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Original Article

Analysis of the Effectiveness Implementation of the Denpasar City Biodiversity through the DPSIR Method Framework

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Abstract *- This study evaluates the effectiveness of the implementation of the Biodiversity Management Master Plan in Denpasar City through the Driving Force, Pressure, State, Impact, Response (DPSIR) method framework, which aims to understand the dynamic interactions between human activities and urban ecosystems. Due to rapid urbanization, changes in green spaces, and the challenges posed by climate change, which worsen the conditions of local habitats, Denpasar City is facing substantial problems regarding the loss of biodiversity. This study identifies the main drivers, such as population expansion, climate change, and ecological stressors, that seem to negatively impact natural resources through habitat degradation, deteriorating ecosystems, and decreasing resilience of endemic species populations. The DPSIR framework is useful for exploring the linkages between anthropogenic drivers and environmental pressures, and its impact on environmental states, in addition to having indicators regarding policies enforced by municipal authorities. At the same time, these pressures considerably affect the urban ecosystem, decreasing in quantity and quality of ecosystem services with the provision of clean water and erosion control, affecting not only its eco-health but also social and economic conditions via lowering the satisfactory conditions of ecosystem services. This study identifies barriers to existing conservation policy on biodiversity and suggests research-providing solutions designed to increase effectiveness in its management. Maintaining the ecological balance of urban areas is such a continuous and complicated effort that it has been suggested to take cross-sectoral collaborative and adaptive policies, and increase public awareness.*

Keywords *- Biodiversity, Denpasar City, Urbanization, DPSIR, Climate Change*.

1. Introduction

Denpasar City is the development of the capital area of Bali Province, and is naturally beautiful and rich in biodiversity. Denpasar is a city comprised of its pristine flora and fauna, but also interactive (to simulate a cultured nature). The city features a variety of ecosystems, from natural ecosystems such as mangrove forests to artificial ecosystems like rice fields and reservoirs. They sustain many economically and conservationally important plant and animal taxa while also providing a vast quantity of vital ecosystem services. For instance, the rice fields of Denpasar not only support food production but also preserve traditional agrarian culture through the distinctive Subak system. Moreover, improper waste disposal can lead to environmental pollution, further threatening the already declining biodiversity. The negative impacts of rapid development on the environment, including a loss of biodiversity, are mainly the result of population increases, the construction of new infrastructure, and changes in land use. Biodiversity loss compromises a range of critical benefits, which include both ecological and economic value. Biodiversity is essential to the functioning of biotopes and the provision of ecosystem services that are critical to human survival and development [1]. Out of the 1,812,700 species identified globally, 31,750 species (1.75%) are found in Indonesia, with the moss group accounting for more than 10%. Indonesia, like Brazil, is one of the most biodiversity-rich countries in the world. Among the many differentiating features of Indonesia, its flora and fauna are extremely diverse. Indonesia is home to 12% of the world's mammals and 16% of the world's reptiles; and seventeen percent of bird species. Indonesia also has many mammals and amphibians; it is the country with the most mammals and the sixth country with the most amphibians. Indonesia is also renowned for its coastal ecosystem diversity, containing 18% of the world’s coral reefs, over 70 genera and 500 coral species, 2,500 species of fish, 2,500 species of mollusks, 1,500 species of crustaceans, and various other marine organisms [2]. As the city builds out, there are increasing pressures on

ecosystems from land conversion to pollution and climate change. One of the primary threats is uncontrolled urbanization, which degrades the quality of natural ecosystems, including the reduction of green open spaces [3]. The impacts of biodiversity loss can be ecological, social, and economic [4]. Various human activities, including deforestation and natural resource exploitation, have threatened this biodiversity [5]. However, the effectiveness of its implementation ensures that the policy remains impactful in resolving challenges like climate change and biodiversity loss [6]. Therefore, researchers aim to develop a Biodiversity Management Master Plan as a guide for the integrated protection and management of ecosystems using the Driver Pressure State Impact Response (DPSIR) approach, which is globally recognized for analyzing the complex interactions between human and environmental factors. This creates a consistent understanding of the drivers, be they biophysical, human, or climatic, creating pressure on the system (drivers), changing conditions/state, and impact, causing changes in state/ecosystem function, and adaptation responses. This research is aimed at developing a framework for strategic planning in managing, protecting, and conserving biodiversity in Denpasar.

Urbanisation, causing land-cover change, directly influences biodiversity through the alteration of natural habitat into an urban area, in addition to loss and fragmentation of habitats [7]. It has been revealed that urban expansion has caused a significant loss of quality in local ecosystems, with indirect effects being recorded for almost 60% of threatened species, meaning less capacity for the environment to support biodiversity and more habitat loss [8]. The pressure exerted on the environment through habitat loss and fragmentation associated with protected areas, especially in a biodiversity hotspot, has led to serious threats to endangered species survival and to the decline of environmental quality [9].

