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Design Optimization of Bird Conservation Stations Upon Analysis of Bird Food and Habitat Requirement

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ABSTRACT

This study aims to address the issue of bird conservation along the coastal regions of China, specifically focusing on the coastline of Guangdong Province. By establishing various types of bird observation and conservation stations, as well as facilities such as fish ponds, the study seeks to provide better living spaces and food supplies for birds. Initially, the distribution and survival conditions of birds in Guangdong Province are discussed, listing several large existing conservation stations and introducing their biological conditions. The study also delves into the living habits of birds, outlining the seasonal patterns of common migratory bird species. Furthermore, the potential impacts on waterbirds are analyzed, with a focus on the potential hazards of food to birds, and the importance of strengthening the management and protection of aquatic ecosystems is emphasized. By comprehensively considering factors such as habitat environment and food supply, more effective protection of coastal birds in China can be achieved. The study uses data to roughly simulate the potential demand for bird conservation stations in various regions of Guangdong Province. The task primarily involves establishing a linear programming model to determine the number and type distribution of bird conservation stations along the Guangdong coastline. Relevant coastal data from Guangdong Province are collected, and the parameter values of each model are substituted into the model. The solution is obtained using Matlab software, followed by an analysis of the results and recommendations provided to relevant departments.

Introduction

Waterbirds are relatively common, especially along the coast. Herons, such as the great egret, little egret, and night heron, are common, but certain sandpipers and ducks, such as the spoon-billed sandpiper and Chinese merganser, are critically endangered species. Despite the government's efforts to protect the environment, some species have become extinct, such as the Auckland merganser, due to past environmental damage. To prevent such tragedies from happening again and to better protect birds, coastal bird conservation areas and habitats, which are crucial for bird resting and feeding, are particularly important[1]. The question arises of how to economically and efficiently establish conservation areas to protect birds. One of the more effective and rapid methods for bird conservation is the establishment of various types of conservation stations[2].

Literature Review

Previous scholars have conducted in-depth research on this issue. Honda et al.[3] studied the changes in the proportion of metal elements in birds over time, finding that these metals were highly concentrated in the liver, kidneys, feathers, bones, and skin, with lower concentrations in muscles and the brain. They concluded that fish, as a food source for birds, contribute to the increase in elements like Pb, Ni, and Hg with age. Jinling Liu et al.[4] researched the retention of heavy metals in birds, discovering the significant retention of heavy metals in fish in the South China Sea and highlighting its dangers. Penghou et al.[5] studied the distribution of birds along the Chinese coastline, presenting data on 488 different bird species and highlighting their main aggregation areas. Lu Zhang et al.[6] emphasized the

dependence of over 240 migratory bird species on the Chinese coastline and pointed out the ongoing reduction of wetlands, concluding that bird conservation should focus on urbanizing rural areas. Theunis Piersma et al.[7] addressed the serious loss of species in the Yellow Sea mudflats and its adverse impact on bird survival, noting potential threats from development in Jiangsu. Zeng Xiangwu et al. analyzed waterbirds in the Haifeng Bird Conservation Area in Guangdong using transect and point sampling methods, identifying 92 bird species, with storks and herons being the most numerous, and found greater species diversity but lower overall diversity in winter. Li Hui et al.[8] used the MaxEnt model to collect bird data from Shenzhen Bay, concluding that water sources significantly impact birds and that bird numbers decrease with habitat fragmentation. Xuege Wang et al.[9] studied changes in coastline length and environment from 1980 to 2018 in specific regions of China, highlighting environmental damage caused by human activities, particularly construction and land reclamation. Jeganathan Pandiyan et al.[10] found a strong correlation between metal content in waterbirds' tissues and their food, using non-invasive biomonitoring techniques to analyze deceased waterbirds. They emphasized the need for enhanced management and protection of aquatic ecosystems to ensure the survival of wild species.

In summary, current research primarily analyzes bird survival from various aspects such as food and habits. However, there is a lack of comprehensive consideration of the construction of conservation facilities that integrate habitat environment, food supply, and other functions for bird protection. This paper attempts to study the distribution of birds along the Chinese coast and resource allocation, focusing on the coastline of Guangdong Province, particularly the South China Sea. Recommendations are made for bird conservation along the Chinese coast by establishing various types of bird observation and protection stations, as well as fish ponds, to provide better living spaces for both migratory and resident bird species.

Analysis of Bird Survival Status Along the Guangdong Coast

Currently, due to extensive urbanization, bird habitats are continuously being compressed. This paper will attempt to deduce habitat requirements for birds in Guangdong by analyzing national data, and prioritize the establishment of different bird conservation stations through priority and funding planning. This section will focus on analyzing the basic conditions and survival status of birds along the Guangdong coast[11].

