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# A Bayesian Approach to Infer the Sustainable Use of Artificial Reefs in Fisheries and Recreation

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**Abstract:** The presence of artificial reefs (ARs) in the south of Portugal that were deployed a few decades ago and the corroboration of fishing patterns and other activities related to the use of these habitats have not been followed. It is important to note that monitoring the use of ARs was difficult in the past but is currently facilitated by the application of non-intrusive tools. In the present study, an approach is developed where, based on monitoring data from fishing and non-fishing boats, influence diagrams (IDs) are constructed to provide some evidence on fisheries or other use patterns and consequent AR effectiveness as coastal tools. These IDs allow us to infer various usefulness scenarios, namely catches, which are tangible, and satisfaction, which is intangible, and overall assessment of ARs and nearby areas in terms of human activities. After calibrating the Bayesian ID based on monitoring evidence, the obtained model was evaluated for several scenarios. In the base case, which assumes the occurrence of more fishing than recreation (assuming 3:1, respectively), the obtained utility is 18.64% (catches) and 31.96% (satisfaction). Of the scenarios run, the one that obtained the best results in the utility nodes together was the second one. The use of these tailored tools and approaches seems to be of fundamental importance for the adequate management of coastal infrastructures, particularly with regard to the inference of fishing resources and their sustainable use. An adequate interpretation based on the use of these tools implies being able to safeguard the ecological balance and economic sustainability of the communities operating in these areas.

**Keywords:** angling; automatic identification system (AIS); diving; fisheries; influence diagram (ID); monitoring; recreational activities; vessel tracking



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## 1. Introduction

Pioneering structures that can now be called artificial reefs (ARs) were discovered by chance but had immediate utility to humans. An observed increase in fish (i.e., food production) was found in these artificial habitats due to the fortuitous existence of three-dimensional fish-aggregator structures [1,2]. For some decades now, there has been a decision to deploy artificial reefs on marine seabeds and lakes all over the world [3,4].

Reef placement is, however, not arbitrary and several documents regulating the placement of structures have also been created [5,6]. This reef placement is also very dependent on the regulations and legislation of the different countries that adopt this type of structure [1,7,8].

ARs are often thought to improve biodiversity in places devoid of three-dimensional structures, which are known to be aggregators of marine life, but also to allow people to know and enjoy these structures in their potential to create biodiversity [9]. There are many studies have demonstrated the usefulness of artificial reefs in biodiversity enhancement [10,11]. Some others have provided insight into ARs in the provision of various ecosystem services [12–14]. Activities such as scientific diving make it possible to demonstrate this type of improvement [15]. There are also experimental fishery studies that allow us to verify the usefulness of ARs in the production of commercial fish [16–19].

Concerning management, and particularly monitoring human use in reef areas—despite the growing interest in the 1990s regarding binomial MPAs and ARs [20], particularly in monitoring and evaluating the effectiveness of MPAs—there is, to date, a great lack of studies that address this issue systematically. One of the reasons why this happens is the difficulty in obtaining use data, not only non-intrusively but also in a scientifically reliable way. Until the early 2000s, obtaining reef monitoring data was only possible through the collection of primary data, mainly through either direct field observations on board research vessels or by identifying stakeholders who were willing to answer questionnaires or be interviewed about reef benefits [21–23]. Both forms had some degree of inherent intrusion.

However, with the advancement of technology and decision analysis techniques, the possibility of developing more reliable approaches to the collection of primary data for socioeconomic monitoring purposes has increased [24,25]. In this regard, high-resolution cameras have been utilized in the last decade, for example [26,27].

A practical example of non-intrusive monitoring occurs when working with data from vessels that have an automatic identification system (AIS), which is a signal emission technology on board for satellite and terrestrial reception systems [28]. Vessels that meet these conditions—the AIS is a vessel-tracking system, used as a global tool since 2004—allow vessels to be tracked from various perspectives, such as route tracking by the companies that own them, safety and ease of providing assistance in the case of need, and scientific purposes [29,30]. In the tracking of vessels for scientific purposes, it can be applied in the case of transport of goods or people, fishing monitoring, and recreational activities [31].

Most of the activities related to the use of ARs (e.g., fishing, recreational SCUBA diving) are conducted on a small-scale and are data-poor or data-limited [32]. Bayesian modeling allows for inferences about the probabilities of the occurrence of phenomena, even in data-poor conditions. Bayesian networks have already been used in research on ARs, particularly in work related to monitoring colonization and trophic relationships [33,34]. However, approaches using Bayesian networks in monitoring human use of ARs are still scarce.

The objective of this article is to conceptualize a methodology that facilitates the analysis of georeferenced data—coming mainly from fishing vessels but also recreational vessels or passenger transport—from AIS signals emitted by vessels that are usable through Industry 4.0 tools. The approach taken in this article is to develop an appropriate sampling procedure to monitor and infer, with the aid of influence diagrams, the use of ARs and surrounding areas in the sustainable exploitation of coastal living resources. Regarding the data collection itself, this approach is conducted in a more sustainable way as it does not require many energy resources. After this introduction, there is a literature review section covering the four topics considered important in this study. Next comes the materials and methods section covering the study site, data collection, data mining, vessel typology and behavior, and Bayesian modeling with influence diagrams. Next comes the results considering the base case and some analyzed scenarios. Afterward comes the discussion of the results obtained and the potential of using Bayesian networks for similar studies. Finally, conclusions are drawn and some recommendations are included.