The purpose of this study is to assess the implementation of the Biodiversity Management Master Plan in Denpasar City employing the Drivers, Pressures, State, Impact and Responses (DPSIR) framework. This allows for exploring the causal relationship between urbanisation and biodiversity states, as well as estimating the impact of local policy- or context-induced changes to these ecosystems. It aims to identify the factors that have caused failure in policy up until now and provide evidence-based advice to strengthen and support future implementation of new policies [10]. Research related to biodiversity management in urban areas shows that policy responses often fail to adequately counterbalance the level of pressure from human activities [11]. Hence, the need for more dynamic and evidence-based biodiversity management policies, at least at the area level heavily influenced by the dynamics of urban development. Urban landscape and biodiversity within an urban area are becoming a growing concern, due to the increasing effects of rapid urbanisation, climate change, land-use conversion, and environmental degradation in compromising ecosystem stability and species extinction risk, particularly in growing city systems such as Denpasar City, Bali. Previous works conducted by Ren et al. [12] focused on the impacts of global urban expansion on habitat loss and biodiversity declines at scale, while Cui et al. [13] focused on urbanization-induced declines in functional diversity of vegetation. In addition, Zhao et al. [14] applied the DPSIR framework to evaluate urban ecosystem resilience in large Chinese cities, whereas Kristiadi et al. [15] emphasized climate change management in urban areas using DPSIR. Previous literature has, however, been more ecological, ecosystem resilience, or Climate pressure focused since the last three decades and has not conducted a thorough assessment of biodiversity management implementation efforts at the municipal level with a simultaneous Environmental, Social, and Governance (ESG) perspective. Moreover, research providing a DPSIR framework on urban biodiversity governance in Indonesia tropical cities are scarce. The innovative aspect of this study is in integrating the DPSIR framework to evaluate biodiversity management implementation success through quantifying linkages between driving forces, environmental pressures, ecosystem condition, ecological impacts and policy responses into a rapidly urbanizing tropical urban ecosystem case study in Denpasar City. This is in contrast to previous studies which predominantly focus on analysing biodiversity degradation trends; but in the present study integrated this analysis with policy evaluation and strategic governance recommendations for adaptive and sustainable urban biodiversity management in Denpasar City.

2. Literature Review

2.1. Urban Expansion and Biodiversity Loss

The destruction of habitats and loss of biodiversity are global concerns. Urban sprawl and urban infill are key examples of this phenomenon. In their article Impacts of global urban expansion on natural habitats undermine the 2050 vision for biodiversity, " they discuss the impacts of global urban expansion on natural habitats. Ren et al. [12] discuss the effects of global urban expansion on natural habitats and the loss of potential access to the 2050 global targets for the conservation of biodiversity. Rapidly developing areas indicate increasing habitat loss, particularly in areas with high biodiversity. This is where the potential for extinction increases and where the threats to the stability of the ecosystem are increasing.

Similarly, Shi et al. [16] have shown that building cities over hills destroys a whole ecosystem and natural habitat, which is something of major importance. Their studies express that regions with specific topographic aspects are enormously sensitive since the alteration of the land use process in these hilly zones hastens soil erosion, diminishes vegetation, and fragments it. Urban sprawl reduces a habitat, but increases the loss of an ecosystem; this serves as confirmation. On a more ecological scale, Cui et al. [13] employ some index of Rao's Q

to ease the analysis and do a broader ecological investigation into how urbanization reflects on vegetation functional diversity. The results show that urbanization has a negative impact and promotes loss of functional diversity. Urbanization and the reduction of functional diversity have led to a diminished active capacity and multifunctionality of the ecosystems. The loss of functional diversity is an indicator of the loss and degradation of ecosystem services, which are essential to the ecosystems surrounding tropical cities. Additionally, Liu et al. [17] confirm that receipt of new urban spatial form in the framework of expanding cities will have notable consequences for China's endemic species and project that projected changes to land use will strongly affect regional endemics. Production sites that host endemic species become even more sensitive to spatial dissection, and urban sprawl enhances the likelihood of extinction by local genocide. The conclusions presented here reaffirm the increased pressure exerted by unplanned urban growth on biodiversity conservation and ecosystem-related sustainability.

2.2. DPSIR Framework and Urban Ecosystem Resilience

The Driving Force – Pressure – State – Impact – Response (DPSIR) framework has been widely applied over the last few decades to decipher socio-ecological interactions, especially in urban settings. Use of DPSIR with Ecological Network Analysis (ENA) in his study on resilience of urban ecosystems. Zhao et al. [14] illustrate these socioeconomic drivers with the ecological impacts of this model. They illustrate the utility of DPSIR in a systematic examination of ecological resilience and evidence-based environmental decision making.

Kristiadi et al. [15] provide the DPSIR framework for identifying climate stressors and assign a certain value to the DPSIR approach for isolating the multi-causal human linear chain triggering the ecosystem loss in terms of climate destruction. This structured mapping of drivers and responses can help policymakers to formulate adaptive measures for further enhancing environmental resilience. These studies affirm that the DPSIR framework is a valuable tool for the analysis of the impact of the management of biodiversity in the ecosystems of the areas undergoing urbanization.

2.3. Urban Biodiversity Governance and Sustainable City Development

Increasing pressures from urbanisation, climate change, and changes in land use have led to the increasing importance of urban biodiversity governance as one critical part of sustainable city development. Biodiversity governance is the policies, institutional arrangements, involvement of stakeholders, and management strategies that comprise human interventions, which in turn affect ecological sustainability and ecosystem functions (in urban areas). As McPhearson et al. [11] have stated, urban ecosystems are really complex socio-ecological systems, and in order to provide integrated governance mechanisms for these dynamics, urgent cross-cutting urban solutions are required that more holistically take into account the interrelations between environmental, economic, and social dimensions at once. Sustainable biodiversity governance also considers ecosystems and the public good, as well as cities' resilience.

There are many studies that emphasize the need to incorporate biodiversity conservation in urban development policies. Brodsky et al. [7] said that to ensure sustainable management of urban biodiversity, there should be cooperation between governments, communities, and researchers, as well as relevant private stakeholders in searching for a proper balance between development needs and nature conservation. Fang et al. [18], green infrastructure and nature-based solutions can contribute to urban resilience by enhancing the provision of ecosystem services (flood control, carbon sequestration, temperature regulation, habitat connectivity, pollination/interaction niche). These approaches are now viewed as effective means of reducing the adverse environmental impacts stemming from fast urbanising cities.

