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Marine coastal zone management proposal from Pacocha, Ilo to Morro Sama, Sama, Peru

Lima - Perú

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***Abstract*– The highest demand for ecosystem services for human activities worldwide comes from the coastal marine zone (CMZ). In areas with inadequate management, this demand can lead to the degradation of ecosystems and the loss of the services they provide. This study aimed to develop management scenarios for the coastal marine zone (CMZ) between Pacocha (Moquegua) and Morro Sama (Tacna) in Peru. The study area extended five kilometers inland from the coastline and encompassed a marine area stretching five nautical miles offshore.**

The development of the management proposal was based on the identification and mapping of local ecosystems, the ecosystem services they provide, and the pressures exerted by human activities. To support this, the Marxan with Zones program was used, incorporating data on ecosystems, ecosystem services, human-induced pressures, as well as the presence of natural mollusks banks and rivers.

The modeling process resulted in the proposal of four management zones: Protection, Preservation, Sustainable Use, and Recovery. The Sustainable Use zone was the largest, covering 30% of the total area, while the Recovery zone was the smallest, occupying 16%. These results provide valuable support for decision-makers in implementing an integrated CMZ management plan.

Keywords--Ecosystem Services, Ecosystem Pressures, Ecosystems, Management, coastal.

I. Introduction (Heading 1)

There is increasing urbanization worldwide, especially in coastal areas. the importance of the coastal marine zone lies in its uniqueness as a space of public interest, and for being the area responsible for 25% of primary biological production and 61% of global economic production [1]. Due to the prominent importance of preserving these areas, which are highly threatened because of an increasing human pressure, since the 60s approximately, 700 management initiatives have been developed in more than 140 countries around the world [2]. In this context, coastal management programs have been efficiently implemented in many countries.

The Integrated Coastal Zone Management (ICZM) is an instrument that promotes the sustainability of coastal resources, the resolution of conflicts in coastal communities, as well as the economic benefit of the stakeholders [3, 4].

In Latin America, an important initiative was the Ibero-American Integrated Coastal Management Network (IBERMAR), which developed studies for the implementation of ICZM in Mexico, Cuba, Dominican Republic, Puerto Rico, Costa Rica, Panama, Colombia, Brazil, Chile, Argentina, Uruguay, Spain, and Portugal [5].

In Peru, the Ministry of Environment (MINAM), published in 2015 the national guidelines for the Integrated Management of Coastal Marine Areas [6]. In 2019, MINAM and the Instituto del Mar del Perú (IMARPE), implemented at the national level the third phase of the project "South Pacific Information Network in Support of Integrated Coastal Area Management" (SPINCAM), whose first phases were carried out since 2009 in Chile, Colombia, Ecuador, Panama and Peru. The project goal was to establish a framework of indicators for ICMZ at the regional level in the Southeast Pacific [7].

Peru is one of the three most vulnerable countries to climate change, due to its geographical characteristics and the socioeconomic conditions of the most exposed population [8]. Over the years, measures have been implemented that aim to transform the current economy into an eco-friendlier one [9].

The country has adopted the "National Competitiveness and Productivity Plan 2019-2030," which outlines key objectives, including: (1) providing the country with high-quality economic and social infrastructure (Objective 1), and (2) promoting environmental sustainability in the operation of economic activities (Objective 9). Creating a legal framework to support initiatives for marine coastal management, and the progressive shift towards a circular economy, which makes efficient and intelligent use of natural resources, without depleting them and thus generating the least possible amount of waste [10].

This study proposes coastal marine management scenarios in the southern area of Peru, between Pacocha and Sama. using the ecosystem-based approach (EBM), which consists of the evaluation of the society - ecosystem relationship, analyzing ecosystem services (ES) and the pressure on the ecosystems, considered within ecological limits [1].

The scenario was generated with the program Marxam With zones using information of the ES identified and qualitatively assessed, as well as the pressures on ecosystems, adopting the methodology implemented by AQUACROSS project [11], adapted for the SPINCAM project [12]. These results could be used by decision-makers in the implementation of marine-coastal management.

A. *Study Area*

The study area is located between the districts of Pacocha in Ilo and Morro Sama in Sama (Fig. 1). It is bounded at sea by a 5-nautical-mile radius from the coastline and, on land, extends up to 5 kilometers from the shore.It is part of the ecoregions of the Cold Sea of the Peruvian (Humboldt) Current and the Pacific Desert.

The study area is in the Locumba river basin, a short distance from the mountain range to the coastal zone. The main activity in the basin is agriculture [13]. At the mouth of the Locumba River is the Ite wetland, which is considered an Important Bird Area (IBA - PE 047) [14]. To the north of the city of Ilo is the Osmore or Ilo River, which has an irregular flow regime, increasing in the summer months [15].

The total estimated population in the study area is 76,981 inhabitants. It 86.6% is located in the city of Ilo, which is mostly urban, while the other districts have a mainly rural population [16, 17].