Analysis of Bird Conservation Areas Along the Guangdong Coast

Guangdong Province is rich in bird resources. Through literature review and data collection, typical bird conservation areas in Guangdong Province have been compiled. Below is the distribution of some bird conservation areas in various cities within Guangdong Province:

Shenzhen Bird Watching Conservation Area: Located on the east side of Shekou Peninsula, Nanshan District, Shenzhen, this is the only bird-watching conservation area in Shenzhen. It primarily protects coastal and wetland ecosystems and has high ornamental value.

Guangzhou Liwan Lake National Urban Wetland Park: Located in the northwest part of Liwan District, Guangzhou, this urban wetland park features lakes and rivers as its main landscapes, protecting many rare and endangered waterbirds.

Shaoguan Xianüyan Nature Reserve: Located in the northeast of Wujiang District, Shaoguan, this is the only karst peak forest nature reserve in southern China. It protects rare species such as Mandarin Duck, Golden-throated Barbet, and Pine Bunting.

Zhanjiang Dongshan Island Archipelago Nature Reserve: Located in the southeast sea area of Zhanjiang, this is an important area for the habitat of rare birds in China, primarily protecting over 130 species of rare birds including the Black-headed Gull, Black-tailed Gull, and Three-toed Woodpecker.

Other Nature Reserves and Wetland Parks: Several other nature reserves and wetland parks also possess significant bird resources, such as the Maoming Panlongjiang Wetland Park and the Nanhai Jianghai Waterbird Nature Reserve in Foshan.

By focusing on these conservation areas, the study aims to provide recommendations for the effective protection and management of bird habitats in Guangdong Province.

Table 1. Area, Bird Species, and Vegetation Conditions in Various Cities of Guangdong Province

City	Area	Bird Species	Vegetation Conditions
Shenzhen City	Bird Watching Protection Zone: approximately 380,000 square meters	Common Bird Species: Kingfisher Family: Red-billed Blue Magpie (Urocissa erythroryncha), White-throated Kingfisher (Halcyon smyrnensis), Little Blue Kingfisher (Alcedo atthis), Blue-winged Pitta (Pitta moluccensis). Heron Family: Grey Heron (Ardea cinerea), Intermediate Egret (Ardea intermedia), Great Egret (Ardea alba), Black-crowned Night Heron (Nycticorax nycticorax). Endangered Bird Species: Yellow-breasted Bunting (Emberiza aureola), Silver Pheasant (Lophura nycthemera), Scaly-sided Merganser (Mergus squamatus).	Coastal Grassland: Found in beaches and coastal salt marshes, mainly composed of plants like bulrush (Typha) and seablite (Suaeda). Coastal Secondary Forest: Comprised of small trees and shrubs, such as Chinese White Olive (Canarium album), Chinese Holly (Ilex chinensis), and Camellia (Camellia japonica). Wetland Vegetation: Includes three types: submerged plants, floating-leaved plants, and riparian vegetation, such as water caltrop (Trapa natans), water chestnut (Eleocharis dulcis), bulrush (Typha), and common reed (Phragmites australis). Coastal Shrubs: Predominantly found in dikes and coastal areas, featuring species like Phragmites (Phragmites australis), Cyperus (Cyperus spp.), and Michelia (Michelia figo).
Guangzhou City	Liwan Lake National Urban Wetland Park: 270,000 square meters	Common Bird Species: Duck Family: Wild Duck (Anas platyrhynchos), Mallard (Anas platyrhynchos), Spot-billed Duck (Anas poecilorhyncha). Heron Family: Grey Heron (Ardea cinerea), Yellow Heron (Ardeola	Herbaceous Plants: Reed Family: Includes species such as reed (Phragmites), bulrush (Typha), and calamus (Acorus), which grow around the lake's wetlands, stabilizing the shorelines and contributing to oxygenation while

City	Area	Bird Species	Vegetation Conditions
		bacchus), Egret (Egretta garzetta), Little Egret (Egretta garzetta).	absorbing carbon dioxide. Sedge Family: Includes species like sedge (Carex) and rush (Juncus), which thrive in wetlands and help absorb nutrients from water, maintaining ecological balance.