The participation of the general public is also vital to governance in biodiversity and sustainability. Deep explains that public engagement with environmental planning and conservation initiatives leads to greater awareness, bolsters policy implementation, and improves long-term sustainability results. More participatory governance approaches foster a culture of co-decision making and promote collective action for the preservation of ecosystem resources. Moreover, adaptive governance complemented with ongoing monitoring of urban environmental challenges and climate hazards based on real-time evidence would enable effective responses to such changing situations. The strengthening of biodiversity governance is increasingly important, especially in tropical urban cities like Denpasar, where ecologically sensitive ecosystems such as mangrove forests, wetlands, rivers, and coastal ecosystems are under pressure from urban risk management and climate variability. Thus, integrated planning and policy evaluations, as well as cooperation with different stakeholders to enhance diversity governance and ecosystem-based management approaches in sustainable urban areas, are vital for maintaining the long-term ecological resilience of cities.

3. Methods

3.1. Study Area

This study is located in Denpasar City, Bali Province (Figure 1), which serves as an economic, cultural, and administrative hub. Although often identified with its vibrant tourism activities, the city is also home to fascinating biodiversity. Despite its limited land area, Denpasar showcases impressive flora and fauna diversity in city parks, rivers, and urban forests. Moreover, this biodiversity also encompasses unique local cultural heritage, such as traditional dances, paintings, and crafts. With proper management, the biodiversity potential of Denpasar City can become a source

of pride and valuable knowledge for local residents, as well as an attraction for tourists seeking a deeper understanding of Bali beyond its conventional image. According to Sugianthara et al. [19], Denpasar City is situated between 08° 35' 31" and 08° 44' 349' South and 115° 10' 23". 115° 16' 27" East. Denpasar City is really big. It covers about 30,000 square meters of land. A lot of Denpasar City is pretty flat because 59.10 percent of Denpasar City is between 0 and 25 meters above sea level. The rest is between 0 and 75 meters asl. The topography of Denpasar is mostly flat (82.2%) with a general slope of 0-2% towards the South, while other areas have slopes ranging from 2-8%. In some regions, primarily near riverbanks, the slope can reach 2-15%. The weather in Denpasar City is really hot and humid all the time. Denpasar City has two seasons: the rainy season and the dry season.

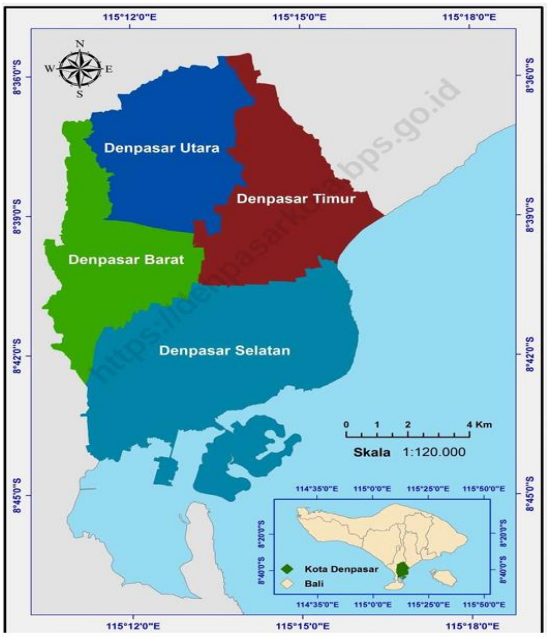

Fig. 1 Map of Denpasar City Area

3.2. DPSIR Component and Indicator Selection

In this study, the choice of DPSIR components and indicators was based on a combination of an extensive literature review, field observations, stakeholder interviews, and eco-regional environmental planning documents relating to biodiversity management in Denpasar City. The indicators were chosen to reflect the linkages between socio-economic drivers, environmental pressures, ecosystem status, and other background information. Driving Force variables consisted of the population, urbanization rate, highway length expansion, and climate fluctuations. Land use conversion, reduction of green open spaces, pollution, and fragmentation were identified as pressure indicators. In particular, the state indicators representing ecosystem states may include the amount of green open space availability, conditions of mangrove ecosystems, and the status of biodiversity. Impact indicators related to ecosystem degradation, decline of ecosystem services, and endemic species threatened, followed by Response indicators addressing environmental policies, ecosystem restoration programs, urban greening initiatives, and stakeholder involvement. To ensure the relevance, reliability, and consistency of the selected indicators in representing biodiversity management conditions in Denpasar City, the validity of these indicators was validated by triangulation methods involving both secondary data comparison and field observations, as well as expert judgement from academics, government agencies, and environmental practitioners.

3.3. Procedures

Master Plan for Biodiversity Management of Denpasar City 2024-2028 using the Driving Force-Pressure-State-Impact-Response (DPSIR) method to achieve conservation and biodiversity management goals. DPSIR (Driving Force-Pressure-State-Impact-Response) is a general framework for gathering information about environmental conditions [20]. The conceptual framework in the DPSIR model offers a comprehensive approach that can be applied to various regional issues by capturing and organizing the environmental, social, and economic outcomes of human decisions [21].

This research began with the collection of secondary data from previous studies, including research reports and articles published in both international and national journals related to biodiversity, government regulations, regional regulations, and available maps. Subsequently, primary data collection included field observations and interviews with local communities, local government, academics and researchers, as well as non-governmental organizations. The collected data was then tabulated and analyzed using the DPSIR approach (Driving Force, Pressure, State, Impact, and Response) (Figure 2), which provides clear and specific information regarding the triggering factors (Driving Force), environmental pressures generated (Pressure), environmental conditions (State), impacts resulting from environmental changes (Impact), and potential responses from the community (Response) [21].