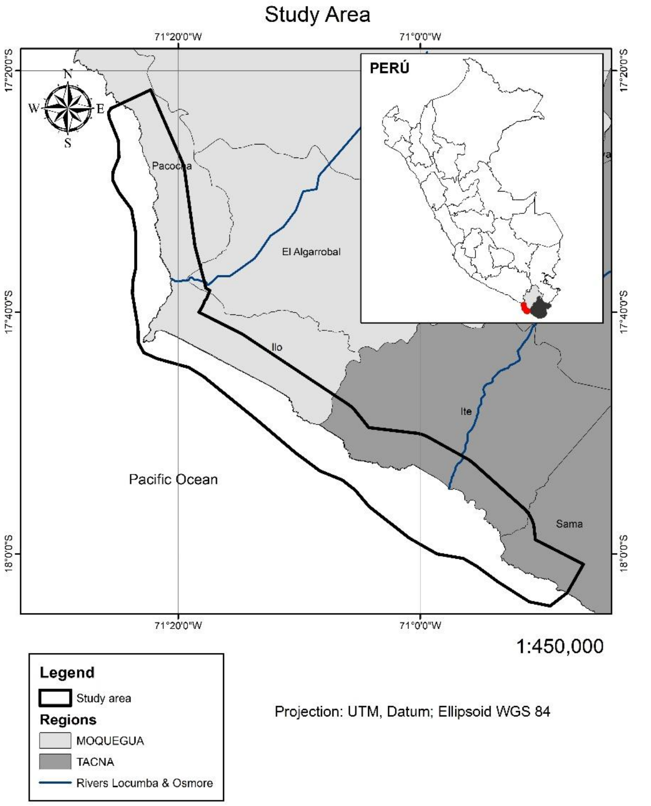

Fig. 1 Location of the study area.

II. Methods

The methodology was based in the framework of the ecosystem-based management (EBM). EBM considers both ecosystem variables and use variables to achieve integrated management of living resources, land, and water bodies. In addition, this approach recognizes humans as an integral component of many ecosystems [18]. In this context, the analysis focuses on the supply and demand of ES, prioritizing management based on ecological boundaries rather than political ones, as is the case with other management approaches [1]. Figure 02 illustrates the procedure flow for generating and mapping the management proposal using EBM [11].

A. *First step: Identification of ecosystems*

The definition of ecosystems was based on the EUNIS classification system, level 2, modified to ESPINCAM 3, in which the substrate, bathymetry, light, altitude, uses and vegetation were analyzed [19, 20].

The spatial information of terrestrial ecosystems was obtained from the "Vegetation Cover" map, provided by the geoserver of the Ministry of Environment (http://geoservidor.minam.gob.pe/recursos/intercambio-de-datos/). The polygon layer was downloaded in shapefile format and processed with ArcMap software (ESRI), the information corresponding to the terrestrial area of the study was extracted with a 5 km wide mask from the line coast to the continent. Then, the resulting polygon geometries were updated with shapefiles from studies provided by the Functional Area of Coastal Marine Research (AFIMC) of the IMARPE.

To map the ecosystems of the intertidal zone, a polygon covering its entire extent was generated. Finally, the polygon was edited taking as a reference the type of substrate observed in the satellite images of the "Imagery" base map of the ArcMap program (ArcGIS 10.1) [21]. The images are dated 04/06/2020, with a resolution of 0.5 meters and a precision of 5 meters.

For the marine area, spatial information on ecosystems was taken from the substrate information delimited in the technical reports of natural banks, from the research activities carried out by AFIMC and Coastal Laboratory of Ilo - IMARPE (2014 and 2017), as well as from the sediment data of the "Bioceanographic and Macrobenthos Monitoring" report. The polygons obtained were contrasted and redefined according to the bathymetric information achieved from the Hydrography and Navigation Directorate of the Navy of Peru (DHN), according to the information achieved in each polygon, it was assigned the name of the ecosystem it represented according to the classification of EUNIS, level 2, modified to SPINCAM3. Finally, all the areas were unified. The geographic information of the ecosystems determined were validated by expert consultation of the scientist of the Functional Area of Marine-Coastal Research of IMARPE [11].

B. *Second step: Definition of components to be considered*

Ecosystem characteristics were used in the modeling of management areas. The data considered were ES (supply, regulation and cultural) (the definition of Costanza et al. 1997) [22] and ecosystem pressures (chemical, physical and biological) (definition of Gari, Newton & Icely, 2015) [23], as well as other characteristics of the areas, such as: the presence of rivers and natural banks. That information was analyzed and processed based on the bibliography on the chosen study area.

C. *Third step: Identification of ecosystem services (E.S.)*

The CICES (Common International Classification of Ecosystem Services) [24] classification model was used, with a double-entry matrix developed. On one side were placed all existing ES in the study area, divided into their respective categories (social, provisioning and regulatory), for biotic and abiotic services. On the other side, the habitats defined in the study area were included. The table was recorded according to the documented information about the area (Table I). Urban/rural zones were considered as ecosystems and the possible services they provide were assigned, to include them in the planning model.

The result was incorporated into the attribute table of the ecosystems map, which was created in the first step.

Then a raster was generated for each type of ecosystem service (Provisioning, Regulating and Cultural) at spatial resolution 0.0026 miles, from the initial polygon map.

TABLE I
DIAGRAM OF THE TABLE USED TO DEFINE ECOSYSTEM SERVICES FOR EACH ECOSYSTEM EVALUATED IN THE STUDY AREA.

	Regulation ES		Provisioning ES		Cultural ES	
	R. ES 1	R. ES 2	P. ES 1	P. ES 2	C. ES 1	C. ES 2
Ecosystem 1	X	X	X		X	
Ecosystem 2		X	X	X	X	X
Ecosystem 3	X			X	X	
(…)						

D. Fourth step: Identification of uses, pressures and current condition of the Ecosystems

The ecosystem pressures were defined based on the environmental quality information of the area and compared with the information on uses, that was taken from the technical research reports carried out by AFIMC and the Ilo Coastal Laboratory of IMARPE in shapefile format.