Table 1. Area, Bird Species, and Vegetation Conditions in Various Cities of Guangdong Province

City	Area	Bird Species	Vegetation Conditions
Guangzhou City	Liwan Lake National Urban Wetland Park: 270,000 square meters	Pigeon Family: Spotted Dove (Streptopelia chinensis), Red-billed Pigeon (Columba livia), White-necked Long-tailed Pigeon (Columba palumbus). Gull Family: Black-headed Gull (Chroicocephalus ridibundus), Great Gull (Larus argentatus), Little Tern (Sternula albifrons). Endangered Bird Species: Spotted Dove (Streptopelia chinensis), Cockatoo (Cacatua galerita), Great Bustard (Otis tarda).	Aquatic Plants: Floating-leaved Plants: Examples include duckweed (Lemna) and water smartweed (Polygonum amphibium), which float on the lake's surface and reduce algal growth, keeping water clean. Submerged Plants: Examples include water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes), whose roots anchor in the lakebed, maintaining ecological balance by absorbing nutrients and oxygen from the water.
Shaoguan City	Xiannüyan Nature Reserve: approximately 1.07 million hectares	Common Bird Species: Egret (Egretta garzetta), Tern (Sternidae), Red-billed Gull (Larus ridibundus), Oriole (Oriolus), Mallard (Anas platyrhynchos), Bar-headed Goose (Anser indicus), Red-legged Duck (Anas erythrorhyncha). Endangered Bird Species: Sichuan Partridge (Arborophila rufipectus), Yellow-headed Parrot (Amazona oratrix),	Primary Forest: Xiannüyan Nature Reserve contains dense primary forests with both tree and shrub layers, featuring common tree species such as Eucommia (Eucommia ulmoides), Hedyotis (Hedyotis diffusa), and large-leaved privet (Ligustrum lucidum). These trees form dense canopies that provide habitats for

		Watercock (Gallicrex cinerea), Red-bellied Pitta (Pitta erythrogaster).	wildlife.Lithophytic Plants: Due to the unique geological conditions of Xiannüyan Nature Reserve, many exposed rocks and cliffs are present, hosting lithophytic plants adapted to rock environments by absorbing moisture from rain and air. Common lithophytes include rock fern (Asplenium) and lichen (Lecanora).

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City	Area	Bird Species	Vegetation Conditions
Shaoguan City	Xiannüyan Nature Reserve: approximately 1.07 million hectares		Climbing Plants: Xiannüyan Nature Reserve is also a haven for climbing plants, which thrive by covering trees and rocks. Common climbing plants include magnolia vine (Schisandra chinensis) and wisteria (Wisteria sinensis). Herbaceous Pants: Various herbaceous plants can be found in the open areas and wetlands of Xiannüyan Nature Reserve, exhibiting diverse flowers and leaves with seasonal changes. Common herbaceous species include purslane (Portulaca oleracea) and wild lilies (Lilium spp.).
Zhanjiang City	Dongshan Island Archipelago Nature Reserve: approximately 142,000 hectares	Common Bird Species: Red-billed Egret (Egretta eulophotes): A large waterbird commonly found in wetlands and coastal areas, primarily feeding on fish. They breed and forage within the reserve. Scarlet Ibis (Eudocimus ruber): A	Mangroves: Mangroves are one of the most significant vegetation types in this reserve. Mangrove plants are adapted to saline and intertidal environments and are tolerant of salinity and waterlogging. Common mangrove species in the reserve include mangrove trees (Rhizophora spp.) and sea hibiscus (Hibiscus tiliaceus). The moist

City	Area	Bird Species	Vegetation Conditions
		heron species with distinctive red plumage, commonly found in mangroves and mangrove wetlands. They breed in the reserve and feed on small fish, shrimp, and insects. White-breasted Waterhen (Amaurornis phoenicurus): A medium-sized waterbird commonly found in wetlands and rivers.	understory of mangroves provides essential habitats for numerous bird species and marine organisms. Beach Vegetation: The reserve's beaches host some sand dune plants, such as sea blite (Suaeda salsa) and dock (Rumex spp.).

Table 1. Area, Bird Species, and Vegetation Conditions in Various Cities of Guangdong Province

City	Area	Bird Species	Vegetation Conditions
Zhanjiang City	Dongshan Island Archipelago Nature Reserve: approximately 142,000 hectares	They breed in the reserve and feed on fish, frogs, and mollusks. Kingfisher (Alcedo atthis): A small bird commonly found near woodlands and water bodies. They breed in the reserve and feed on insects and small invertebrates. Endangered Bird Species: Black-faced Spoonbill (Platalea minor): A rare spoonbill species with very limited global population, primarily inhabiting wetlands and estuaries, feeding on small fish. The reserve provides crucial habitat and protection measures to support the reproduction and survival of the Black-faced Spoonbill. Black-necked Crane (Grus nigricollis): A tall crane species also classified as endangered. They breed in wetlands and marshes, feeding on insects, fish, and amphibians. The establishment of the reserve helps to provide a safe habitat for the conservation and recovery of the Black-necked Crane.	These plants play a vital role in stabilizing sand dunes and maintaining beach ecosystem balance. Coastal Wetland Vegetation: Wetland areas of the reserve, including estuaries and wetlands, are populated with wetland plants like common reed (Phragmites australis) and water bamboo (Zizania latifolia), which can adapt to moist environments and provide critical ecological functions and habitats for wetland ecosystems. Woodland and Shrub Vegetation: Besides coastal vegetation, the islands in the reserve also contain woodland and shrub vegetation, such as beech (Fagus spp.) and camellia (Camellia japonica). These plants provide green cover for the terrestrial ecosystems of the islands and offer habitats and foraging sites for some terrestrial animals.
Maoming City	Panlong River Wetland Park: approximately 1,400 hectares	Common Bird Species: Red-billed Gull (Larus ridibundus), Family: Laridae. Tern (Sterna spp.), Family: Sternidae. Little Egret (Egretta garzetta), Family: Ardeidae. Cattle Egret (Bubulcus ibis), Family: Ardeidae. Spot-billed Duck (Anas poecilorhyncha), Order: Anseriformes, Family: Anatidae.	Wetland Vegetation: The park features extensive reed beds, shallow water areas, lakes, and rivers, where dense reed (Phragmites australis) and bulrush (Typha spp.) grow, providing essential wetland habitat.