The use of the DPSIR method in this context helps to evaluate the effectiveness of the policy implementation by assessing the factors affecting biodiversity in Denpasar. The status of biodiversity is determined by driving and pressing factors. Driving factors are related to human needs that cause pressure on the status of biodiversity. Identified driving factors include population growth and climate change, which lead to two main problems: habitat loss and reduced carrying capacity of the remaining habitats. These main issues are often referred to as primary pressures. In addition to primary pressures, based on observational results, several secondary pressures on the status of biodiversity in Denpasar City can also be identified, such as environmental pollution, expansion of built-up areas/land occupation, alien species, poaching, and overexploitation.

3.4. Data Analysis

Descriptive, comparative, and statistical analytical approaches to the DPSIR framework were conducted to assess biodiversity management performance in Denpasar City based on the collected data. The qualitative data were descriptively analysed to uncover linkages among driving forces, pressures, states, impacts, and responses. Biodiversity management interventions were assessed temporally between periods before and after the intervention by analysing trends in quantitative variables (population growth, green open space cover, and environmental indicators) using comparative trend analysis. Statistical analysis for urban development pressures and ecosystem conditions trend relations. The effectiveness of the biodiversity management strategies was assessed by means of comparative analysis of availabilities, land-use changes, and environmental conditions before and after implementation at different time periods. Furthermore, the triangulation method was employed to ascertain the validity of data by cross-verifying results obtained from interviews with observational data and secondary sources. The DPSIR framework allows the integration of descriptive and statistical analyses to assess biodiversity management performance and environmental sustainability challenges in Denpasar City. As stated by Zhao et al. [14], the DPSIR framework is widely used to evaluate the complex interactions between humans and the environment. The DPSIR framework is applied through the following stages:

1. Data are collected through field observations, interviews, and literature studies from secondary sources. According to Quevedo et al. [22], data collection within the DPSIR framework must consider the various stressors impacting biodiversity, as identified through a literature review. This involves collecting data on driving forces (including aquaculture expansion, environmental pressures), ecosystem status, changes in states, and management responses, including restoration and community-based approaches.
2. The data are then tabulated for analysis after collection. Similar to Cloutier and Ravasi [23], data tabulation facilitates a more systematic qualitative and quantitative analysis. Qualitative processing of primary data based on observations and interviews, while secondary data is analysed descriptively.
3. The data are analyzed based on the five main components of the DPSIR framework:
   a. Driving Force: Factors (like population growth, climate change, and development) that increase pressures on biodiversity. According to Maja and Ayano [24], population growth is heavily impacting ecosystems.
   b. Pressure: anthropogenic activities that exert pressure on ecosystems, such as pollution, urbanization, and resource extraction. Research by Soni et al. [25] shows that biodiversity is severely degraded by pollution and urbanization.
   c. State: Condition of the ecosystem or state of biodiversity of the environment. According to Johnson et al. [26]**,** the ongoing biodiversity loss is a major challenge to the quality of ecosystems. Biodiversity decline is a huge threat to ecosystem sustainability, and global biodiversity declines need to be halted.
   d. Impact: Evaluates how changes in environments affect biodiversity, such as habitat destruction or pollution that causes environmental degradation. A study by Chase et al. [27] found that habitat loss is likely to increase pressure on endemic species.
   e. Response: Evaluates the policies and actions of governments, communities, or organizations to lessen pressures on biodiversity. As concluded by Bowgen et al. [28], appropriate conservation measures can mitigate the adverse impacts on ecosystems from human activities.
4. Data obtained from interviews are validated through triangulation with other sources, such as observational data and secondary data from previous studies. Based on Carter et al. [29], data triangulation is an important step in enhancing validity in qualitative research.
5. The DPSIR analysis results are presented descriptively to provide a comprehensive overview of the biodiversity conditions in Denpasar City and efforts to manage them. According to Dunning [30], the findings of this study can assist policymakers in understanding issues related to biodiversity.

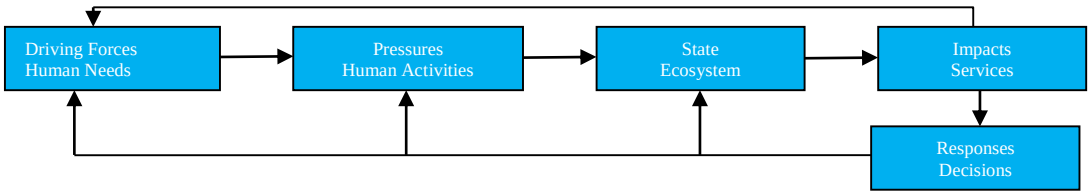

Fig. 2 DPSIR analysis method framework

4. Results and Discussion

4.1. Driving Force

The driving factors that cause pressure on the status of biodiversity in Denpasar City are population growth and climate change.

4.1.1. Population Growth

Urban environmental problems are caused by population growth. The rapid growth of the urban population puts increasing pressure on the provision of urban infrastructure. One of the biggest worries when it comes to population growth

is land-use change. Increasing populations require increasingly more land to be transformed from a natural ecosystem into a built environment. Besides limiting the amount of green spaces, this process leads to decreasing ecosystem services like air purification, water regulation, and carbon sequestration [31]. This phenomenon ultimately leads to shifts in the physical environment and urban planning that prioritize economic aspects over environmental ones (including its historical value), making the city uncomfortable, insecure, ugly, polluted, and unhealthy. Uncontrolled urban growth damaged by climate change is aggravated by the consequent loss of biodiversity and destruction of habitats [29]. Although population growth has long been regarded as the engine of economic development, little attention has been paid to "the high ecological costs in terms of impact on urban biodiversity. Cities are frequently hot spots of biodiversity loss, due to habitat degradation, pollution, and the spread of non-native species [12]. The urbanization process that has grown rapidly in Denpasar City threatens sensitive ecosystems such as wetlands and coastal mangroves, which are crucial for the economy and life support of many species.