Ecosystem condition was measured with the Impact Risk Index (IR), adapting the methodology of Borgwardt et al. (2019) [25] and Robinson et al. (2012) [26] to the available information. The resulting formula is shown below:

Exposure (E) = (E Frequency + E Persistence) nE, Impact Risk (IR) = √ (E - 1)2 + (C-1)2, where:

E: Exposure criteria score given as a function of the extent of activity pressure.

E Frequency: Exposure criteria score given as a function of the frequency of exposure.

E Persistence: Exposure criteria score given as a function of the persistence of the activity pressure.

nE: Number of exposure criteria.

c: Consequence criterion score given as a function of the severity of the activity pressure.

Because only marine but not terrestrial pollution scores were available, each of these two zones was worked independently. The numerical scores assigned were adapted from Knights et al., (2015) [27] for each of the two sectors (Table II)

TABLE II
SCORING CRITERIA FOR THE MARINE AREA AND THE TERRESTRIAL AREA OF THE STUDY ZONE.

Feature	Description	Standards		Score
		Sea and rivers	Continent	
Frequency	Occasional	Present in 1 year of monitoring	Stays in the ecosystem for less than one year	0.5
	Frequent	Present in 2 years of monitoring	Stays in the ecosystem for more than one year	1
Persistence	Low	0 to 2 years	0 to 2 years	0.01
	Moderate	2 to 10 years	2 to 10 years	0.06
	High	10 to 100 years	10 to 100 years	0.55
	Persistent	More than 100 years	More than 100 years	1
Severity	Low	Measured with ecotoxicity data from IMARPE studies.	Theoretical ecotoxicity data	0.01
	Chronic			0.1
	Acute			1

The Terrestrial Zone was evaluated with a double-entry matrix to identify the pressures or pollutants generated by each use. In this table, the activities were classified into five major groups: Urban/Rural, Agriculture/Fishing, Energy/Mining, Tourism/Conservation and Ports. And the pressures were classified into three groups: Biological, Chemical and Physical [12].

TABLE III
DIAGRAM OF THE TABLE USED TO DEFINE ECOSYSTEM PRESSURES FOR EACH ACTIVITY EVALUATED IN THE STUDY AREA.

	Biological pressures		Physical pressures		Chemical pressures	
	B.P. 1	B.P. 2	P.P. 1	P.P. 2	C.P. 1	C.P. 2
Ecosystem 1	X	X	X		X	
Ecosystem 2		X	X	X	X	X
Ecosystem 3	X			X	X	
(…)						

Then another double-entry table was created for each activity evaluated, the ecosystems affected by the activity (those that according to the geo-referenced information were located within a perimeter of 1 km around the evaluated activity) were placed on lines, and in the columns were placed the criteria to be scored for each group of pressures (Table IV).

TABLE IV
DIAGRAM OF THE TABLE USED TO SCORE THE ECOSYSTEM PRESSURES FOR EACH ACTIVITY EVALUATED IN THE STUDY AREA

Activity 1	Biological pressures			Physical pressures			Chemical pressures			Formula (IR)
	Frequency	Persistece	Severity	Frequency	Persistece	Severity	Frequency	Persistece	Severity	
Ecosystem 1	1	0.01	1	0.5	0.6	0.01	1	0.55	1	IR
Ecosystem 2	0.5	0.6	0.01	1	0.6	0.01	1	0.01	1	IR
Ecosystem 3	1	0.55	1	0.5	0.6	0.01	1	0.6	1	IR
(…)										

The resulting IR value was mapped to 1 km around the activity to which it was related.

For the Coastal Marine Zone and Rivers environmental quality information was taken to the internal technical reports on research activities carried out by AFIMC and the Ilo Coastal Laboratory of IMARPE (years 2015 and 2017, respectively). Those contaminants that were outside the Environmental Quality Standards (EQS) for water, categories 2:C1 (sea) and 4: E2 (rivers) were considered.

A raster layer for each pollutant was estimated using the IDW (Inverse Distance Weighted) analysis method. Then, the values of each raster were reclassified, assigning zero (0) to the areas that complied with the ECAs, and one (1) to those that did not comply with the ECAs.

The resulting raster maps were summed with the map algebra tool, categorizing them into physical, chemical and biological pressures. The areas with values over 1 were evaluated with the criteria of persistence, frequency and severity of the pollutant observed there.

If an area had more than one pollutant per category, all were evaluated, and the value of the most harmful pollutant was considered.

The value for each analyzed zone was included in the table of attributes of the final raster, by category, thus obtaining the IR for each pixel at 0.0046 km2. The final IR score was scaled between 0 and 1.

E. Fifth step: Definition of management zones

After making steps 1, 3 and 4 on each ecosystem, the management needs of the study area were analyzed. And the following management zones were defined, (modified from: Invemar and Cardique, 2014; Barboza et al., 2018) [28; 11]:

TABLE V

CRITERIA APPLIED TO EACH PLANNING UNIT TO BE CATEGORIZED IN THE CORRESPONDING PLANNING ZONE.