Table 1. Area, Bird Species, and Vegetation Conditions in Various Cities of Guangdong Province

City	Area	Bird Species	Vegetation Conditions
Maoming City	Panlong River Wetland Park: approximately 1,400 hectares	Eurasian Tree Sparrow (Passer montanus), Order: Passeriformes, Family: Passeridae. Great Egret (Ardea alba), Family: Ardeidae. Mallard (Anas platyrhynchos), Order: Anseriformes, Family: Anatidae. Red-throated Thrush (Turdus ruficollis), Family: Turdidae. Blue-crowned Hanging-Parrot (Loriculus galgulus), Order: Psittaciformes, Family: Psittacidae. Endangered Bird Species: Black-faced Spoonbill (Platalea minor), Family: Ciconiidae. Daurian Redstart (Phoenicurus auroreus), Order: Muscicapiformes, Family: Muscicapidae. Oriental Scops Owl (Otus sunia), Order: Strigiformes, Family: Strigidae. Orange-bellied Leafbird (Chloropsis lazulina), Family: Chloropseidae.	Aquatic Plants: Lakes and rivers support various aquatic plants such as water lilies (Nymphaea spp.), sweetflag (Acorus calamus), and duckweed (Lemna spp.). Woodland Vegetation: Surrounding the wetland park, there are woodlands with numerous trees and shrubs, including cypress (Cupressus spp.), pine (Pinus spp.), willow (Salix spp.), and mahogany (Swietenia spp.).

Bird Behavior and Habits

Given that the fundamental survival needs of birds include habitat, food, reproduction, and cooperation, this section will analyze their living habits in terms of habitat, foraging, reproduction, and cooperation. The living habits of birds encompass habitat selection, food acquisition, reproduction, cooperation, and defense mechanisms. Habitat refers to the environments that birds choose for their survival, including different types such as aquatic areas and forests. These habitats provide protection and shelter, allowing birds to evade predators, find food, and reproduce.

Food acquisition is one of the basic needs of birds. Different species adapt to various types of food based on their beak shape and body structure. Their food sources include insects, seeds, fruits, fish, and small mammals. For example, eagles prey on other birds and small mammals, finches primarily consume seeds, while pelicans are adept at catching fish.

Reproductive behavior is closely related to the seasons. Birds choose suitable sites to build nests or find cavities. Male birds often attract female partners by displaying feathers, singing, and dancing. Once mating is successful, the female lays eggs in the nest, and both parents participate in incubating and feeding the young until they can live independently.

Some birds live in social groups, forming colonies and cooperating with each other. Migratory birds gather in large flocks and fly collectively during migration, helping and protecting each other. Additionally, some birds exhibit social behavior, such as magpies, which form complex social structures and cooperate to protect nests and compete for food resources.

Living in groups can provide better defense and protection mechanisms. Waterbirds in a group can collectively monitor the surrounding environment, detect potential threats early, and react accordingly. When a predator approaches, they can act collectively, using their numbers to intimidate or mislead the predator. Moreover, group living can offer more efficient foraging methods. Waterbirds in groups coordinate their actions to find food resources more effectively. For example, some waterbirds form circles to drive fish towards the surface, making it easier to catch them.

Seasonal Patterns of Bird Species and Populations in Guangdong Province

As a significant stopover on the migratory routes of birds, Guangdong Province sees a large influx of migratory birds in spring and autumn. In spring, many migratory birds travel from the south to Guangdong Province, such as the Siberian Crane, Whooper Swan, White Stork, and Black Swan. In autumn, these birds begin their northward migration, including species like the Common Crane, Ruddy Shelduck, Black Stork, and White-tailed Eagle. Additionally, some migratory birds that overwinter also stay in Guangdong Province, such as the Red-necked Grebe and Black-headed Gull.