## 2. Literature Review

### *2.1. ARs in Portugal*

The deployment of ARs in the South of Portugal was conducted for the first time in 1989–90. Subsequently, after satisfactory results of reef colonization were verified, the pilot project was extended [35]. It was only in the 2000s that it was possible to make an approach to reef efficiency for fishing [16,36] and the importance of modules in SCUBA diving options [37]. These experimental fisheries allowed the inference of the capacity of aggregation or production of fish, due to the presence of the new structures. In the same way, it was possible to infer a little about the contribution of these areas in terms of reef biomass production and the exploitation of the fishery resources of specific species due to the ARs' effects [32].

### *2.2. Progress in Artificial Reef Monitoring*

In AR monitoring via field sampling through direct site observation, not only were sampling costs high, but sampling was very time-consuming [38]. However, these studies of observation of fishing patterns have been fundamental, as they provide some evidence about catches and the sustainability of fishery resources and their consequent renewability [39–41]. Proving the use of ARs was difficult in the past because sampling methods were intrusive and deterrent. Nowadays, the methods are facilitated by the application of non-intrusive tools such as onboard Vessel Monitoring Systems (VMSs) and AIS, which can be tracked by Industry 4.0 IoT applications [42,43].

### *2.3. Presence and Behavior of Vessels*

Vessels that are eligible for a reef-monitoring approach are those engaged in fishing, recreational or passenger transport activities [2,21,44,45]. Despite being important, the Algarve AR case study analyzed here was considered only as complementary to other alternative fishing areas for sea-related recreational activities [46]. In the case of fishing, vessels that operate trawl gear occupy areas further offshore in the Algarve coast and consequently do not benefit from the reef effect. Artificial reefs have sometimes been created as a deterrent to this fishing gear [47,48]. Regarding other active gear such as purse seine nets, ARs can in some way facilitate the fishing process, which is most often directed at pelagic species [49]. However, the fishing gear that could benefit most from the presence of ARs is passive gear, namely nets (trammel and gillnets), traps and pots [50].

### *2.4. Decision Analysis Using Influence Diagrams*

Influence diagrams (IDs) were developed in the 1970s by decision analysts [51–53]. An ID presupposes intuitive and easy-to-understand semantics and compact graphical and mathematical representations to support decision making [54]. It is a generalized form derived from a Bayesian network, which includes not only probabilistic inference but also scenarios for making decisions based on the criterion of maximum expected utility [55,56]. The potential of IDs is great, and they are a tool that we believe is especially useful for approaching the monitoring of AR use in relation to different human activities. There are few applications with these Bayesian tools in the context that we decided to explore in this research.

## **3. Materials and Methods**

### *3.1. Study Site*

For the purposes of this research, the south of mainland Portugal, the Algarve coast, was selected. Several AR systems exist in this area. In the surroundings, there are several fishing and recreational ports. Potential users have activities based on these locations (Figure 1). Vessel positioning data were acquired from maritime traffic service networks [57].

The ARs in the study sites are modular porous concrete structures with cubic and octagonal shapes and occupy areas of approximately 6 km$^2$ (Oura and Vilamoura) [14] and 12.2 km$^2$ (Faro-Ancão) [36]. The ARs are found between 16 and 40 m deep [35], and their distance from the coast varies depending on the slope but can be up to almost 6.5 km [14].

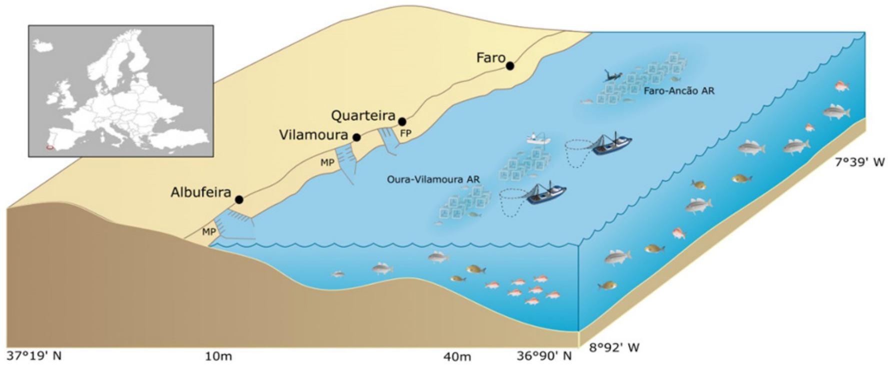


**Figure 1.** Infographic representing three artificial reef systems on the central Algarve coast (Portugal), showing the main locations where there are operators who use them (fishing and recreational ports or marinas of Albufeira, Vilamoura, Quarteira and Faro). The figure was created by AM and JC using Inkscape (version 1.3, https://inkscape.org).

### *3.2. Data Collection*

As pointed out in [58], access to vessel geopositioned data can enhance scientific research particularly when conducting monitoring tasks. To track vessels, marked spatial-temporal data were used, provided by MarineTraffic [59]. These data are collected from the AIS, which relies on a collaborative approach through a self-reporting system. This AIS system allows vessels to transmit information related to their identification and positioning (latitude and longitude coordinates and time information). There is also the transmission of other information from various onboard devices, such as the vessel's location and speed over time. However, it should be noted that there are some limitations to this system, as only larger fishing boats and passenger vessels are required to have an AIS. However, it is expected that in the near future, it will be frequent practice for all vessels to have this system installed on board.