			Protected Areas	Preservation areas	Areas of sustainable use	Recovery Areas
Criteria (%)	EP	Biological P.	0	0.4	0.4	0.4
		Physical P.	0	0.4	0.4	0.8
		Chemical P.	0	0.4	0.4	1
	ES	Provision	0.6	0.6	0.8	0.2
		Regulation	0.8	0.6	0.4	0.2
		Cultural	0.8	0.8	0.6	0.4
	Natural Banks		0.5	0	1	0
	Rivers		0	0.4	0.3	0
	PNR		1	0	0	0

- Protected Areas: Pre-existing National Reserves (PNR), areas in a good state of conservation, i.e., low pressure from human activities. With a high percentage of Regulation and Culture ES, and a medium percentage of Supply ES, where the conservation objectives are to maximize natural values.

  "The Natural Protected Areas constitute patrimony of the Nation. Their natural condition must be maintained in perpetuity and the regulated use of the area, and the exploitation of resources may be permitted, or the restriction of direct uses may be determined" (According to Law No. 26834).
- Preservation areas: Areas of high supply potential, with indispensable and irreplaceable resources for adjacent activities (e.g., water). The objective is to guarantee the continuity of resource use through sustainable management and strict regulations.
- Areas of sustainable use: Areas with a greater number of cultural ES and slightly impacted by pre-existing activities. With seasonal Supply ES such as the presence of natural banks or water catchment. The objective is to identify these zones for future sustainable economic proposals that can replace other activities with greater environmental impact.
- Recovery Areas: Areas impacted by high pressures from pre-existing activities. The number of ES is usually less than their healthy counterparts and can be repurposed once they are recovered and designated to sustainable uses.

F. Sixth step: Modeling of the management scenarios

In this step it was essential to spatially determine the planning units, which were defined in a grid with cells of 1 x 1 km in size. Subsequently, all the values of the characteristics mentioned in step two were entered as percentages in the corresponding cells.

The program Marxan with Zones, version 2.1 [29] was used to generate the coastal marine management scenario. This is a tool for ecological spatial planning, according to the data entered, allows the management of different conservation objectives in several zones at the same time. The work was carried out according to the instructions of the two guides of this program.

All the files required by the program were used according to the manual specifications, including those lacking information (“costs” and “zone costs”), which were assigned a value of 1. Optional files were used to delimit the boundary perimeters between cells and zones (bound.dat and zoneboundcost.dat), to calibrate the model. Likewise, the puzone.dat file was used to establish the arbitrary entry of the existing Natural Protected Areas in the "Protection" zone, as well as the cities and towns in the "Sustainable Use" zone.

The results from Marxan with Zones were mapped, and the result was edited to give values to the pixels without any management classification, the value of the area with the greatest presence around the pixel was assigned.

G. Seventh step: Baseline mapping

To compare the management proposal with the current situation in the study area. The information for the Pacocha area in Ilo was obtained with the terrestrial Ecological Economic Zoning (ZEE) polygon map, which was downloaded in shape format [3]. The area of Ite, Morro Sama and the entire marine area of the project was modeled from the previously mapped uses. Finally, the output files output_mvbest and output_sum were used to analyze the results [30].

III. RESULTS

A. Ecosystems identified

Fifteen ecosystems were identified for the study area, 8 in the terrestrial zone and 7 in the marine zone (Fig. 2).

Ecosystems considered for the study area, EUNIS, Level 2 modified to ESPINCAM 3 [20]:

- A1: Coastal rock and other hard substrates
- A2: Coastal sediments
- A5: Sublittoral sediments
- B1: Beaches, dunes and other coastal sandy areas
- B3: Núcleo de población construido y compacto (ciudades, pueblos, etc)
- J1: Núcleo de población construido y compacto (ciudades, pueblos, etc)
- J2: Núcleo de población diseminado
- J6: Landfills
- X04: Wetlands

- X31: Mosaics of mobile and non-mobile substrates in the littoral zone.
- X32: Mosaics of mobile and non-mobile substrates in the infralittoral zone.
- X42: Coastal hillocks
- I1: Plowed land and orchards

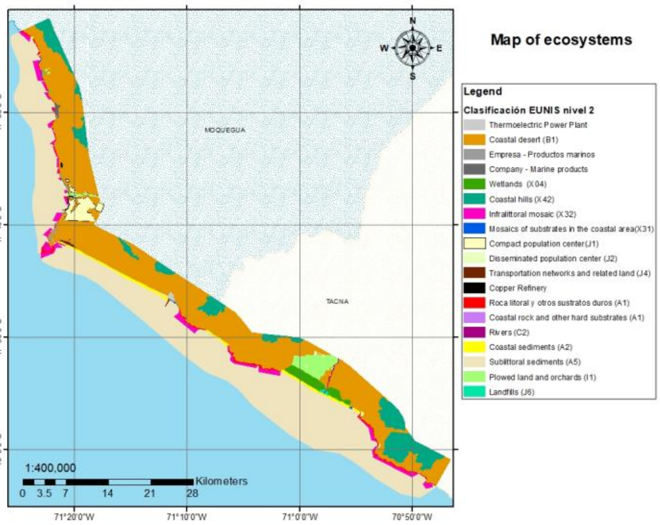

Fig. 2 Map of ecosystems identified in the study area.

B. Ecosystem Services

10 cultural, 16 supplying and 21 regulating services were identified. Of these, the plowed land and orchard zone had the highest number of provisioning ES, while the coastal mosaic area had the highest number of regulating ES Finally, a greater number of cultural ES was found in the desert zone (Fig. 3).