Guangdong Province also hosts numerous resident birds that breed, overwinter, and reside locally. The resident bird species are relatively stable in comparison to migratory birds. For example, species like the Light-vented Bulbul, Yellow-bellied Prinia, White-browed Laughingthrush, and Fairy Pitta are common resident birds in Guangdong Province. The populations and species of these resident birds also vary with the seasons. According to historical data and research, the number and variety of migratory birds in Guangdong Province show significant seasonal dynamics. Most migratory birds peak in numbers between March to May and September to November each year, with a more concentrated and abundant presence from March to May.

The changes in the number and types of resident birds are small but also vary with the seasons. For instance, in summer and autumn, some resident birds begin to breed or migrate, resulting in a slight increase in their numbers. The presence of these migratory and resident birds enriches the bird diversity in Guangdong Province and provides abundant opportunities for bird watchers. Protecting the habitats and ecological environment of Guangdong Province is crucial for maintaining the stability and normal migration of bird populations.

Below are examples of common migratory and resident birds in Guangdong Province:

(1) Migratory Birds:

1. Black-headed Gull (Larus ridibundus): Appears in Guangdong Province during spring and autumn, with significant populations in areas such as Shenzhen, Zhuhai, and Zhanjiang.
2. Barn Swallow (Hirundo rustica): Migrates from the south to Guangdong Province in spring and autumn, with spring migrations being more numerous.
3. Great Egret (Egretta alba): Typically migrates to Guangdong Province in autumn and breeds locally. The southern coastal and inland river areas of Guangdong Province are the primary regions for Great Egret breeding and habitation.

(2) Resident Birds:

1. Common Kingfisher (Alcedo atthis): A resident bird in Guangdong Province that inhabits mountain rivers, ponds, and lakes.
2. White-naped Crane (Grus vipio): A resident bird in Guangdong Province, usually overwintering locally. Major habitats in Guangdong Province include Shenzhen, Zhuhai, and Shantou.
3. Long-tailed Shrike (Lanius schach): Another resident bird in Guangdong Province, primarily inhabiting grasslands, shrubs, and forest edges in mountainous and hilly areas. Their breeding season is mainly in spring

and summer.

Seasonal changes impact the bird population in the region studied in this paper, with the arrival of migratory birds significantly increasing food demand. Therefore, this paper attempts to analyze the necessity of constructing bird conservation stations and determine the optimal strategies for their layout by studying bird behavior, distribution characteristics, and the current bottlenecks in their survival environment[12].

Analysis of Basic Characteristics and Layout Optimization Model for Bird Conservation Stations

Basic Concept of Bird Conservation Stations

Bird conservation stations are institutions or locations specifically established for the protection and study of birds. Their primary functions include bird surveys, monitoring and research, habitat protection and restoration, and educational outreach. These stations employ various methods such as fixed-point observation, banding, and sound recording to systematically record and analyze bird populations, distributions, species, and behaviors. This aids in understanding bird population dynamics, migration routes, and timing, providing a scientific basis for conservation measures. Additionally, they undertake educational outreach tasks. Through exhibitions, lectures, training, and tours, bird conservation stations educate the public about bird conservation, raise awareness, and promote harmonious coexistence between humans and nature. These educational activities help cultivate public interest and understanding of bird conservation, encouraging participation from all sectors of society in conservation efforts.

However, the core function of bird conservation stations is to provide basic habitat and food supplies to maintain bird populations and ecological balance. These stations maintain and improve bird habitats through measures such as vegetation restoration and water quality improvement, including the protection of natural wetlands, forests, grasslands, and artificially created habitats like artificial wetlands and vegetation restoration areas. These measures help provide abundant food resources, safe breeding sites, and suitable migration stopovers, creating an appropriate living environment for birds.

Below is an image (Figure 1) of a small bird conservation station. For such small conservation stations, an optimization model for layout can be established to enhance their conservation effectiveness and sustainable development capacity.

Figure 1. Bird Conservation Station

Analysis of Basic Survival Needs of Birds

Coastal birds have different food preferences. Seabirds and waterbirds primarily inhabit marine or coastal areas, relying mainly on marine fish, fish eggs, and crustaceans. Gulls, albatrosses, and kites are examples of seabirds. Predatory waterbirds such as pelicans and cormorants primarily hunt fish. They possess keen vision and agile bodies, enabling them to catch fish through diving. Algae-eating waterbirds, including some ducks and geese, feed mainly on aquatic plants and plankton, absorbing proteins and nutrients from submerged vegetation.

Different bird species have varying food intake requirements. Waterfowl, which swim to forage, such as cormorants and terns, typically need to consume about 20-30% of their body weight daily to meet their energy needs. Waders, which forage in shallow waters, such as mandarin ducks, need to consume about 15-20% of their body weight daily. Seabirds, which live or forage in marine environments, such as gulls, typically require about 15-25% of their body weight in food daily.