Table 1. The growth of the population in Denpasar City

Subdistrict	Population		
	2021	2022	2023
Denpasar Selatan	217,485	217,500	188.998
Denpasar Timur	128,503	128,500	182.422
Denpasar Barat	207,325	207,400	120.826
Denpasar Utara	173,286	173,300	168.738
Kota Denpasar	726,599	726,800	660.980

Note: BPS Kota Denpasar [32]

Data in Table 1 shows the population increasing in 2021 and 2022, then decreasing in 2023. Even with a recorded decline in the state of biodiversity for the city of Denpasar in 2023, the citizens of Denpasar City will have to endure a further worsening of the biodiversity status in Denpasar City. The population of 2023 may have experienced an exponential decline due to various reasons, including migration, economic downturn, or changes in the birth and death rates. Although this decline might suggest reduced pressure on urban infrastructure and the environment, this is not always the case. Even with a smaller population, a lack of sustainable urban planning can continue to harm ecosystems if land-use policies are not adjusted to prioritize environmental sustainability [25].

4.1.2. Climate Change

One of the main causes of habitat loss and a decrease in the carrying capacity of the remaining habitats is climate change. Climate change caused by global warming can be seen in things like high climate variability, changes in the start of seasons, and extreme weather events. Dinas Lingkungan Hidup [33] defines climate change as a change in the average and/or variability of climate-related factors that occurs over a long period, generally spanning decades or more. Statistically, climate change is defined as a change in the trend of rising or falling elements of the climate, accompanied by daily, seasonal, and cyclical variability that remains applicable over a long period. Climate change is measured based on changes in the main components of climate, which include temperature, seasons (rainy and dry), humidity, and wind. Among these variables, the most common by far are temperature and rainfall. The summer season lasts for 1.5 months, which spans from October 12 to November 29. Denpasar City experiences November as the peak month of heat, with an average of 31°C and 25°C as the minimum average. The winter season lasts for 2.3 months, which spans from June 21 to August 29, with the average daily highs below 30°C. August is the coldest month of the year in Denpasar City with a low average of 24°C and a high average of 29°C [34]. Shifting patterns of temperature and rainfall for the season have an effect on the health of the community, the natural environment, and the city's ability to protect its growing biodiversity.

These changes in temperature and rainfall align with global findings, which show that rising global temperatures are causing significant disruptions to the water cycle, resulting in more extreme weather variability, including droughts and floods [35]. Denpasar is experiencing changes that could result in a reduction of the quality of the habitat of the flora and fauna that rely on a stable environment. The tropics constitute Bali, and the climate of the region is characterised by increasing water vapour and Atmospheric Vapour Pressure (AVP). The freshwater is being evaporated, and the ecosystems that live around the water source are being hurt by the lack of water. One bad thing about global warming is that it makes water less available. The pests and the flooding become more severe. Such effects deteriorate the ecosystem and worsen water scarcity. Global warming becomes more severe, and the climate of Denpasar becomes more constructive. The ecosystem of the region is affected, and the mangrove swamps are more affected. Global warming deteriorates the climate and the vegetation of the region, the floods, and the pests. The vegetation and the mangrove ecosystems are affected by the Denpasar. The flooding and the freshwater ecosystem devastate the region of Denpasar. This mitigation is essential to prevent further degradation of urban ecosystems and to maintain biodiversity sustainability in the region [36].

4.2. Pressure

The condition of habitat loss as a living space for flora and fauna is a trend that occurs due to the expansion of built-up areas. The high expansion of built-up areas is a result of increased infrastructure needs, rising population numbers, and spatial planning policies that do not favor the protection of green open spaces. Urban development often prioritizes economic aspects, resulting in a lack of green open space (RTH), leading to inefficiencies in some economic activities. According to Law No. 26 of 2007 concerning Spatial Planning, the urban spatial planning must include the

provision and utilization of RTH with a minimum area of 30% of the total area [37]. The provision of green open space is categorized into public and private spaces, with the allocation determined by local authorities to ensure access and promote urban sustainability and citizens' well-being, as part of efforts to create healthy and resilient cities [38].

The availability of RTH in Denpasar City in 2011 was recorded at 36.28% of the entire city area, amounting to 4,636.09 hectares, consisting of public and private RTH. The proportion of public RTH was 2,341.48 hectares or 18.32%, while private RTH was 2,294.60 hectares or 17.96% of the total area of Denpasar City. Based on this data, the proportion of public and private RTH areas remains balanced, indicating the need for an increase in public RTH.

Meanwhile, the availability of public RTH in Denpasar City in 2019 was recorded at 1,572,990 hectares or 12.49% [39]. There are 768,490 hectares or 5.83% more data between 2011 and 2019. Based on this information, it can be concluded that the Public Green Open Space in Denpasar City has decreased over time. The provision of green open spaces is shaped by multiple factors, including pressures from urban population growth, land resource demands, and the need to balance recreational standards with ecosystem services and benefits [40]. These three aspects of RTH provision cannot be separated from the commitment of planners and the government to its implementation.