ES identified, according to the CICES classification model:
Cultural Services:

- Features of living systems that enable education and training.
- Natural abiotic features of nature that allow physical and intellectual interactions.
- Natural, abiotic features that have either existence, option, or legacy value.
- Features or characteristics of living systems that have either existence, choice, or bequest value.
- Features of living systems that enable activities that promote health, restoration, or enjoyment through passive or active interactions.
- Characteristics of living systems that enable scientific research or the creation of traditional ecological knowledge and aesthetic experiences.

Provision Services:

- Wild plants (terrestrial and aquatic, including fungi and algae) used for nutrition, and for breeding new strains or varieties
- Cultivated terrestrial plants (including fungi, algae) and animals raised for nutritional purposes
- Animal material harvested for the purpose of maintaining or establishing a population
- Individual genes extracted from organisms for the design and construction of new biological entities
- Wild animals (terrestrial and aquatic) used for nutritional purposes
- Seeds, spores, and other plant materials collected to maintain or establish a stock
- Ground (and subsurface) water used as (non-potable) material
- Mineral and non-mineral substances used for material used for material purposes
- Surface water and groundwater used for drinking purposes

Regulation Services:

- Bioremediation by microorganisms, algae, plants and animals.
- Control of erosion rates
- Mediation of anthropogenic wastes or toxic substances by living processes.
- Mediation of landscape disturbances of anthropogenic origin
- Dilution by marine and freshwater ecosystems
- Buffering and attenuation of mass movement.
- Maintaining nursery populations and habitats (including protection of the gene pool)
- Seedbeds
- Hydrologic and water flow cycling (including flood control and coastal protection)
- Pollination (or dispersal of gametes in a marine context)
- Regulation of the chemical condition of saline waters by living processes
- Pest control (including invasive species)
- Weathering processes and their effect on soil quality
- Water quality
- Decomposition and fixation processes and their effect on soil quality.
- Mass fluxes
- Maintenance and regulation by natural inorganic chemical and physical processes.
- Mediation of disturbances by abiotic structures or processes
- Regulation of the chemical composition of the atmosphere and the oceans
- Dilution of toxic substances by marine and freshwater ecosystems by non-living processes
- Regulation of the chemical composition of the atmosphere and the oceans, and regulation of temperature and humidity, including ventilation and transpiration.

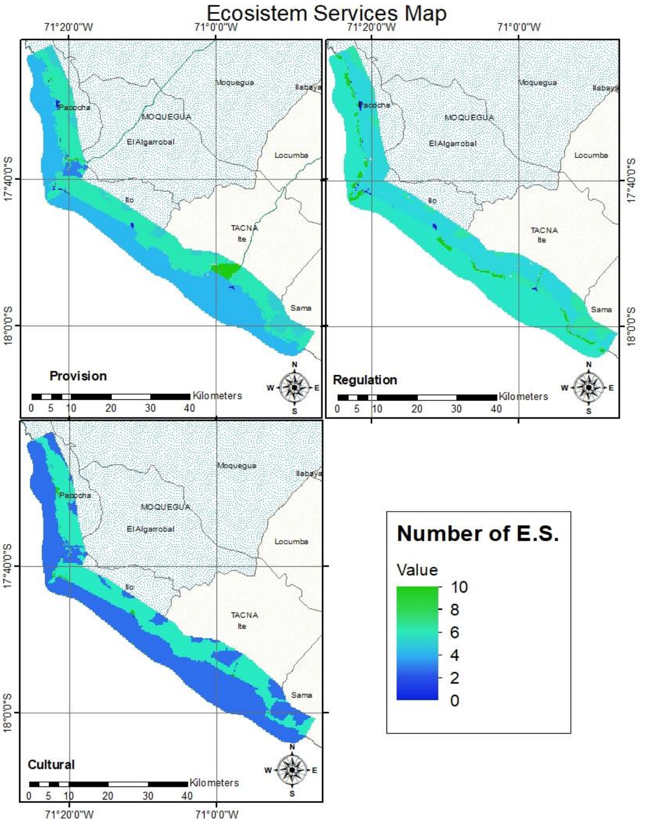

Fig. 3 Maps of the number of ecosystem services per ecosystem evaluated.

C. *Ecosystem Pressures*

The IR analysis, shown that the areas with the high biological pressure were the marine areas near to the mouth of the Osmore and Locumba rivers, both affected by urban/rural activities, i.e., waste from the city of Ilo and the town of Ite (Fig. 4).

Chemical pressure is more intense and dispersed than the other pressures because mining is the main economic activity in the region and its effect is notorious in the coastal zone, with the area in front of the Ite wetlands being the point of greatest chemical pressure (Fig. 5).

Finally, physical pressure has the least spatial presence and is most intense in the area of Puerto Grau (Fig. 6).