Waterbirds primarily source their food from fish, crustaceans, and insects. However, these food sources can pose safety hazards, particularly due to toxins. Some fish and crustaceans live in heavily polluted waters, potentially accumulating harmful substances like heavy metals and pesticides. When waterbirds consume these animals, they ingest these harmful substances, posing health threats. An example is mercury's impact on piscivorous birds. A notable case is St. Louis River estuary in Minnesota, USA. This area, once a thriving industrial city, suffered severe water and soil contamination due to significant mercury emissions. The bald eagle, a common bird in the area, faces widespread high mercury exposure. Research shows that mercury can transfer from fish to birds through the food chain, causing various health issues.

The bald eagle, a piscivorous bird, relies mainly on fish. When mercury enters the water, it is absorbed and converted into methylmercury by microorganisms, accumulating in small plankton, benthic organisms, and fish, which are then preyed upon by birds like bald eagles, exposing them to high levels of methylmercury. Prolonged exposure to high levels of methylmercury can lead to symptoms such as sluggish behavior, reduced immunity, and reproductive problems in bald eagles. It's noteworthy that the impact of mercury on piscivorous birds like bald eagles is not short-term. Mercury persists in the environment and accumulates over time, meaning bald eagles may face mercury exposure for decades, even in the absence of new emissions, causing long-term health problems.

Similarly, birds that consume shellfish face risks due to toxic substances like red tide toxins. A notable event occurred in the Pacific Northwest of the USA in 1987, where a red tide event impacted local wildlife, including birds like gulls that feed on shellfish and small fish. These birds were exposed to high levels of red tide toxins, resulting in health issues. Red tide toxins, produced by certain single-celled algae, can form tides in the ocean. Shellfish like oysters, scallops, and clams absorb these toxins. When birds like gulls consume these shellfish, they ingest the toxins, leading to symptoms such as neurological problems, muscle spasms, and respiratory difficulties.

In Guangdong Province, China, such toxin-related incidents are less common, but the phenomenon still exists and has certain impacts. In 2011, a bird poisoning incident occurred in Jinwan District, Zhuhai City, Guangdong Province. Local waters were heavily polluted by waste and contaminants, including industrial wastewater and pesticide residues, causing severe contamination of aquatic life.

In this context, fish and shellfish are exposed to polluted water bodies and ingest contaminants. When local birds, such as seagulls, prey on these contaminated fish and shellfish, they also ingest these toxins. As a result, these birds suffer from poisoning, experiencing health issues such as respiratory difficulties and neurological abnormalities.

In addition to ingesting toxins, many seabirds in coastal and island areas are often observed consuming floating marine debris. This debris includes plastic fragments, fishing nets, polystyrene foam, and other materials. Prolonged exposure to plastic waste in the ocean leads to its breakdown into small particles known as "microplastics." Seabirds mistakenly ingest these microplastics as food, leading to the ingestion of significant amounts of plastic.

The consumption of plastic debris can lead to severe health problems for seabirds. Plastic waste fills their stomachs, causing a false sense of fullness and resulting in malnutrition. Furthermore, the chemicals within the plastic may release toxic substances, adversely affecting the birds' physiological functions. These issues can lead to reduced reproductive success, lowered immunity, and mortality among seabirds.

In Zhuhai City's Xiangzhou District, the Gongbei Coastal Wetland Park was once a dense mangrove wetland, providing habitat and feeding grounds for numerous waterbirds. However, in recent years, rapid urbanization and land reclamation activities have led to the degradation and destruction of this wetland. Extensive landfilling, river pollution, and severe damage to the wetland ecosystem have resulted in many waterbirds losing their habitats and feeding sites, with some endangered species facing the risk of extinction.

In summary, bird food sources are diverse and fraught with safety hazards. Birds also require suitable habitats, making the construction of protection stations crucial for their survival. The types of protection stations include fishponds, residential stations, and rescue stations. Different regions and bird species require tailored protection stations.

Establishing an Optimization Model for the Layout of Protection Stations

The optimization model for the layout of protection stations is a site selection optimization model designed to determine the locations of a certain number of protection stations to best meet the needs of bird populations and service areas. This model takes into account the distribution characteristics and requirements of protection stations, as well as their types and functions. In this model, protection stations are divided into three categories: type 1 protection stations for fishponds and food supply, type 2 protection stations for residential areas, and type 3 protection stations for rescue. Each type of protection station is represented by the parameter ($l = 1, 2, 3$).

The model's inputs include the coastline length (L), the number of birds along the coastline (M), and the number of birds that each protection station can serve (m_1, m_2, m_3), along with the coverage radii (r_1, r_2, r_3). Additionally, the number of each type of protection station to be established (x_1, x_2, x_3) needs to be determined. To optimize the layout of protection stations, survey data can be used to understand the construction patterns of protection stations, particularly in terms of coverage areas. This helps in determining the optimal locations of protection stations to maximize the number of birds served and the range of services provided.