AIS systems allow vessels to share data with other ships, satellites and AIS stations. Inland antennas capture AIS information, and an AIS receiver processes it, sending it over the internet to a database for storage and utilization (Figure 2).

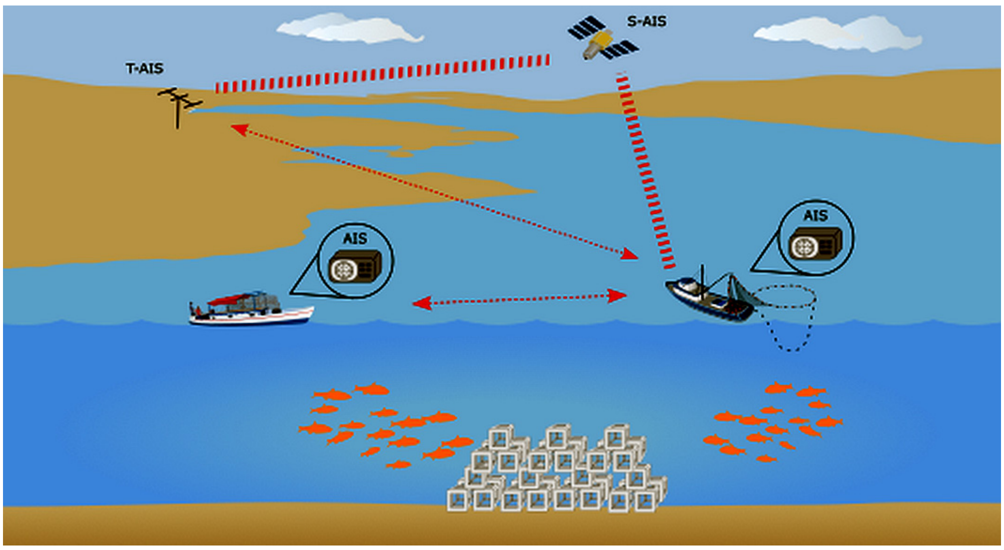


**Figure 2.** Representation of the communication system via AIS. Vessels transmit signals for satellite (S-AIS) and terrestrial (T-AIS) reception systems, which are broadcast via satellite to networked equipment (e.g., MarineTraffic data can be viewed on multiple devices). The figure was created by AM and JC using Inkscape (version 1.3, https://inkscape.org).

As a rule, it is in the warmer months that more leisure activities are developed, namely diving. Trips for recreational fishing purposes are distributed throughout the year but with a greater incidence in summer, due to the more pleasant temperatures. This season also coincides with the time when most people have the most free time available. Practicing leisure water activities at sea, such as diving, enhances the physical and mental health of practitioners [60].

In the present study—and considering annual variation—it was decided to compare seasonal vessel activities and patterns. So, it was decided to use information on fish activity around ARs in winter (January, February and March) and summer (July, August and September) for the years 2022 and 2023. The data acquired include information on each individual boat (MMSI) with their status (motion), speed (knots), positioning (latitude and longitude coordinates), direction or navigation route, date (year, month and day) and time (hours and minutes of the day) and the station that collected the signal.

### *3.3. Data Screening*

Data mining consisted of several phases (Figure 3). First, it was necessary to clean up all data that were not relevant to the study. The data to be excluded at this stage were from stationary vessels or those that are in inland areas such as in ports and types of vessels not relevant such as cruise ships, tugboats or personal vessels. In the second phase, it was important to distinguish between the typologies of the selected vessels. These vessels of interest for the study are fishing, recreational, and passenger boats.

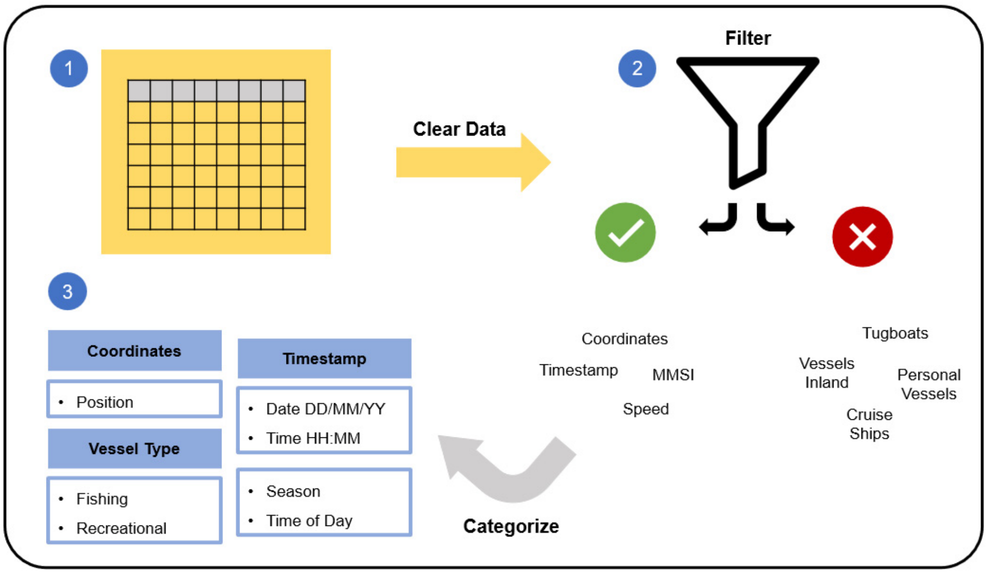


**Figure 3.** Diagram illustrating the procedure from the raw database: its screening, sorting through filters and its subsequent categorization for a posteriori modeling.

