch (kg) by coastal purse seine vessels from July 2019 to June 2020 based on AIS data. Each 0.25° grid cell represents the spatial distribution of catch, with darker colors indicating higher catch amounts (kg). Figures 13 and 14 use the same color scale for interannual comparison.

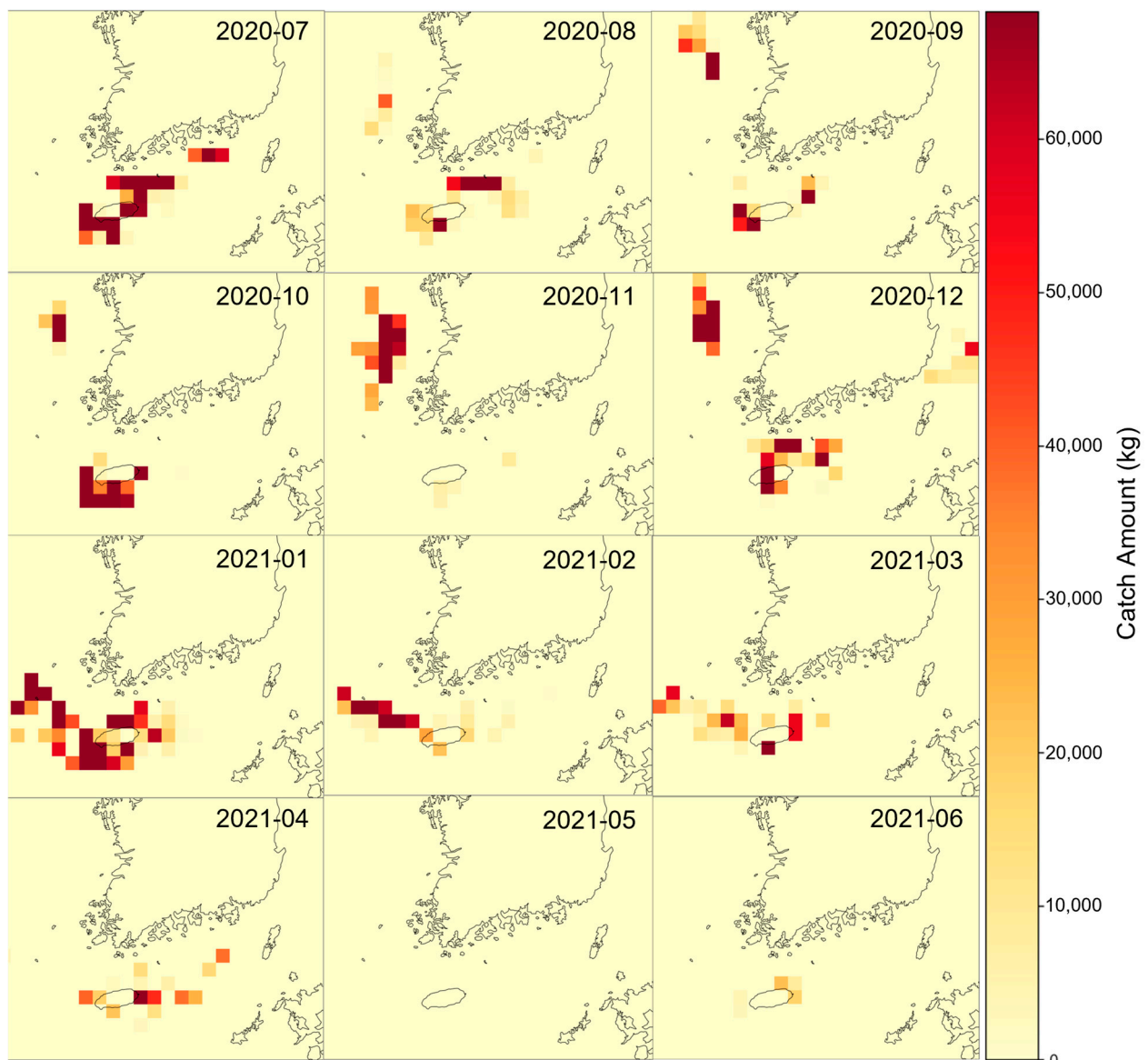


Figure 13. Spatial distribution of estimated monthly catch (kg) by coastal purse seine vessels from July 2020 to June 2021 based on AIS data. Each 0.25° grid cell represents the spatial distribution of catch, with darker colors indicating higher catch amounts (kg). Figures 12 and 14 use the same color scale for interannual comparison.