To summarize, the optimization model for the layout of protection stations aims to determine the locations of a certain number of protection stations to best meet the needs of bird populations and service areas by considering factors such as bird numbers, service areas, and protection station types and functions. The model's inputs include coastline length, bird numbers along the coastline, the number of birds each protection station can serve, coverage radii, and the number of each type of protection station to be established. By studying the construction patterns of protection stations, their layouts can be optimized to provide maximum protection and service.

The construction cost of each protection station is represented by (c_1, c_2, c_3), with the total available funding being (B). After setting the objective function and constraints, linear or nonlinear programming methods can be used to solve and optimize the model.

The objective function is to maximize the total number of birds served, given by: $Maximize\ (m_1\, x_1 + m_2\, x_2 + m_3\, x_3)$

The constraints include:

1. The total number of all types of protection stations should not exceed the total number of protection stations: ($x_1 + x_2 + x_3 \leq k$)
2. The coverage range of each protection station should not exceed the coastline length: ($r_1\, x_1 + r_2\, x_2 + r_3\, x_3 \leq L$)
3. The total construction and operational costs should not exceed the available funding: ($c_1\, x_1 + c_2\, x_2 + c_3\, x_3 \leq B$)

By solving the above linear programming problem, the optimal layout scheme for protection stations can be obtained to maximize the total number of birds served. The following table (Table 2) contains reference values for the parameters and variables used in the model, obtained from network searches and relevant literature.

Table 2. Parameters Used in the Model

Parameter	Range
r_1	5-15 kilometers
r_2	10-20 kilometers
r_3	3-10 kilometers
c_1	250,000 - 400,000 CNY
c_2	300,000 - 600,000 CNY
c_3	150,000 - 300,000 CNY
m_1	1,000 - 2,000 individuals
m_2	500 - 1,500 individuals
m_3	200 - 800 individuals
B	10 million CNY
k	Maximum of 20 protection stations
L	Total length of Guangdong coastline, approximately 3,368 kilometers

Solution and Result Analysis of the Optimization Model for Protection Station Layout

Parameters for Coverage Radius (r):

- (r_1) (Type 1 Protection Station): 5-15 km, taken as 10 km for model solving
- (r_2) (Type 2 Protection Station): 10-20 km, taken as 15 km for model solving
- (r_3) (Type 3 Protection Station): 3-10 km, taken as 6.5 km for model solving

Parameters for Construction Cost (c):

- (c_1) (Type 1 Protection Station): 2.5-4 million CNY, taken as 3.25 million CNY for model solving
- (c_2) (Type 2 Protection Station): 3-6 million CNY, taken as 4.5 million CNY for model solving
- (c_3) (Type 3 Protection Station): 1.5-3 million CNY, taken as 2.25 million CNY for model solving

Parameters for the Number of Birds Served per Protection Station (m):

- (m_1) (Type 1 Protection Station): 1000-2000 birds, taken as an average of 1500 birds for model solving
- (m_2) (Type 2 Protection Station): 500-1500 birds, taken as an average of 1000 birds for model solving

- (m_3) (Type 3 Protection Station): 200-800 birds, taken as an average of 500 birds for model solving

Parameter for Total Available Funding (B):

- Assumed government grant: 10 million CNY

Parameter for Total Number of Protection Stations (k):

- Assumed government approval for the construction of up to 20 protection stations

Model Solution Process and Results: By substituting the above parameter values into the model, we obtain the following solution process and results:

Objective Function: Maximize the total number of birds served: [\text{maximize: } 1500 x_1 + 1000 x_2 + 500 x_3]

Constraints:

1. The total number of all types of protection stations should not exceed the total approved number:
$$x_1 + x_2 + x_3 \leq 20$$
2. The total construction cost should not exceed the available funding:
$$32.5\,x_1 + 45\,x_2 + 22.5\,x_3 \leq 1000$$
3. The coverage range of protection stations should not exceed the coastline length:
$$10\,x_1 + 15\,x_2 + 6.5\,x_3 \leq 3368$$
4. Non-negativity constraint:
$$x_1 \geq 0, x_2 \geq 0, x_3 \geq 0$$

By programming and solving this model using MATLAB, we obtain
$$x_1 = 20, x_2 = 0\ and\ x_3 = 0$$

And the maximum number of birds that can be served is 30,000. Therefore, it is concluded that in Guangdong Province, the primary type of protection station should be Type 1, which maximizes the number of birds served to 30,000, while being an approximating model.