### *3.4. Type of Vessels and Motion*

From the inference of the data, it is possible to verify which fishing vessels have eligible gear and those not (or less) eligible for AR use. The literature also provides corroborating information in this regard [61,62]. In vessels operating with active gear, trawlers mostly operate outside the AR area, due to technical and legal limitations. Seiners are eligible for fishing in the reef zone. With regard to vessels using static gear, such as multi-gear fleets or artisanal fleets, gillnets and trammel nets, traps and pots are deployed in the AR vicinity or between the AR groups.

Recreational boats have to be linked to their potential to develop leisure activities, such as recreational diving and sport fishing. The owners of this type of vessel do not have gear licenses, only licenses for leisure activities.

Likewise, the vessels that have a passenger transport license can be rented as charter boats to develop activities related to sport fishing or diving. This type of activity can be linked to professional activities that are part of maritime tourism.

The speed at which vessels move, as well as their successive positions, is important to understand their situation [63]. The distinct types of boats also have different navigating speeds. In addition to navigating speeds, the vessels also have specific speeds for fish detection purposes: stationary or drifting for gear set-up, or diver collection if it is a recreational vessel. In the case of recreational vessels, they usually navigate at higher velocities, but their behavior and patterns vary according to the activity. Therefore, in the case of fishing vessels, as the various stages of fishing are known, it is possible to use vessel speed to understand if the boat is fishing or just navigating, which allows us to better understand fishing activity patterns (Figure 4).

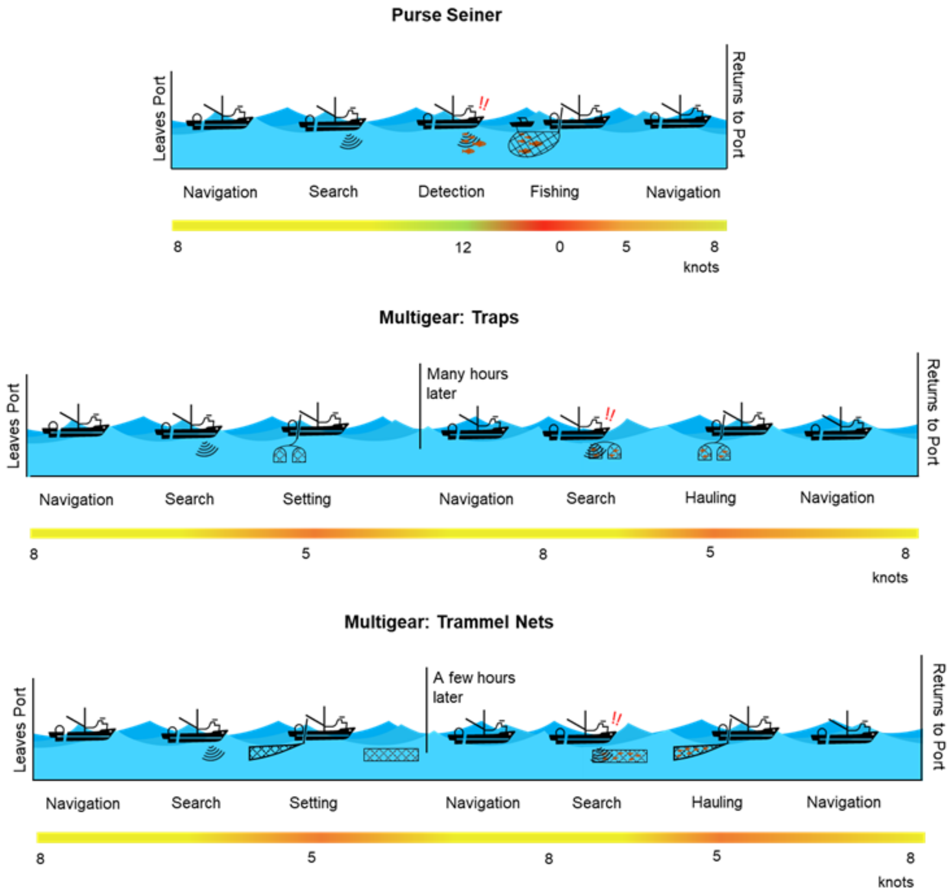


**Figure 4.** Illustration of speed and fishing vessel activity stages driven by data. Each stage, regardless of the type of vessel, takes a different amount of time depending on conditions such as the distance covered and weather. The vessel icon is the same for all vessel types to make it easier to understand, as each vessel is different in reality.

For example, since leaving port, purse seiners navigate at a regular speed in search of fish aggregations with the help of echo-sounders until they detect fish assemblages. When shoals of fish are detected, there is an increase in boat velocity in order to surround the fish. This occurs when the fishing stage begins. It begins with the help of an auxiliary boat to set the purse net around the shoal, and the fishing stage ends by manually hauling the net full of fish caught into the vessel [61]. In this stage, the purse seiner is stopped, and the speed is zero knots or slightly above in the case that it is drifting. Depending on varied reasons, the vessel can repeat the cycle of navigating–searching–detecting to find another shoal of fish or it can keep navigating to return to the origin port to berth.

For artisanal fisheries or multi-gear, there are cases of gill or trammel nets and traps/pots. Their behavior is similar: both set out to navigate at a faster speed, then start to haul or deploy nets or traps/pots, which necessitates slowing down the speed [64]. Both nets and traps/pots are usually left in the sea despite variations in the soaking time of gears. However, in Algarve, regardless of the static gear use, hours or days after gear setting, boats return to the port before hauling [65,66]. Then, they return to the fishing ground from the port at a higher navigating speed.