The subsequent year (July 2020–June 2021; Figure 13) demonstrated a broadly similar seasonal pattern but with some notable shifts in spatial dynamics. Intense fishing activity was again observed from September to December 2020, with high catch densities concentrated off Jeju Island and in adjacent waters to the west and south. However, in early 2021, a marked shift occurred as elevated catch densities were detected further east and southeast of Jeju, suggesting changes in the spatial distribution of mackerel and an adaptive fleet response characterized by longer steaming distances between port and successive hauling clusters, greater inter-haul spacing (an expanded operating footprint), and longer on-ground fishing duration per trip. Particularly in January and February 2021, catch concentrations expanded longitudinally, extending from the East China Sea to the southern approaches of the Korea Strait. This interannual shift in fishing grounds is consistent with oceanographic forcing: during this period, the southward movement of the fishing-intensity centroid was temporally aligned with a southward tendency of the SST frontal latitude (proxied by the domain-mean SST-gradient maximum) and elevated chlorophyll-a along

the Jeju frontal region, suggesting that mackerel aggregation strengthened near temperature fronts where prey availability was higher.

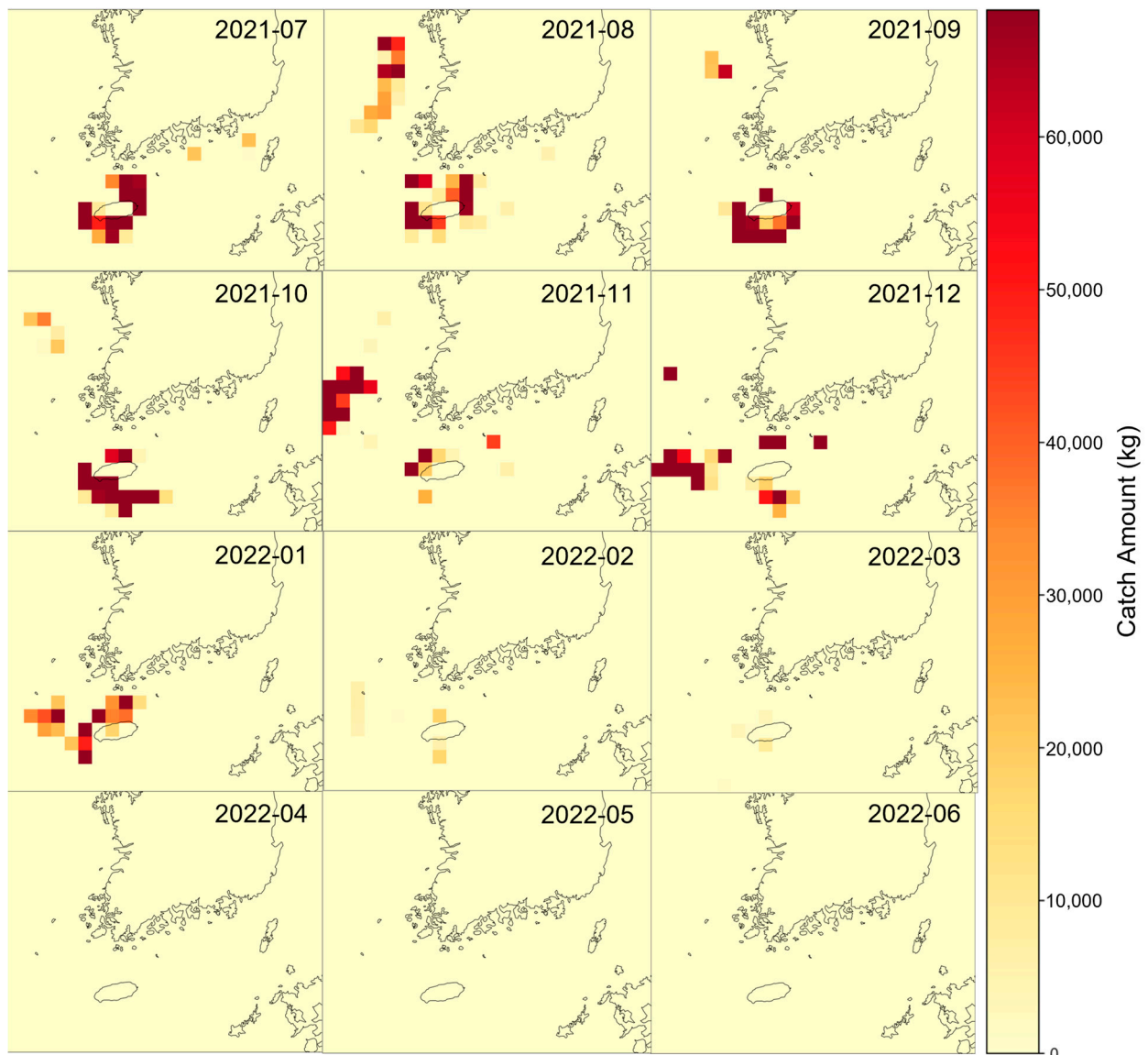


Figure 14. Spatial distribution of estimated monthly catch (kg) by coastal purse seine vessels from July 2021 to June 2022 based on AIS data. Each 0.25° grid cell represents the spatial distribution of catch, with darker colors indicating higher catch amounts (kg). Figures 12 and 13 use the same color scale for interannual comparison.

In the final observation year (July 2021–June 2022; Figure 14), seasonal pulses of fishing activity were once again evident, though with a distinct redistribution of catch hotspots compared to the preceding years. High catch densities were concentrated around Jeju Island during July–September 2021, followed by intense fishing in October and November further north and east, extending toward the central Yellow Sea. Interestingly, elevated catch activity persisted into December 2021 and January 2022 extending beyond the historical baseline season end in late November to early December (as defined from the reference years by the decline of daily estimated-catch intensity below the season-end threshold). By early spring 2022, however, catch distributions contracted sharply, with negligible activity recorded after March—defined as months when the estimated total catch was below 5% of the annual monthly peak and when over 80% of the days fell below the operational

threshold—suggesting an abrupt decline in mackerel availability or a deliberate cessation of fishing effort by the fleet in response to regulatory or market factors.