From an economic perspective, the efficiency of urban economic activities can also be hindered by the decline in environmental quality. Green spaces are known to play a vital role in creating a comfortable and healthy environment, which ultimately supports economic productivity. A lack of public green spaces can lead to increased healthcare costs due to high air pollution and diminished quality of life (Ziter et al., 2019). In Denpasar, the reduction of green open spaces can affect the city's attractiveness as a tourist destination and decrease economic competitiveness in the tourism and business sectors. The plan for RTH in Denpasar City can be seen in the following Table 2:

Table 2. Green open spaces in Denpasar City

No.	Name	Location	Area (Ha)
1	Green corridor	Kota Denpasar	28.99
2	Cemetery	Kota Denpasar	24.97
3	City Jungle	Denpasar selatan	24.98
4	City Park	Kota Denpasar	123.58

Note: Pemerintah Kota Denpasar [41]

Table 2 presents the plan for the provision of public green spaces (RTH) in Denpasar City, which includes various types of green areas such as green corridors, cemeteries, city jungles, and city parks. However, the planned area of public green spaces still falls short of the minimum requirements mandated by law. The Denpasar City Government needs to pay more attention to its commitment to increasing public green open space in order to achieve results that can be used to maintain ecological balance and improve the quality of life for society. Research indicates that these negative effects can be ameliorated through planned spatial distributions, which also provide adequate public green spaces. Edeigba et al. [42], It needs to be stressed that public policies must favour the development of environmentally-oriented measures such as Reforestation (RTH), not only to improve environmental conditions, but also to provide opportunities for social and, above all, economic benefits as well. Therefore, establishing the management of public green spaces based on alterations in Demographics, rising social issues, and climate change impacts is essential.

Ensuring effective adaptation and mitigation strategies takes on an increasingly important role in light of the challenges related to the urbanization of green spaces (RTH). Urban green space restoration and conservation strategies are vital to sustain urban ecological balance. Research by Fang et al. [18] shows that ecosystem-based adaptation strategies, such as public-green-space restoration (RTH) and sustainable urban infrastructure based on green systems, can all be used successfully to help improve city resilience to environmental shock. The same applies to educating people about RTH and getting them engaged in keeping it alive, running, and even contributing. Implementing vegetation greening programs with community involvement will raise consciousness about environmental issues and also connect people emotionally to the surroundings where they live, helping in improving environmental stewardship [42].

4.3. State

Status is related to the condition of ecosystems and biodiversity elements in the management of biodiversity in Denpasar City. These may be: A) ecosystem health and or sustainability, including ecosystems of both aquatic and terrestrial flora and fauna types, the functional importance of a non-anthropogenic unit; B) such units as forested wetlands or other wetlands containing water. Apart from Endemic and Endangered species, especially fauna, there are also economically high-value species in Denpasar biodiversity, as affected by human activity and changing environments. Economically important endemic species include ornamental marine fish and Birds; they are also found, contributing to the economy, particularly in tourism and trade in wildlife. However, much rapid expansion and urbanisation to convert large land areas into settlement habitat, which leads to fragmentation, affects key species and loss of genetic diversity all over again. Dispersal failure of fragments can affect the interactions of these populations with one another as well as the quality of their habitats, increasing the extinction vulnerability [43]. Moreover, the increasing economic activities and infrastructure development in Denpasar often do not take environmental sustainability into account, exacerbating the condition of biodiversity.

Additionally, this status reflects the level of genetic diversity and the balance of ecosystems, measured by the health of key species populations and habitat quality. Monitoring this status is crucial for understanding the extent to which pressures from external factors such as urbanization, pollution, climate change, and land conversion impact the sustainability of biodiversity [44]. This information then serves as a basis for determining the necessary interventions to respond to changes, which can happen via sustainable management actions and conservation policies to safeguard and sustain the ecological balance and the essential roles of ecosystems in Denpasar City. A case in point is the coastal area of Denpasar, where safeguarded wetlands and mangrove forests provide protection to the city and local biodiversity from the impacts of climate change, including sea level rise and other disasters.

Regarding the management of biodiversity, the development of mitigation and adaptation plans is essential in navigating the changes that are a certainty in urbanization and climate change. One strategy that can be implemented in Denpasar is the development of green infrastructure that can serve dual purposes as public green spaces and ecological corridors for species migration and interaction [45]. Furthermore, the government, in conjunction with the community, must create partnerships to increase awareness of the need to value and protect biodiversity, potentially through workshops, education, and participatory activities. Community engagement in activities such as tree planting, restoration of natural ecosystems, and working to revive natural habitats can alleviate the stress on the ecosystem and boost the likelihood of success for conservation efforts.

4.4. Impact

In the management of biodiversity in Denpasar City, impact refers to the various consequences of changes in ecosystem status due to pressures such as urbanization, pollution, and land conversion. The main consequences include ecosystem degradation, which leads to losses of habitat and severity and geographic extent of bioinvasions, seconded by local extinction and the overall risk occurring. The degradation of these ecosystems also leads to a decline in ecosystem services, specifically the provision of clean water and flood control, as well as carbon storage, which ultimately influence community well-being. Sharma and Birman [1] maintain that maintaining the quality of these services is essential for species survival, but also to support the well-being of communities that depend on these services as part of their daily lives.

Biodiversity loss also has possible negative implications for many economic sectors, such as tourism and fisheries, and the viability of local cultural and spiritual practices that are intimately related to the natural environment. Decreases in species populations and habitat degradation degrade tourism experiences, reducing revenues from that sector. Moreover, the fisheries sector that depends on marine ecosystems and aquatic resources is at risk of overuse degradation as environmental quality declines from pollution and land conversion. The reduction of fish populations directly impacts the income from fishing-based communities through damaged habitats and decreases in water quality [46]. Biodiversity loss threatens to decimate the cultural and spiritual practices in local communities that rely on nature. With the decline of biodiversity, traditional and sustainable practices associated with natural resource utilization might vanish in decades. As such, these impacts highlight the need for robust conservation policies and sustainable development to mitigate future environmental, social, and economic losses.

These effects underscore the necessity for general conservation approaches and sustainable management methods to mitigate potential ecological, social, and economic consequences of developing crises in the near future. Conservation policy needs to uphold the provision of critical habitats and species at risk while improving the management of natural resources. Involvement of the community in the planning process is necessary so that better knowledge about biodiversity and how it affects their daily lives can be achieved [47]. Promote restoration of ecosystems to enhance their resilience and sustainability of ecosystem services through an ecosystem-based approach. Sparrow et al. [48], this last approach would require continuous monitoring of ecosystem states and the impact of measures taken. This is essential to ensure that implemented strategies respond effectively to evolving ecosystem circumstances and community needs.