Access to AIS data from the MarineTraffic application's big data allows us to infer the behavior of vessels. There are several authors who have used this information for scientific work, including contributions to the improvement of sustainable fisheries as referenced, e.g., [67,68].

### 3.5. Influence Diagrams

Influence diagrams were used in the context of Bayesian analysis to determine the factors that influence the usefulness of ARs (Figure 5). Influence diagrams are representations where there is at least one node representing a decision that can be chosen by the decision makers. Another node represents the utility associated with certain outcomes [69–71]. In the present case, an influence diagram was developed from the primary data derived from AIS data. The diagrams specify the structure of the causal relationships between the variables (nodes). In this example, variables were identified that were considered of interest and that represented the respective nodes in the influence diagram. In total, the model includes twelve nodes: three decision nodes (rectangles with square edges), seven chance nodes (rectangles with round edges) and two utility nodes (hexagons). In this study, the open-source Bayesian network program OpenMarkov [72] was used to build and develop the model scenarios, based on real data from the AIS.

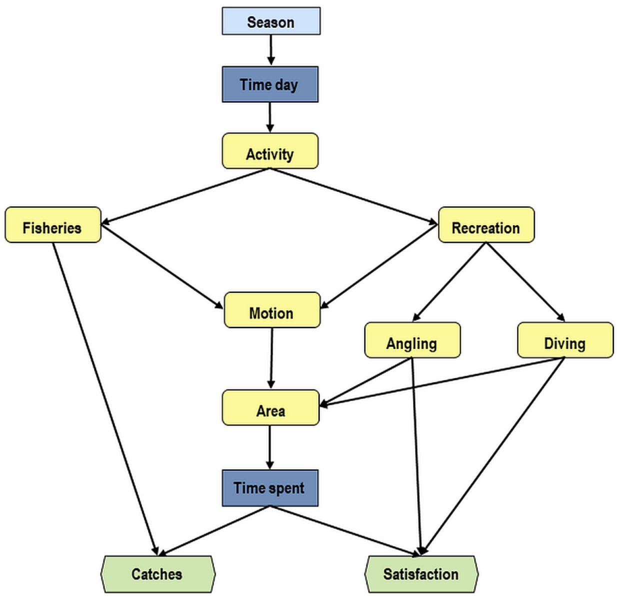


**Figure 5.** Illustration using a simple Bayesian influence diagram (ID) for the purpose of modeling the system in the present study. Rounded rectangles represent chance nodes, rectangles represent decision nodes and hexagons represent utility nodes.

The main objective of the ID was to infer the combinations of reef use and surrounding areas where the usefulness of human activities can be maximized, namely in the capture of living resources (professional fishing) and in the satisfaction of the practice of recreational activities (recreational fishing and diving). For each decision and chance node, several discrete states were considered (ranging from two to four), while for each utility node, continuous states were considered, as can be seen in Table 1.

**Table 1.** Nodes used in the influence diagram (ID), their types, description and discretization.

| Node Type | Description | Discretization |
|---|---|---|
| Activity (chance) | Activities involving fishing vessels are practiced regularly throughout the year. Activities involving recreational boats are mainly found in the summer. Therefore, when comparing vessel types, the proportion of vessels should be 3:1. | Fisheries<br>Recreation |
| Fisheries (chance) | The data collected via AIS show that there are vessels that operate with different fishing gear. Multi-gear vessels can operate with various gear depending on the season of the year, e.g., seiners only use the purse gear; there may also be other vessels that do not have a very well-defined way of fishing. Trawlers are excluded as they are not eligible to fish in the AR bathymetries. Multi-gear fishermen most often operate individually or with a few men on board. Seiners generally operate with more than 10 men on board. | Multi-gear<br>Seiner<br>Other |
| Recreation (chance) | The data collected via AIS show that there are non-fishing vessels that surround the reef deployment area. These vessels are charter boats, passenger boats, sailboats or other vessels for individual recreational use. They can be involved in recreational fishing, diving or simple observation and contemplation activities. This last activity does not contribute to saying whether they take advantage of reef use or not, therefore it is excluded from the model (influence diagram). | Passenger<br>Charter<br>Sail/Other |
| Diving (chance) | This activity can be practiced in many ways, either through companies that provide diving services or through ad hoc recreational activities, such as scientific diving. The boats used are normally related to recreational activities. | Yes<br>No |
| Angling (chance) | This activity is related to vessels belonging to companies that provide group angling services in leisure or tourism activities. There are also leisure boats where people dedicate themselves to this type of recreational activity. | Yes<br>No |
| Motion (chance) | This node refers to speed. Regardless of the type of vessel, it can move in diverse ways or be stationary, anchored or drifting. The movement of a vessel can be related to navigation speed, search speed when using the probe or sonar and fishing speed, depending on the type of gear used. | Drifting<br>Navigating<br>Searching<br>Fishing |
| Area (chance) | The location of a given vessel at a given time may vary. In this model, the positioning of vessels over the AR and its area of influence is considered: between them and the coast (inner), between them and the open sea (outer) and other locations (reef bathymetries outside the areas of reef influence). | Over the AR<br>Inner<br>Outer<br>Other areas |
| Season (decision) | Only data from two seasons of the year are used: winter and summer. The winter season is considered to be January, February and March. For the summer season, July, August and September. For simplicity of analysis, it is considered that both seasons have the same importance in occurrence, whether for professional or leisure activities, related to the use of vessels in reef areas. | Winter<br>Summer |
| Time day (decision) | Two types of occurrences are identified with regard to the reception of the AIS signal from vessels depending on the moment: day and night. For the day (06:00–17:59) and for the night (18:00–05:59). For simplicity of analysis, it is considered that both moments have the same importance in the occurrence, whether for professional or leisure activities, related to the use of vessels in reef areas. | Day<br>Night |
| Time spent (decision) | The time spent by each vessel in the reef area is important in the decision process. It is considered that vessels that are in the reef area for up to 1 h do not give much importance to ARs. On the other hand, vessels that stay longer than 4 h give primary importance to ARs. | Less than 1 h<br>Between 1 and 4 h<br>Over 4 h |
| Catches (utility) | For professional fishing, it is essential to capture target species in quantity and quality depending on their potential market. Usually, ARs are considered just one potential fishing option. Therefore, it is assumed that, at most, a vessel does not depend more than 40% on a reef zone for its catches over time [14,38]. | Numeric (continuous variable) |
| Satisfaction (utility) | When a service is provided or enjoyed for recreational or tourist purposes, which is practiced in the reef area, the non-tangible obtainment can reach a maximum value (100%) simply by using the AR [12,37]. | Numeric (continuous variable) |