These spatially explicit reconstructions reveal three key patterns. First, coastal purse seine catches of mackerel exhibit strong seasonality, with peak fishing activity consistently concentrated between late summer and winter months (August–January). Second, while Jeju Island serves as a recurrent focal area of fishing effort across years, the geographic extent of high catch zones exhibits interannual variability, shifting between western, southern, and eastern offshore waters. Third, the spring months (April–June) are consistently characterized by minimal activity, indicating a temporary contraction of fishing operations and a northward shift in the main fishing grounds. These findings underscore the utility of integrating AIS trajectories with landing data to elucidate fine-scale spatiotemporal dynamics of coastal fisheries and highlight the adaptive strategies of purse seine fleets in response to environmental variability and shifting resource distributions.

5. Discussion

The spatiotemporal redistribution of estimated catch by coastal purse seine vessels between 2019 and 2022 highlights the dynamic nature of fishing grounds and their sensitivity to both environmental and anthropogenic drivers. The spring contraction of fishing activity, observed consistently between April and June, likely reflects a biologically driven northward migration of mackerel in response to seasonal changes in temperature and prey distribution. This seasonal movement aligns with known patterns of mackerel migration in the Northwest Pacific, where warming surface waters and shifting frontal zones drive the species toward cooler, offshore habitats during late spring and summer.

The progressive shifts observed across the three fishing years suggest that the spatial distribution of target species, particularly chub mackerel and small pelagic assemblages, is not static but responds strongly to environmental variability. Such redistributions are often associated with oceanographic processes, including sea surface temperature (SST) fluctuations, changes in primary productivity, and mesoscale eddy activity, which collectively influence prey availability and habitat suitability [37,38]. In the Northwest Pacific, where the Korean purse seine fleet operates, interannual variability in the Kuroshio–Oyashio system and associated shifts in thermal fronts are known to drive marked changes in species distribution, particularly for squid and mackerel populations [39]. Although the discussion refers to the Oyashio–Kuroshio transition zone as a key environmental boundary influencing mackerel migration, the present methodology is limited to coastal fishing grounds within the Korean EEZ, where AIS and cooperative landing data are available. Application to offshore or high-seas fisheries would require additional data sources such as VMS or logbook-based catch verification. The catch-redistribution patterns documented here are therefore consistent with broader climate linked ecological shifts observed in other mid-latitude fisheries. Although this study focused on seasonal and annual patterns, future research will extend the analytical framework to incorporate monthly and daily time scales. This refinement will enable more detailed assessments of short-term variations in fishing activity and environmental responses, thereby improving the ecological interpretation of catch dynamics.