4.5. Response

The diverse challenges posed by nature - not limited to climate crises but also including innumerable others dependent on region - necessitate response actions that are also regional. Taking Denpasar City as a prototype, researchers have developed a more regionalized solution regionally to tackle challenges that exist in nature. This approach has been modeled in the DPSIR framework (Driving forces – Pressures – State – Impact – Responses). For a specific example, such as in Denpasar City, where one type of challenge is mainly tackled with multi-layered policies, programs, and actions to cope with these challenges related to nature itself, the prototype response had integrated better social issues to reduce fragmentation of systemic challenges. Responses can, therefore, include enhancement of existing policies or enactment of new ones and programme/actions specifically created for tackling and improving impacts related to ecosystems; That is the nature of land-use policy shift in accordance with what is ideal as set forth in the Master Plan for Biodiversity Management under the auspices of the Ministry of Environmental and Forestry. It is such policies, which promote and enforce protection of natural habitats and ecosystems by mitigating detrimental land uses and ecosystem-damaging activities like illegal logging or land clearing, in addition to illegal land development, speculation,

and destruction of ecosystems associated with development and high-impact development. Urban biodiversity depends on ecosystem protective policies and legal enforcement.

Fifth, community-boosted and state-supported rehabilitation actions such as coral reef restoration, the planting of native forestry in severely damaged micro-environments, and the restoration and rehabilitation of mangrove forests. Besides protecting biodiversity and freshwater ecosystems, restoration of mangrove ecosystems is also important for climate change mitigation through reducing climate-related carbon emissions and enhancing disaster risk reduction and resilience systems in nature.

Having environmental studies included in school curricula in addition to an environmental campaign raises community awareness and recognition of the importance of community biodiversity conservation. Providing education and raising awareness about the conservation actions of the community itself might impact the results in both direct and indirect ways.

This strengthening of institutional frameworks and multi-stakeholder collaboration is led by the government, and together with researchers from the private sector and community, facilitates the development/implementation of sustainable management programs, underpinned by scientific research. Many of these efforts are still relevant to and fall under the wider umbrella of what the Sustainable Development Goals (SDGs) encompass, with a much broader scope.

Green economic incentives will compel the move toward ecotourism and aggregation for organic farming, which are perfect examples of sustainable economic activities. Sustainability economic incentives generate the preservation and social benefits of positive welfare development in job creation as green employment.

Finally, the policy-in-action, as well as program success, is recorded through continuous assessments, and systems are created to promote adaptive management, which modifies strategies based on fluctuations in the environment and society. The response reflects the need for an inclusive and cooperative approach towards biodiversity conservation, including ecological, social, and economic trade-offs within Denpasar City. The necessity of periodically reevaluating our efforts to protect biodiversity to ensure that our initiatives remain relevant and effective.

4.6. Study Limitations and Future Research Directions

First, there is a temporal inconsistency and spatial inconsistency report which means a combination of some government reports and some previous studies Second, considering the DPSIR framework is useful as to structure the environmental assessment have depressed the socio-ecological systems by creating linear cause and effect relationship where urban biodiversity systems are actually very complex and this relationship is non-linear vibrate, also this one is descriptive and non-spatial non-statistical evaluation of process that describe account of enter processes Thirdly, lack modelling for local projection scenario modelling in support to discusses other impact areas due climate change on future changes in urban biodiversity.

Future studies should explore the DPSIR framework more thoroughly, integrating it with both other spatial analyses and with additional quantitative methods of measuring biodiversity; also underpinning this approach to assessment of ecosystem degradation would be a valuation of ecosystem services that will support future advances in biodiversity policy as well as climate scenario modelling and resilience enhancement for better adaptive management while further work on governance, institutional flow and stakeholder participation, as they relate to urban ecosystems, is likely to result in closing gaps in the governance of urban biodiversity.

4.7. Comparative Analysis of DPSIR Implementation in Different Cities

The DPSIR framework for Denpasar City local biodiversity management could be discussed with other world cities: East Asia (Singapore) and Western Europe (London). By establishing the "City in Nature" concept, Singapore deeply entwines biodiversity planning with urban designs, making a case for integrating green infrastructures, ecological corridors, and intelligent environmental governance to work towards the resilience of ecosystems amid high-density urbanization. Recent studies advocate that an appropriate urban biodiversity strategy, which optimises the trade-off between ecosystem conservation and compact city as promoted by Singapore, can be achieved via nature-based solutions, ecological restoration, and other urban sustainability projects using appropriate spatial planning [49]. At the same time, London diversified urban planning oriented to restoring ecosystems through green infrastructure rehabilitation and climate-change adaptation policy to restore central ecosystems. However, unlike these cities, Denpasar is constrained again by the lack of green space, rapid land-use change, and fragmented governance of biodiversity. On the other hand, Denpasar is a local sociocultural success, for there is local wisdom and ecological strength through community-based environmental practices, such as Subak. To the best of our knowledge, this is the first study demonstrating how the DPSIR framework has allowed integrated assessments of environmental use and governance factors and socio-cultural considerations supporting adaptive responses to urban biodiversity management in tropical developing cities, whereas earlier studies have focused more on ecological indicators.