## 4. Results

Decision and chance nodes were determined from the AIS data and the ratio between human activities (i.e., the presence of fisheries and recreation boats in different spatial-temporal setting combinations). Based on these primary data sources, it was possible to construct condition probability tables (CPTs) for the nodes included in the ID. For instance, the values selected for the CPT of the decision node 'Time spent' consisted of finding probabilities for boats spending their recorded activity time in three discretization states, i.e., less than one hour, between 1 and 4 h and over 4 h (Table 2).

The following influence diagram starts from a base case, where the main activity conducted was fishing (75%) rather than recreation (25%). The model takes into consideration equal probabilities for motion, angling and diving chance nodes. It is important to note that—as previously mentioned in the materials and methods section—only larger vessels and passenger boats contribute to the results presented here in the ID.

**Table 2.** Conditional probability table (CPT) of two chance nodes of the influence diagram: (a) 'Fisheries' and (b) 'Recreation'.

| | (a) | | | (b) | |
|---|---|---|---|---|---|
| **Activity** | **Recreation** | **Fisheries** | **Activity** | **Recreation** | **Fisheries** |
| Multi-gear | 0.0 | 0.3 | Passenger | 0.333 | 0.001 |
| Seiner | 0.0 | 0.7 | Charter | 0.333 | 0.800 |
| Other | 1.0 | 0.0 | Sail/other | 0.333 | 0.199 |

In relation to recreational activities, the type of vessel with the highest value is charter, followed by sailboats and passenger vessels. For fisheries, the main type of vessel used is a seiner, followed by other types of vessels and multi-gear. As for the area, it is considered that the outer area of the reef has the highest value of probability (0.50%), than other nearby areas, followed by the area over the reef and the inner area. These variables give a probability of 18.64% for the catch utility node and 31.96% for the satisfaction (Figure 6).