While the present framework was developed and validated for a single-species purse-seine fishery targeting chub mackerel, its structure can be adapted to multi-species fisheries if landing records are disaggregated by species or combined with species-specific biological sampling. Future research will focus on integrating species-resolved landing statistics and acoustic or EM-based catch composition data to enable multi-species allocation of estimated catch. This extension will enhance the framework’s applicability for Total Allowable Catch (TAC) management and stock-assessment applications involving mixed-species fisheries.

Beyond the environmental signal, these redistributions also reflect the adaptive behavior of fishing fleets responding to both stock availability and management constraints. As vessel operators detect changes in catch per unit effort (CPUE) across traditional grounds, they dynamically adjust spatial effort to maximize returns. Such adaptive mobility underscores the socio-economic resilience of the fleet but also presents challenges for management, as it complicates the ability of static spatial measures (e.g., marine protected areas or fixed closures) to effectively regulate effort [40]. The observed shifts imply that current management regimes, which are often bounded by historical fishing areas, may not adequately capture the changing ecological reality. This raises the risk of spatial mismatches between management boundaries and stock distributions, potentially undermining conservation and stock recovery efforts.

From a policy perspective, these findings highlight the urgent need for adaptive management frameworks that integrate climate variability into fisheries governance. Climate-ready management, which incorporates predictive modeling, real-time monitoring, and flexible spatial allocations, has been advocated as a means of reducing the vulnerability of fisheries to environmental pressure [41,42]. For Korean coastal purse seine fisheries, the integration of AIS-derived fishing effort data with environmental monitoring offers a powerful tool for real-time assessment of shifting fishing grounds. This would allow managers to anticipate redistribution trends and implement responsive measures such as dynamic spatial closures, temporal effort adjustments, or flexible quota allocations. Importantly, such approaches also have equity implications, as shifts in species distributions can alter access rights and benefits among fleets, heightening the need for transparent and adaptive allocation mechanisms [43]. In the broader context of climate change, the redistribution of catch observed here provides empirical evidence that local fisheries are already experiencing ecological regime shifts with direct socio-economic consequences. As warming intensifies, such redistributions are expected to accelerate, leading to increased competition for resources, potential range expansions into higher latitudes, and heightened management complexity [44]. Incorporating these realities into fisheries policy will therefore be central to sustaining both ecological integrity and livelihoods. The current analysis thus not only documents a clear pattern of spatial redistribution but also emphasizes its broader relevance for climate adaptation and the resilience of marine socio-ecological systems.

6. Conclusions

The redistribution of purse seine catches documented between 2019 and 2022 provides compelling evidence that the spatial dynamics of coastal fisheries are increasingly shaped by environmental variability and climate-related processes. These shifts not only reflect the ecological responsiveness of short-lived, climate-sensitive species but also expose the limitations of static management frameworks that assume relative stability in resource distribution. If management systems do not adapt to this emerging reality, they risk exacerbating ecological pressures in newly productive habitats and intensifying socio-economic inequities among fishers with unequal capacity to follow shifting stocks. Moving forward, the sustainability of these fisheries will depend on the integration of real-time monitoring, predictive environmental modeling, and flexible regulatory tools that allow management to adjust dynamically to changing conditions. It is very important to consider social dimensions, ensuring that adaptive strategies support not only stock conservation but also fair access and livelihood resilience. In this context, climate-resilient and equity-conscious governance offers the most promising pathway to sustaining both ecosystems and fishing communities in the face of accelerating environmental change. Concretely, this calls for the adoption of adaptive spatial planning tools such as dynamic closures, real-time quota adjustments, and habitat-based forecasting systems that can operationalize

environmental signals into timely and equitable management actions. The integration of AIS-based catch distribution with ecological understanding of target species provides valuable insights for fishery resource management. By linking spatial variability in fishing grounds to species migration and habitat use, the results support adaptive management under the TAC system and contribute to the implementation of ecosystem-based fishery management in Korean coastal waters. This study thus bridges technological monitoring with biological and management applications, reinforcing its relevance to sustainable and adaptive fisheries in an era of rapid environmental change.