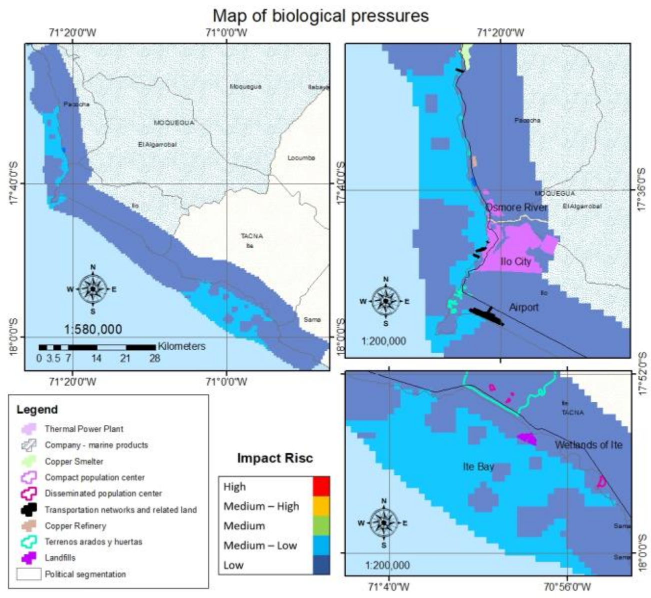

Fig. 4 Ecosystem Pressures - Biological Pressures

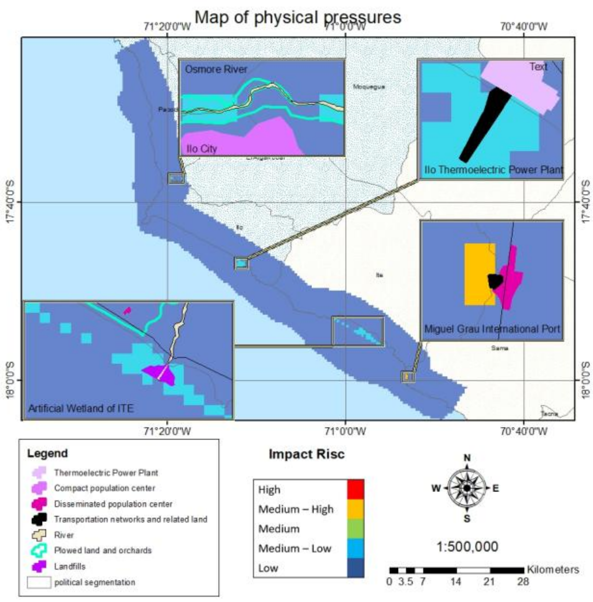

Fig. 5 Ecosystemic Pressures - Physical Pressures Maps

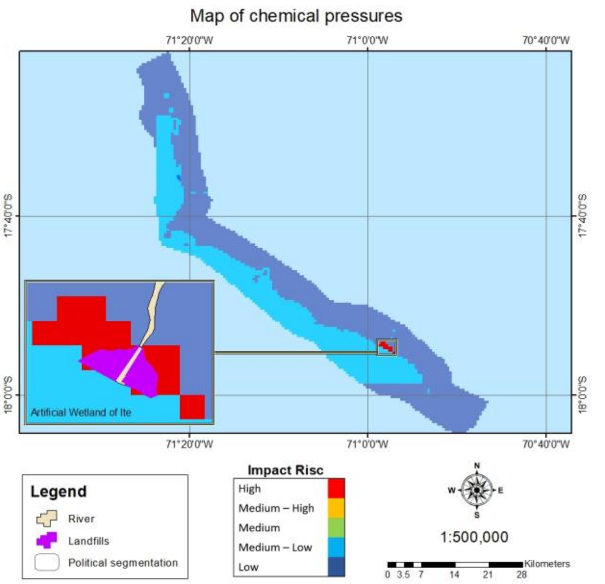

Fig. 6 Ecosystemic Pressures - Chemical Pressures Maps

C. Proposed Management Scenarios

Two large coastal marine conservation (protection) areas were suggested, which include hilly ecosystems (Lomas de Morro Sama, Huacaluna and Tacahuay), part of the coastal desert, the intertidal zone, and natural banks. These zones are spatially located very similarly to the baseline reserve zones but are different in size.

For the preservation zones, the model establishes the river basins and areas with little human intervention, and areas adjacent to the conservation zones, as a buffer. There covers a larger area than those zones with similar management characteristics in the baseline (Fig. 7).

The sustainable use zones areas are placed in the urban/rural, farming and fishing areas.

Finally, three recovery zones are proposed in areas with the highest incidence of ecosystem pressures, there are located in the marine zone in front of the Ite wetlands (high chemical pressure), in front of Pacocha (high biological pressure) and in front of the Southern Copper Corporation copper refinery (chemical and biological pressure) (Fig. 7). Consequently, a restore work should be done to the health of these ecosystems, focusing on remediation of metal and human waste contamination.

The Sustainable Use zones are those that cover a greater percentage of the study area (30%), as shown in Figure 8, while the zones that are less representative are the recovery areas (16%) (Fig. 8).

Regarding the distribution of features, we can observe that rivers were mostly considered within preservation areas, while natural banks were prioritized in sustainable use areas. Ecosystem pressures were distributed among the recovery, sustainable use and protection zones (respectively), while ES were distributed similarly, with the protection zones containing more regulating and cultural ES, and the sustainable use area presenting more supplying ES (Fig. 9).

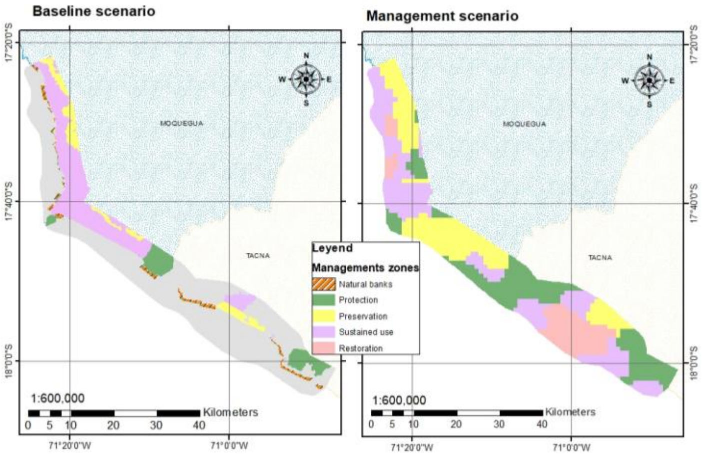

Fig. 7. Base map of current management and map of proposed management.