4.8. Civil Engineering Integration in Biodiversity Responses

The DPSIR framework structure in the response component of this paper is arranged from a set of sustainable

civil engineering aspects by scales, where the scale is named from simple to complex, maximum achieved linearly or funnels. One possible adaptation measure for the need to develop green infrastructures is the price and containment of urbanisation and climate change-induced degradation of natural ecosystems. Developing engineering solutions from Sustainable Urban Drainage Systems (SUDS), permeable pavements, and ecological retention ponds to riverbank sediment stabilization and utility corridors, provides the basis for an enabled system of green or natural-based coastal protection through mangrove restoration. According to Fang et al. [18], green infrastructure elements are a means to creating an integrated system that enhances ecosystem services, improves the ability of urban areas to handle floods and adversity from climate change impacts like heavy rainfall events, reduces adverse microclimate conditions caused by urban heat island effect, allows species redistribute to keep viable populations when adapting to climate change and contributes towards more connected ecosystems. Meanwhile, it can restrict land fragmentation and elevate urban ecological resilience. Thus, in addition to technical functionality and urban development efficiency, some civil engineering methodologies have to be based on principles linked to ecological sustainability and biodiversity conservation.

4.9. Barriers and Enablers in Biodiversity Management Implementation

The biodiversity management policy implementation in Denpasar City is driven by some policy, institutional, social, and technical factors. Insufficient scale between the rapid growth and environmental conservation priorities (i.e., land-use conversion and few public green open spaces). Fragmentation between government agencies and institutional incapacity further limit the efficacy of technical coordination in the governance of biodiversity. Moreover, the challenges of limited environmental monitoring systems, inadequate biodiversity databases, and inadequate financial capacity contributed to problems in policy implementation and ecosystem management. At the social level, low public awareness and low community participation in environmental programs still hinder sustainable biodiversity conservation. On the other side, there are also enabling factors such as greater commitment from the government toward sustainable urban development, increasing public pressure on environmental issues, and widespread acceptance of local ecological knowledge into conservation. The development of integrative strategic cross-sectoral collaboration between local governments and academic institutions, non-governmental organizations, and local communities is also important for enhancing adaptive biodiversity governance and the effectiveness of policy implementation.

4.10. Temporal Effectiveness of Biodiversity Management

The management of biodiversity as one of the most important factors that affect environmental quality in Denpasar City can be seen through temporal change in some environmental indicators. This decline has further accelerated in recent years, as major urban expansions and infrastructure development reduce the area of public green open spaces and intensify the ecosystem pressures on cities. A number of monitoring conservation and restoration programs are in place, but biodiversity patterns continue to be undermined by population expansion, contamination, and climate variability. The steady reduction in green open space status from 2011 to 2019 implies that ecosystem restoration is not yet compensating for land-use pressures due to urbanization. However, regional adaptation measures, for example, mangrove rehabilitation, urban greening programs, and ecosystem restoration initiatives, have played a significant role in enhancing ecological resilience and environmental awareness. This demands indicators that are sufficiently wide and fine-grained to evaluate the experience of policies over extended time periods, while supporting adaptable urban biodiversity management through an ongoing measurement of these new biodiversity indicators; the quality and longevity of nearby ecological systems, as well as their conservation in coordination with habitat connectivity and environmental sustainability.

4.11. Stakeholder Engagement in DPSIR-Based Biodiversity Management

The role of stakeholders in Denpasar City is one important aspect that raises reflections towards a DPSIR-based Biodiversity management system. Local Governments, Academia, Private Sector, and Civil Society, including communities, should be involved in a variety of Biodiversity governance. Governments' institutions develop policy, spatial plans, and regulatory framework for ecosystem rehabilitation programmes; moreover, researchers and academic institutions articulate scientific assessment and evidence on the recommendations put forth. Third, the local people should be incorporated into the plan as they often are in the front of space and time when urban ecosystems take place, as well; they hold much of the socio-cultural knowledge about environmental conditions themselves. Deep narratives on participatory environmental governance lead to greater policy support, stronger environmental attitudes, and more successful general sustainability by the means of communicative rationality. One approach to biodiversity conservation efforts and services for Denpasar City is through community–based activities in hydrology and environmental conservation, such as mangrove planting, river clean-up program, and urban greening initiatives. This highlights the necessity of better cooperation and participatory governance mechanisms for enhanced adaptive management and sustainability of urban biodiversity.

4.12. Comparison with Previous Studies and Research

This integrated urban biodiversity management perspective reflects previous studies better than the more selective DPSIR perspective of them, where only environmental, social, governance, policy, and engineering interactions were studied individually. Ren et al. [12] and Cui

et al. [13] Urban Questions: Livelihoods and Urbanization, Zhao et al. [14], and Kristiadi et al. [15] highlighted the resilience of transboundary ecosystems and climate-related environmental pressures. However, this work has circumvented downscaling temporal-level environmental analyses and statistical comparisons of multiple indicators of biodiversity sampled pre-and post-intervention with stakeholder engagement, policy analysis, and engineering-based responses in a unified framework. Lastly, a comparison of Singapore and London offers another layer to the study by showing different forms of governance for urban biodiversity under climate change that can be learned from primary tropical developing cities. The previous study relied mostly on ecological indicators in assessing the management effectiveness of biodiversity.

5. Conclusion

Population growth and climate change are the major causes of pressure on biodiversity in Denpasar City, while habitat loss aggravates these problems. The vast loss of green open spaces (RTH) due to infrastructure demands and increasing population density. Losing RTH contributes to environmental degradation, and its loss degrades ecosystem quality and threatens biodiversity. This means that the loss of RTH leads to adverse effects for humans, deteriorates the quality of ecosystems, and causes a decrease in species diversity. Loss of RTH, a response: Tough policies for ecosystem conservation; strong policies for ecosystem rehabilitation; educational policies for the public, and more coordinating policies per different community people are required. This contributes to maintaining the ecological and social balance of Denpasar while highlighting the necessity for additional strict policies to guarantee that public RTH is extended and created. The policies, however, are made by urban planners and the government. Denpasar will roll out due to the damage caused by climate change and urbanization, reducing negative impacts on biodiversity. It will also contribute to making the environment safe for residents and generations to come.

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