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References

1. IPCC. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*; Intergovernmental Panel on Climate Change: Geneva, Switzerland, 2019. Available online: <https://www.ipcc.ch/srocc/> (accessed on 4 March 2025).
2. Food and Agriculture Organization of the United Nations. *The State of World Fisheries and Aquaculture 2022: Towards Blue Transformation*; FAO: Rome, Italy, 2022. [CrossRef]
3. Cheung, W.W.; Watson, R.; Pauly, D. Signature of ocean warming in global fisheries catch. *Nature* **2013**, *497*, 365–368. [CrossRef]
4. Pauly, D.; Zeller, D. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nat. Commun.* **2016**, *7*, 10244. [CrossRef]
5. Kang, B.; Zhang, C.I. Directions to fisheries education for achieving UN Sustainable Development Goals (SDGs). *J. Fish. Mar. Sci. Educ.* **2017**, *29*, 453–465.
6. Ministry of Oceans and Fisheries. *Survey on the Status of Fisheries Production and Distribution Industry, 2020*; MOF: Sejong, Republic of Korea, 2020.
7. Baik, C.I.; Park, J.H.; Choi, K.H.; Hwang, S.D. Seasonal and annual variations of catch by large purse seine off Korea. *Sea J. Korean Soc. Oceanogr.* **2001**, *6*, 164–179.
8. Lee, H.-N.; Kim, H.-S. Variation of fisheries conditions of mackerel (*Scomber japonicus*) fishing ground for large purse seine fisheries. *J. Korean Soc. Fish. Ocean Technol.* **2011**, *47*, 108–117. [CrossRef]
9. Lee, J.H.; Lee, J.B.; Zhang, C.I.; Kang, S.K.; Choi, Y.M.; Lee, D.W. A study on fluctuation of the fishing grounds of target fishes by the Korean large purse seine fishery. *J. Korean Soc. Fish. Ocean Technol.* **2012**, *48*, 107–117. [CrossRef]
10. Joo, H.; Yoo, M.; Yun, S.C.; Kim, C.S.; Lee, M.U.; Kim, S.; Yun, S.H. Development of evaluation method of fisheries sensitivity to ocean environments in Korea waters. *Korean J. Fish. Aquat. Sci.* **2021**, *54*, 508–516.
11. Lee, S.; Choi, J.-K.; Park, M.-S.; Kim, S.W. Development of seasonal habitat suitability indices for the *Todarodes pacificus* around South Korea based on GOCI data. *Korean J. Remote Sens.* **2023**, *39*, 1635–1650.