Under the above constraints, different regions should have different limitations. Here, only the simplest limitations are considered, i.e., determining different minimum values for different regions. In different regions, due to varying bird needs, the required number of different types of protection stations will also differ. Additionally, different construction costs in different regions need to be considered. This discussion focuses on several suitable locations for building protection stations in Guangdong Province, providing basic information for each.

Shenzhen City, Bird Demand:

Shenzhen City boasts abundant natural resources and a diverse ecological environment, attracting a large number of resident and migratory birds. The city already hosts several bird protection zones and nature reserves, reflecting a high level of commitment to bird conservation.

Natural Costs:

Shenzhen City's geographical environment is relatively complex, encompassing wetlands, mountains, and coastal areas. Establishing protection stations may require land reorganization and ecological restoration, leading to high natural costs.

Construction Cost Range:

- Type 1 Protection Station: 500,000-800,000 CNY
- Type 2 Protection Station: 600,000-1,000,000 CNY
- Type 3 Protection Station: 300,000-500,000 CNY

Zhuhai City, Bird Demand:

Zhuhai City is located on the eastern bank of the Pearl River Estuary, with rich coastal wetlands and shoreline resources that attract numerous migratory and water birds. The city already has some bird protection zones.

Natural Costs:

Zhuhai City's geographical environment is relatively flat, requiring moderate natural costs for wetland protection and vegetation restoration.

Construction Cost Range:

- Type 1 Protection Station: 400,000-600,000 CNY

- Type 2 Protection Station: 500,000-800,000 CNY
- Type 3 Protection Station: 250,000-400,000 CNY

Zhanjiang City, Bird Demand:

Zhanjiang City is situated in the western coastal area of Guangdong Province, rich in coastal wetlands and shoreline resources that attract many migratory and water birds. The city already has some bird protection zones.

Natural Costs:

Zhanjiang City's geographical environment is relatively complex, including wetlands and mountains, which may require land reorganization and ecological restoration, leading to high natural costs.

Construction Cost Range:

- Type 1 Protection Station: 450,000-700,000 CNY
- Type 2 Protection Station: 550,000-900,000 CNY
- Type 3 Protection Station: 300,000-500,000 CNY

Shantou City, Bird Demand:

Shantou City is located in the eastern coastal area of Guangdong Province, with wetlands and shoreline resources that attract some migratory and water birds. The city already has some bird protection zones.

Natural Costs:

Shantou City's geographical environment is relatively flat, requiring moderate natural costs for wetland protection and vegetation restoration.

Construction Cost Range:

- Type 1 Protection Station: 400,000-600,000 CNY
- Type 2 Protection Station: 500,000-800,000 CNY
- Type 3 Protection Station: 250,000-400,000 CNY

Meizhou City, Bird Demand:

Meizhou City is located in the northeastern part of Guangdong Province, with some wetland and mountainous resources that attract terrestrial birds. The city already has some bird protection zones.

Natural Costs:

Meizhou City's geographical environment is relatively mountainous, requiring moderate natural costs for mountain ecological restoration and vegetation protection.

Construction Cost Range:

- Type 1 Protection Station: 350,000-550,000 CNY
- Type 2 Protection Station: 450,000-750,000 CNY
- Type 3 Protection Station: 200,000-350,000 CNY

Recommendations:

- Shenzhen City: High demand for Type 1 protection stations, moderate demand for Type 2 and Type 3 protection stations.
- Zhuhai City: Moderate demand for Type 1 and Type 2 protection stations, low demand for Type 3 protection stations.
- Zhanjiang City: High demand for Type 1 protection stations, moderate demand for Type 2 and Type 3 protection stations.
- Shantou City: Moderate demand for Type 1 and Type 2 protection stations, low demand for Type 3 protection stations.
- Meizhou City: Moderate demand for Type 1 and Type 2 protection stations, low demand for Type 3 protection stations.

Conclusion

Based on the above analysis and research, the following suggestions are made: Firstly, strengthening habitat protection is crucial for conserving wild bird resources. Protecting the habitats necessary for bird survival and reproduction can reduce the damage and pollution caused by human activities. The government should increase investment in habitat protection and restoration to promote ecological environment recovery and improvement. Secondly, the government should formulate relevant policies and regulations, establish a wild bird protection management system, and strictly combat illegal hunting, selling, and consumption of wild birds to protect their legal rights. Thirdly, conducting scientific research on the ecological environment, ecological functions, and population distribution of wild bird resources in Guangdong Province is essential to provide a scientific basis for formulating protective and management measures. Research institutions should enhance studies on wild bird ecology and behavior to obtain information on their distribution, quantity, species, and ecological needs, thereby providing scientific support for bird conservation and management. Finally, protecting and managing wild bird resources in Guangdong Province is a significant task that requires the joint efforts of governments at all levels and all sectors of society. Only through collective effort can wild bird resources be effectively protected and managed, contributing to ecological environment protection and sustainable development.

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