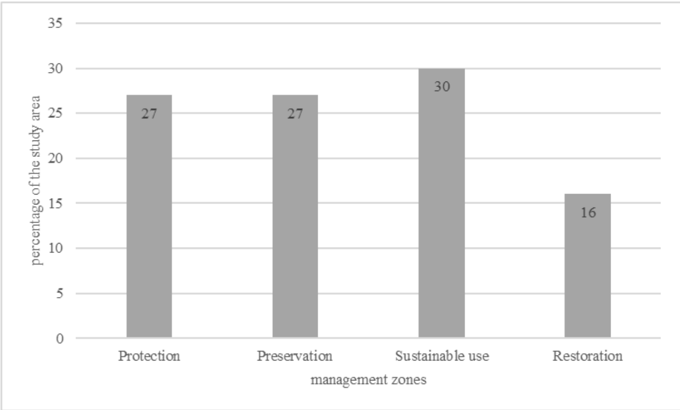

Fig. 8 Percentage of marine and terrestrial areas contained in each management zone.

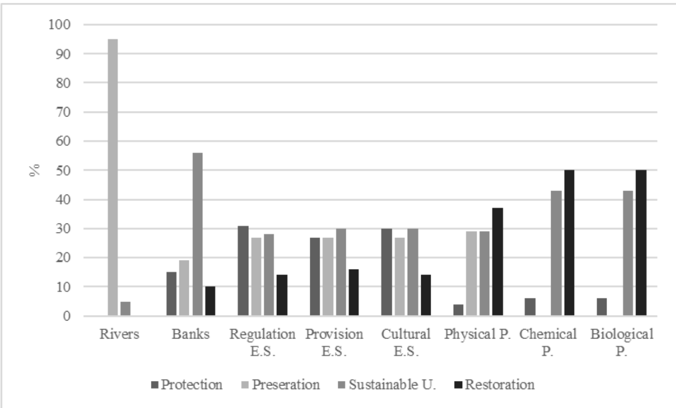

Fig. 9 Maps Total percentage of conserved features in each management zone (banks= natural banks).

The existing and projected natural protected areas were included in the "protection zone", expanding their area according to the model, to optimize the generation of ES, obtaining in the proposal natural protected areas ranging from the marine zone to the coastal hills (Lomas de Morro Sama, Huacaluna and Tacahuay).

Regarding "preservation zones", rivers were included, with the objective of increasing management measures for their care and responsible use, to avoid conflict over their use and pollution. It also includes areas bordering the "conservation zones", which are necessary to provide them with an adequate buffer area.

The areas of greatest chemical and biological pressure were considered as recovery zones, in order to convert them through proper management into productive zones in the near future, similar to their healthy counterpart ecosystems.

The "Sustainable Use" zone covers the largest area of the study

IV. DISCUSSION AND CONCLUSIONS

In the current Ecological and Economic Zoning (EEZ) scheme, the areas designated as "Priority Conservation Zones" include Lomas de Huacaluna and Tacahuay. There are also two natural reserves: Punta Coles and Lomas de Morro Sama [31]. These areas are identified in the proposed management model as protection zones (nature reserves), covering broader areas than the current designations.

As a result of the model, the creation of new marine-coastal natural protected areas is proposed. These protection zones would encompass natural mollusc banks in the marine area, coastal hill ecosystems in the terrestrial area, and the narrow corridor linking both zones. Joint management of these areas is essential due to their ecological interdependence. Coastal hill ecosystems form when the temperature of continental marine waters decreases, producing dense fog during the austral winter that comes into contact with the Andean foothills. This fog supports a unique type of vegetation that can grow from near sea level up to approximately 1,000 meters in elevation [20]. Therefore, avoiding contamination of the adjacent marine zone is crucial, as pollutants may be transported inland and impact these fragile ecosystems.

The ecological importance of hill ecosystems in the study area has been previously documented [32]. In the Tacna region, a study conducted in the Morro Sama hills described how vegetation captures atmospheric water and transfers it to the soil, eventually reaching the water table and emerging at outcrops used by local herders. In addition, these ecosystems may possess the characteristics required for designation as bird-watching areas.

Regarding the marine ecosystems within the proposed protection zone, the presence of significant natural mollusc banks is noteworthy, as highlighted by Baldarrago et al. (2017) [33]. Moreover, this conservation area contains extensive macroalgal beds, including species such as *Lessonia nigrescens* and *Lessonia trabeculata* [34]. Given their high ecological value, it is crucial to include these marine habitats within the protection zones established in the management model.

Additionally, protecting the strip of beach between the sea and the hills can prevent residential development, which poses significant environmental impacts. Avoiding such activities will help ensure proper management of the hills and the nearby natural banks, allowing these areas to remain highly productive in terms of ecosystem services (ES). It is important to note that these areas are not intended to be fully restricted, as Peru's Natural Protected Areas Law [35] allows for their sustainable use, ensuring that these ecosystems continue to provide valuable ES.