12. Eom, J.H.; Lee, S.I.; Yoon, S.C. A quantitative approach to prior setting for relative biomass (B/k) in CMSY++: Application to snow crabs (*Chionoecetes opilio*) in Korean waters. *Fishes* **2025**, *10*, 400. [\[CrossRef\]](#)
13. Lee, K.; Kim, J.; Pyun, Y.; Kang, S.; Lim, Y.; Cha, H. Establishment of a coastal electronic catch reporting system and development of standard devices for fishing operation monitoring. In Proceedings of the Korean Society of Fisheries Science, Aquaculture Division Conference, Gyeongnam, Republic of Korea, 16 July 2020.
14. Ministry of Oceans and Fisheries. *Survey on the Status of Fisheries Production and Distribution Industry, 2022*; MOF: Sejong, Republic of Korea, 2022.
15. Easton, B.A.A.; Scott, K.; Richards, J.; Rees, A. Catch per unit effort of decapod species, *C. pagurus* and *H. gammarus*, from a voluntary marine reserve. *Fishes* **2023**, *8*, 390. [\[CrossRef\]](#)
16. Shi, Y.; Han, H.; Tang, F.; Zhang, S.; Fan, W.; Zhang, H.; Wu, Z. Evaluation performance of three standardization models to estimate catch-per-unit-effort: A case study on Pacific sardine (*Sardinops sagax*) in the Northwest Pacific Ocean. *Fishes* **2023**, *8*, 606. [\[CrossRef\]](#)
17. Samy-Kamal, M.; Abdelhady, A.A. Long-term changes in fish landings and fish community structure in Nile Delta lakes: Implications for fisheries sustainability. *Fishes* **2025**, *10*, 404. [\[CrossRef\]](#)
18. Dong, J.; Song, X.; Zhu, Y.; Liu, Q.; Hu, Z. Diel catch variation of the primary fish species captured by trammel nets in a shallow eutrophic lake in Jiangsu Province, China. *Fishes* **2025**, *10*, 409. [\[CrossRef\]](#)
19. Natale, F.; Gibin, M.; Alessandrini, A.; Vespe, M.; Paulrud, A. Mapping fishing effort through AIS data. *PLoS ONE* **2015**, *10*, e0130746. [\[CrossRef\]](#)
20. Park, J.; Lee, K.; Choi, Y. Acoustic survey techniques for detecting pelagic fish schools in Korean purse seine fisheries. *Fish. Res.* **2019**, *213*, 42–51. [\[CrossRef\]](#)
21. Russo, T.; D’Andrea, L.; Parisi, A.; Martinelli, M.; Belardinelli, A.; Boccoli, F.; Cignini, I.; Tordoni, M.; Cataudella, S. Assessing the fishing footprint using data integrated from different tracking devices: Issues and opportunities. *Ecol. Indic.* **2016**, *69*, 818–827. [\[CrossRef\]](#)
22. de Souza, E.N.; Boerder, K.; Matwin, S.; Worm, B. Improving fishing pattern detection from satellite AIS using data mining and machine learning. *PLoS ONE* **2016**, *11*, e0158248. [\[CrossRef\]](#)
23. Kroodsma, D.A.; Mayorga, J.; Hochberg, T.; Miller, N.A.; Boerder, K.; Ferretti, F.; Wilson, A.; Bergman, B.; White, T.D.; Block, B.A.; et al. Tracking the global footprint of fisheries. *Science* **2018**, *359*, 904–908. [\[CrossRef\]](#)
24. Amoroso, R.O.; Pitcher, C.R.; Rijnsdorp, A.D.; McConnaughey, R.A.; Parma, A.M.; Suuronen, P.; Eigaard, O.R.; Bastardie, F.; Hintzen, N.T.; Althaus, F.; et al. Bottom trawl fishing footprints on the world’s continental shelves. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, E10275–E10282. [\[CrossRef\]](#) [\[PubMed\]](#)
25. Joseph, A.; Dalaklis, D. The international convention for the safety of life at sea: Highlighting interrelations of measures towards effective risk mitigation. *J. Int. Marit. Saf. Environ. Aff. Shipp.* **2021**, *5*, 1–11. [\[CrossRef\]](#)
26. Shelmerdine, R.L. Teasing out the detail: How our understanding of marine AIS data can better inform industries, developments, and planning. *Mar. Policy* **2015**, *54*, 17–25. [\[CrossRef\]](#)
27. Robards, M.D.; Silber, G.K.; Adams, J.D.; Arroyo, J.; Lorenzini, D.; Schwehr, K.; Amos, J. Conservation science and policy applications of the marine vessel Automatic Identification System (AIS)—A review. *Bull. Mar. Sci.* **2016**, *92*, 75–103. [\[CrossRef\]](#)
28. Russo, T.; Franceschini, S.; D’Andrea, L.; Scardi, M.; Parisi, A.; Cataudella, S. Predicting fishing footprint of trawlers from environmental and fleet data: An application of artificial neural networks. *Front. Mar. Sci.* **2019**, *6*, 670. [\[CrossRef\]](#)
29. Rufino, M.M.; Mendo, T.; Samarao, J.; Gaspar, M.B. Estimating fishing effort in small-scale fisheries using high-resolution spatio-temporal tracking data: An implementation framework illustrated with case studies from Portugal. *Ecol. Indic.* **2023**, *154*, 110628. [\[CrossRef\]](#)
30. Martín, P.; Muntadas, A.; de Juan, S.; Sánchez, P.; Demestre, M. Performance of a northwestern Mediterranean bottom trawl fleet: How the integration of landings and VMS data can contribute to the implementation of ecosystem-based fisheries management. *Mar. Policy* **2014**, *43*, 112–121. [\[CrossRef\]](#)
31. Lu, Z.; Song, L.; Jiang, K. Status identification in support of fishing effort estimation for tuna longliners in waters near the Marshall Islands based on AIS data. *Fishes* **2024**, *9*, 66. [\[CrossRef\]](#)
32. Yang, S.; Yu, L.; Jiang, K.; Fan, X.; Wan, L.; Fan, W.; Zhang, H. Spatiotemporal analysis of light purse seine fishing vessel operations in the Arabian High Seas based on Automatic Identification System data. *Appl. Sci.* **2024**, *14*, 10692. [\[CrossRef\]](#)
33. FIRA. *Annual Statistics of TAC-Based Fisheries*; Ministry of Oceans and Fisheries: Sejong, Republic of Korea, 2021.
34. Owiredo, S.A.; Onyango, S.O.; Song, E.A.; Kim, K.I.; Kim, B.Y.; Lee, K.H. Enhancing chub mackerel catch per unit effort (CPUE) standardization through high-resolution analysis of Korean large purse seine catch and effort using AIS data. *Sustainability* **2024**, *16*, 1307. [\[CrossRef\]](#)
35. Owiredo, S.A.; Kim, K.-I. Spatio-temporal fish catch assessments using fishing vessel trajectories and coastal fish landing data from around Jeju Island. *Sustainability* **2021**, *13*, 13841. [\[CrossRef\]](#)