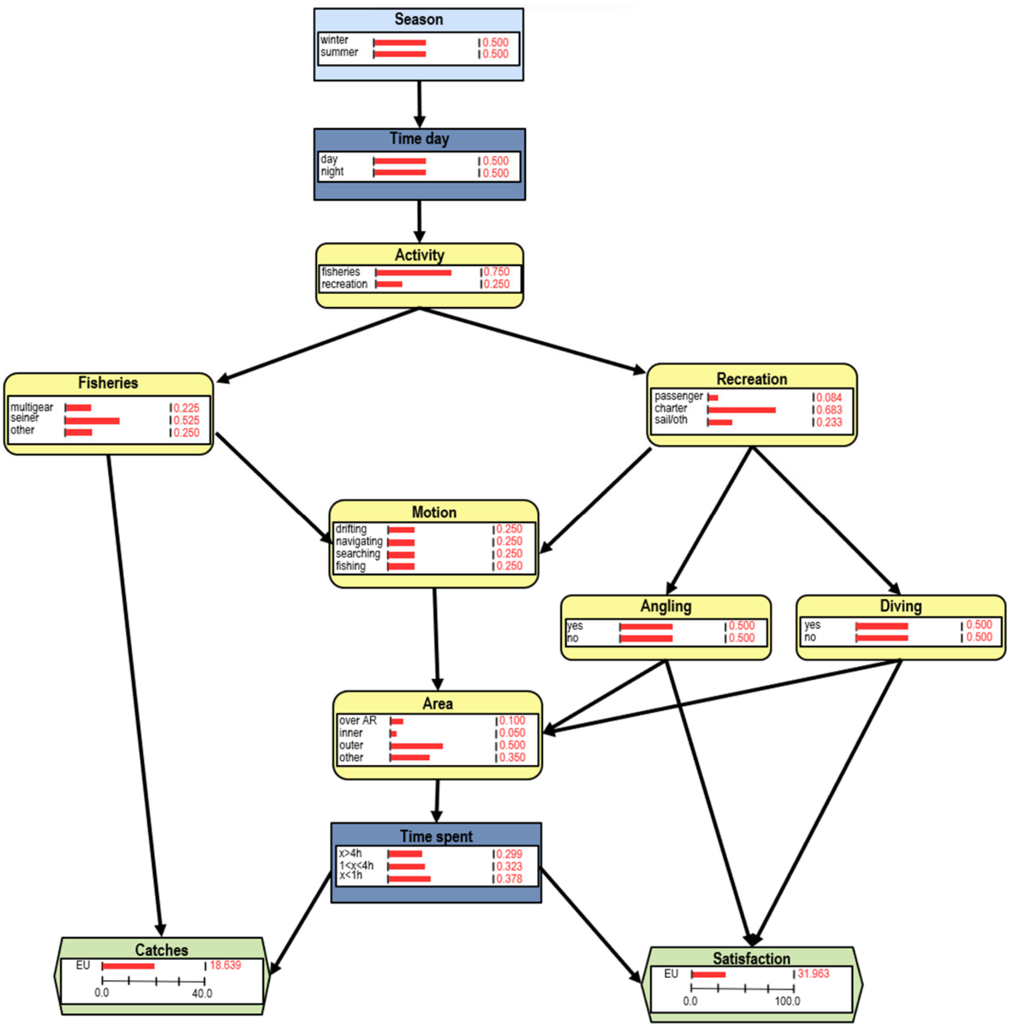


**Figure 6.** Bayesian influence diagram base case run in OpenMarkov [72], which is an open-source program available from http://www.openmarkov.org/.

In the various scenarios using the influence diagram, it can be seen that as there is greater fishing activity (larger catches), the usefulness of recreational activities decreases (Table 3). This is because there is a certain competition for space between fishing and recreational activities. Within fishing, it can be seen that fishing catches are maximized for passive gear, but even so, they rarely reach close to 30% of the total catch utility for these vessels (scenario 2), even if they use these areas for periods longer than 4 h. Seiners do not exceed 24% of the total catch utility nearby ARs.

**Table 3.** Base case and three hypothetical scenarios using the OpenMarkov program [72]. The base case is supported by the set of all the data with no evidence under analysis. Each of the scenarios run in ID is based on random conditions in the decision node (time spent) according to different combinations of human fishing and recreation activities, vessel speed and area of use (chance nodes) and the resulting expected utility (utility nodes of catches and satisfaction).

| Scenarios | Catches (%) | Satisfaction (%) |
|---|---|---|
| The base case presents an initial scenario where the main activity is fishing in comparison to recreational. | 18.64 | 31.96 |
| The first scenario includes the presence of seiner vessels that spend between 1 and 4 h over the AR area. | 20.00 | 35.00 |
| A second scenario includes the presence of multi-gear vessels that spend between 1 and 4 h over the AR area. | 30.00 | 35.00 |
| A third scenario considers that all the recreational activities (diving and angling) are done at the same time that seiner vessels are over the AR area. | 24.00 | 21.00 |

In the case of recreational activities, it can be seen that total satisfaction (100%) occurs only in the case of use for angling activities, in which recreational users can fulfill the expectations created. As far as diving activities are concerned, satisfaction is only partial, because the AR groups are monotonous structures that do not generate grand expectations a priori from divers [37,73].

## 5. Discussion

### *5.1. Access to the AR Areas and the Potential of AIS Data*

As ARs are submerged, their access is limited, and consequently, their observation can only be conducted through remote detection by electronic equipment (e.g., echo sounds) installed on boats or through diving or fishing activities (scientific, professional or recreational) that allow 'direct' contact with the structures. However, the fact that ARs are subject to some inaccessibility does not invalidate the understanding of their role at a socioeconomic level [74].

The possibility of collecting a large amount of data via AIS for a well-defined spatial–temporal situation implies that for those data to be useful, adequate screening is essential [75]. It is important to discard data relating to vessels that are stationary and whose activity is not related to reef use. In the case of trawl boats, there may be many routes coinciding with reef areas, but these vessels will only be in transit or navigate in a reef area as they do not have gear eligible for use in ARs [73].

Although there is no great difficulty in collecting vessel positioning data, their analysis is somewhat difficult. This difficulty arises from the great diversity not only of the type of vessels but also their movement dynamics. Vessels are normally anchored in a harbor (commercial fishing boats) or marina (transport, charter or recreational vessels). When these boats move at sea, they can present varied behavioral patterns. They may be navigating at a more or less constant cruising speed or may be conducting detection maneuvers (e.g., echo-sound or sonar in search of schools of fish, a suitable depth, or certain bottom types of anchoring). Other behaviors may include vessels that may be a little adrift according to the tides. All these different motions (vessel behaviors) are related to specific activities in the water [76].

It is important to be able to contextualize the behavior of vessels present in the information provided by AIS data. It is important to know what activities are related to these vessels, their annual and circadian dynamics, as well as the interaction with other activities that operate in the same spaces, and study them in the context of this inference work.

In the case of fishing vessels, there is activity throughout the year, although these activities depend on bringing fish to land, and they can be compromised if the weather conditions are unfavorable and there is a ban on leaving by maritime authorities [77]. It is also in the winter season, particularly when conditions are more unfavorable, that the boats stay ashore and go for maintenance and repair. With regard to vessel behavior in circadian rhythms, in summer, purse seiners generally go to the sea a little later, while other types of fishing do not have major differences in their daily behavior [78].

In the case of recreational vessels, there is much greater activity during the summer months, due not only to there being more favorable conditions for practicing leisure activities at sea but also more time available for people to practice these types of activities, particularly when they are on vacation. There are many businesses linked to boat rental and service provision that operate essentially at these seasons of the year [79].