Currently, the hill areas are managed as "zones designated for protection due to soil and erosion limitations," according to the Moquegua EEZ [31]. In Tacna, the Ite wetlands have been preserved as tourist areas since their establishment in 1997, aiming to rehabilitate regions affected by former mining tailings [36]. In the proposed management model, the Ite wetlands are classified as "Preservation Zones." It is also proposed that the Osmore and Locumba rivers be designated as "Preservation Zones" due to their ecological importance, alongside areas adjacent to protection zones to serve as buffer zones; selected coastal hills are also included.

The inclusion of rivers in these zones is due to the high demand for water resources for agriculture, livestock, human consumption, and more impactful activities such as mining, which is carried out in high Andean regions. Fernández et al. (2019) describe the socio-environmental conflicts between communities and mining companies, noting the direct relationship between Southern Copper Corporation and the cities of Ilo and Ite. According to these authors, Ilo depends on the operations of the fishing port, fish-processing industries, and the copper smelter and refinery of Southern Peru, while Ite is a mainly rural area dedicated to milk production. These two communities share water sources with the mining company and are jointly impacted by its emissions and waste. At the same time, the company influences both towns by providing employment and development programs [37].

Studies conducted in the Ilo Valley, located within the Osmore River basin, have shown that fruits and vegetables analyzed in the area contained traces of lead [38]. The conflicts between river-dependent activities—particularly mining and agriculture—highlight the need for management plans for these watersheds. This necessity is reflected in the proposed management model, which includes rivers in preservation zones to ensure sustainable use of all associated activities.

Regarding sustainable use zones, the current EEZ management scheme focuses on the productivity of the coastal desert and urban/rural areas. The proposed management model expands this vision to include port zones and marine productivity (fishing, aquaculture), which must also be managed sustainably.

Peru is one of the leading industrial fishing nations in Latin America. De la Puente & López (2019) [39] propose a fisheries management mechanism that assesses the ecological impact of fishing by species. This is essential to ensure resource sustainability by maintaining the environmental conditions required for the reproduction of hydrobiological populations. In the proposed sustainable use zones, this method could be adapted for artisanal fishing to promote sustainability. Similar management approaches could also be implemented in protection and preservation zones, tailored to the specific requirements of each.

Finally, recovery zones should be managed with the goal of transitioning them into sustainable use areas in the future. The model designates the area near the Ilo coastline, in front of the copper smelter and refinery, as a recovery zone. This area experienced improper slag disposal for 22 years, until 1985 [36]. It also includes the marine areas at the mouths of the Osmore and Locumba rivers, where both chemical (heavy metal traces) and biological (human and animal waste) pressures are significant. A current example of a successfully restored ecosystem is the Ite Wetland, which was created over 1,700 hectares of former mining tailings to mitigate their impact [40]. The formation of this wetland has attracted fauna, such as insects, which play vital roles in nutrient recycling and serve as both primary and secondary consumers. These insects, in turn, are food for birds and serve as indicators of ecosystem functionality [41]. The Ite Wetland remains in the process of ecological recovery and is now recognized as an Important Bird Area (IBA) [13].

The proposed management scenario can be classified as a strategic model [42], as it incorporates key elements for decision-makers, such as human activities, population distribution, and the protection of ecosystem resources.

This study was developed using the principles and criteria of Ecosystem-Based Management (EBM), which promotes ecosystem-focused management that ensures the continued provision of ES and supports human well-being. Central to this approach is the recognition of the strong interconnection between society and ecosystems [1, 43].

This approach has been implemented in other contexts and countries such as in the Gulf of Fonseca (Central America), where they propose a regional governance strategy that integrates local people, resource sustainability, and ecosystem conservation. It should be noted that the active participation of local stakeholders is key to the functioning of this model [44].

The work of Periago et al. (2023) in the Argentine Sea highlights the need to use conservation planning based on ecological representativeness and spatial efficiency. It also highlights the importance of models to assist in the creation of new Marine Protected Areas (MPAs) [45]. Periago uses environmental and socioeconomic information to define conservation areas. The inclusion of the socioeconomic component in these models is particularly relevant, since we start from the relationship between ecosystem and human health as a basis for the construction of a management proposal, for example, the conservation of natural shellfish beds and ecological corridors between the sea and the coastal hills would also contribute to ensuring food security in the future.

Regarding the methodology applied in scenario modeling, tools such as Marxan with Zone and Zonation have been widely used because of their flexibility in introducing ecological and socioeconomic criteria. In the eastern English Channel, it was shown that, although both tools gave similar zoning results, Marxan stood out for generating more cost-effective solutions, while Zonation prioritized spatial connectivity [46]. This flexibility is also pointed out by the study of Vandeperre et al. in the Mediterranean Sea, it highlights the high representativeness of biodiversity in the results modeled with Marxan, but at the cost of the loss of potential activities such as fishing. However, when adjusted conservation objectives, the socioeconomic impact of Marxan is comparable to that of Zonation, demonstrating that parameter adjustment plays a crucial role in balancing the ecological and economic benefits of zonation [47]. Thus, selecting the appropriate modeling tool should be according to the specific objectives of the planning process.

IV. Recommentadions

It is recommended to prioritize the creation of interconnected protected areas and to promote participatory governance involving local communities. This study can be used for decision-making in coastal marine planning.

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