36. Maunder, M.N.; Punt, A.E. Standardizing catch and effort data: A review of recent approaches. *Fish. Res.* **2004**, *70*, 141–159. [[CrossRef](#)]
37. Pinsky, M.L.; Selden, R.L.; Kitchel, Z.J. Climate-driven shifts in marine species ranges: Scaling from organisms to communities. *Annu. Rev. Mar. Sci.* **2018**, *12*, 153–179. [[CrossRef](#)]
38. Poloczanska, E.S.; Burrows, M.T.; Brown, C.J.; Molinos, J.G.; Halpern, B.S.; Hoegh-Guldberg, O.; Kappel, C.V.; Moore, P.J.; Richardson, A.J.; Schoeman, D.S.; et al. Responses of marine organisms to climate change across oceans. *Front. Mar. Sci.* **2016**, *3*, 62. [[CrossRef](#)]
39. Zhang, C.I.; Lee, J.B.; Seo, Y.I.; Yoon, S.C.; Kim, S. Variations in the abundance of fisheries resources and ecosystem structure in the Japan/East Sea. *Prog. Oceanogr.* **2004**, *61*, 245–265. [[CrossRef](#)]
40. Pomeroy, R.; Parks, J.; Mrakovcich, K.L.; LaMonica, C. Drivers and impacts of fisheries scarcity, competition, and conflict on maritime security. *Mar. Policy* **2016**, *67*, 94–104. [[CrossRef](#)]
41. Pinsky, M.L.; Mantua, N.J. Emerging adaptation approaches for climate-ready fisheries management. *Oceanography* **2014**, *27*, 146–159. [[CrossRef](#)]
42. Gaines, S.D.; Costello, C.; Owashi, B.; Mangin, T.; Bone, J.; Molinos, J.G.; Burden, M.; Dennis, H.; Halpern, B.S.; Kappel, C.V.; et al. Improved fisheries management could offset many negative effects of climate change. *Sci. Adv.* **2018**, *4*, eaao1378. [[CrossRef](#)]
43. Cheung, W.W.L.; Lam, V.W.Y.; Sarmiento, J.L.; Kearney, K.; Watson, R.; Pauly, D. Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Glob. Change Biol.* **2010**, *16*, 24–35. [[CrossRef](#)]
44. Pecl, G.T.; Araújo, M.B.; Bell, J.D.; Blanchard, J.; Bonebrake, T.C.; Chen, I.-C.; Clark, T.D.; Colwell, R.K.; Danielsen, F.; Evengård, B.; et al. Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science* **2017**, *355*, eaai9214. [[CrossRef](#)]

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