Therefore, to analyze the above-referred type of vessel positioning data, it is important to have reference points and know about the types of vessels and their activities, and have means to corroborate this information (e.g., triangulation through questionnaires and interviews) [80]. In the present study, through the geo-spatial distribution of data, it was possible to construct a plausible ID with several discretization levels. As shown in the results, the ID, when run according to various expected combinations of use based on AIS data, helps us to understand how sustainable the activities conducted are in the context and dependence of the AR area of influence.

### 5.2. Scenario Analysis Using Influence Diagrams

The base case adjusts to the situation where fishing vessels occur three times more often than recreational vessels—regardless of the season of the year or time of day—and seiners correspond to a little more than half of the eligible observations. This situation assumes that AR areas are used in a relatively low proportion—i.e., 10% of the total area under analysis is assumed (Figure 6)—and that these recreational activities are practiced in an identical proportion (i.e., half angling and half diving). This base case also assumes that most activities—whether fishing or recreation—primarily use areas further away from reef areas. Most of the time, vessel activity time is relatively short (i.e., most spend less than 1 h in the same location). This base case assumes a relatively low utility in catches (tangible), presenting the lowest value of all when compared to the scenarios that were evaluated.

In the case of scenario 1, it is evaluated when there is no recreational activity and only purse seiner fishing, practiced exclusively in the reef area, where the fishing trip(s) last up to 4 h. Here, there is a slight increase in catches as well as satisfaction (intangible). This scenario assumes that there is no interference between activities, but there is a limitation—carrying capacity—of the AR area itself that offers limited possibilities in the case of seiner catches (generally pelagic fish species) and the slight increase in satisfaction of being given the possibility of having living resources for future recreational activities (namely species not targeted by purse seiner gear).

In the case of scenario 2, everything is similar to the previous scenario, with the difference being that multi-gear fishing is passive. In this scenario, the behavior of the vessels is different, as the vessel will launch the gear for a relatively brief period, leave the gear fishing continuously for some time and some hours later haul the gear on board. Generally, it is during the hauling process that fish from the catch are counted. In this type of passive gear, there is generally greater selectivity. Therefore, the satisfaction of fishing in these areas is greater than in the case of boats with active gear (e.g., seiners). In this scenario, despite the gear remaining permanently in the reef zone under continuous fishing, the utility in terms of satisfaction for recreational activities is identical to that in scenario 1.

In the third scenario, it is assumed that in fisheries, activities there are only purse seiners, and in recreational activities, both angling and diving are present. Under these conditions, it seems that this is the scenario where recreational activities obtain the least satisfaction, as there is some competition for space.

### *5.3. Potential Derived from Influence Diagrams*

The expected results for usefulness (catches and satisfaction) show that there is a certain incompatibility at the same time. This is explained by the fact that, generally, an increase in catches in the reef area will reduce satisfaction, at least on the part of divers (i.e., there would be less marine life, as they were subtracted from the catch). This fact is in line with the literature, e.g., [3,21,81].

The use of Bayesian modeling approaches helps in structuring data and their analysis to better understand phenomena that occur under certain circumstances [82–89]. Similarly, structuring the data and their analysis with influence diagrams allows us to understand the dynamics in reef areas. The use of the OpenMarkov program is an added value for structuring and analyzing the various possible scenarios that appear plausible [72,90]. The structuring of the chance nodes through the different types of vessel and the activities that may be related to them, the location possibilities in relation to the distance from the reef, as well as the decision nodes related essentially to the time of year, circadian activity and weather duration to practice the different activities, allow us to draw very important lessons in terms of potential catches (professional fishing) and satisfaction with the activity practiced (recreational activities and tourism).

If we move to another geography or scale the analysis, it can be noticed that sustainable fishing governance is desirable as a primary objective. It is essential to maintain biodiversity, whatever the level of interaction of human activities under analysis [91].

## 6. Conclusions

With access to data for a specific, well-defined temporal and spatial period, it becomes possible to conduct adequate sampling and know the type of use by diverse types of vessels in the AR area. Triangulating data to exclude information that is not relevant—e.g., trawlers operate in more offshore areas and their gear is not eligible for use in ARs—and the appropriate analysis of the remaining data are essential to understand the dynamics of the use of reef areas. With these data, it is possible to use influence diagrams to build scenarios to understand patterns of human use of AR areas.

In the present case study, it was somehow managed to build a way to monitor patterns of human use in a well-defined reef area off the central coast of the Algarve (Portugal). With this ID model approach, it was possible:

- to move forward in order to work with the data in more detail;
- to be able to infer the sustainability of the resources generated in the reef area (i.e., services and products);
- to align with the United Nations' sustainable development goals (SDGs), namely goals 12 and 14 (sustainable consumption and production and life under water, respectively).

Finally, it is important to highlight that despite still having some limitations, this type of approach can be replicated for similar monitoring studies anywhere and for more or less extended periods. This approach, being non-intrusive and allowing researchers to work with a large amount of data, gives us the freedom to stress that the inferences resulting from the analyses are quite realistic.

The use of Bayesian influence diagrams is recommended as a feasible and comprehensive approach for cases that present some evidence of human activities in coastal areas, regardless of whether they are AR areas or not. Thus, the use of IDs, particularly when exploring several use scenarios, requires caution due to several adjustments to the models and their constant plausibility checks.

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