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RESP

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Preservation of Marine Resources and Sustainable Fisheries: Analyzing the Stochastic Dynamics of Fishing Grounds Footprints in the Nordic Countries

Deniz Kaynaklarının Korunması ve Sürdürülebilir Balıkçılık: İskandinav Ülkelerinde Balıkçılık Alanlarının Ayak İzlerinin Stokastik Dinamiklerinin Analizi

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Sürdürülebilir Balıkçılık
Stokastik Analiz
Nordik Ülkeleri

ÖZ

Günümüz toplumlarının daha iyi bir yaşam alanı ve bu koşulların sürdürülebilirliğine odaklanmaya başladıkları görülmektedir. Dünya ekosisteminin kritik ve önemli bir paternini oluşturan denizler, trofik basamaklarda birçok canlı türünün yaşam alanını oluşturmaktadır. Buradaki ekosistem paterninde meydana gelecek bozulma tüm ekolojik dengenin bozulmasına yol açabilir. Bu nedenle su alanlarında yanlış avlanma yöntemleri, kaçak avcılık, trol avcılığı ve aşırı avlanma gibi birincil sucul çevresel bozulma etkenlerinin yanı sıra daha büyük ancak ikincil etkenler plastik kirliliği, aşırı tüketim, küresel ısınma, sanayileşme vb. olaylar biyolojik çeşitliliğin yok olmasına deniz ekosisteminin bozulmasına neden olmaktadır. Sürdürülebilir kalkınma amaçlarının (SDG) "sudaki yaşam" olarak etiketlenen SDG14 amacı söz konusu sucul ekosistemin korunmasına yönelik bütüncül bir perspektif sunmaktadır. Çalışma deniz ekosisteminde önemli bir konuma sahip olan Nordik ülkelerinin sucul alanlarının çevresel göstergesi olarak kişi başına FGF'leri ele alınmış ve bu verilerin stokastik davranışları incelenerek politika yapıcılara içgörü sunulması amaçlanmıştır. Çalışmanın sonuçları ise Nordik ülkeleri gibi birbirine benzer gelişmişlik düzeyi ve coğrafi alanda olan ülkelerin ulusal boyutta politika tercihlerinin ve bu politikanın etkilerinin farklı olabileceğini göstermesi açısından literatüre özgün bir katkı sunmaktadır.

KEYWORDS

Environmental Degradation
Sustainable Fisheries
Stochastic Analysis
Nordic Countries

ABSTRACT

Today's societies have started to focus on a better living environment and the sustainability of these conditions. The seas, which constitute a critical and important pattern of the world ecosystem, constitute the habitat of many species at trophic levels. Any disruption in the ecosystem pattern here can lead to the disruption of the entire ecological balance. For this reason, in addition to primary aquatic environmental degradation factors such as improper fishing methods, poaching, trawling, and overfishing in water areas, larger but secondary factors such as plastic pollution, overconsumption, global warming, industrialization, etc., cause the destruction of biodiversity and the deterioration of the marine ecosystem. SDG14 of the Sustainable Development Goals (SDGs), labeled as "life in water," provides a holistic perspective for the protection of this aquatic ecosystem. The study focuses on FGF per capita as an environmental indicator of the aquatic areas of the Nordic countries, which have an important position in the marine ecosystem and aims to provide insights to policymakers by examining the stochastic behavior of these data. The results of the study make a unique contribution to the literature in terms of showing that countries with similar development levels and geographical areas, such as the Nordic countries, may have different policy preferences at the national level and the effects of this policy.

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1. Introduction

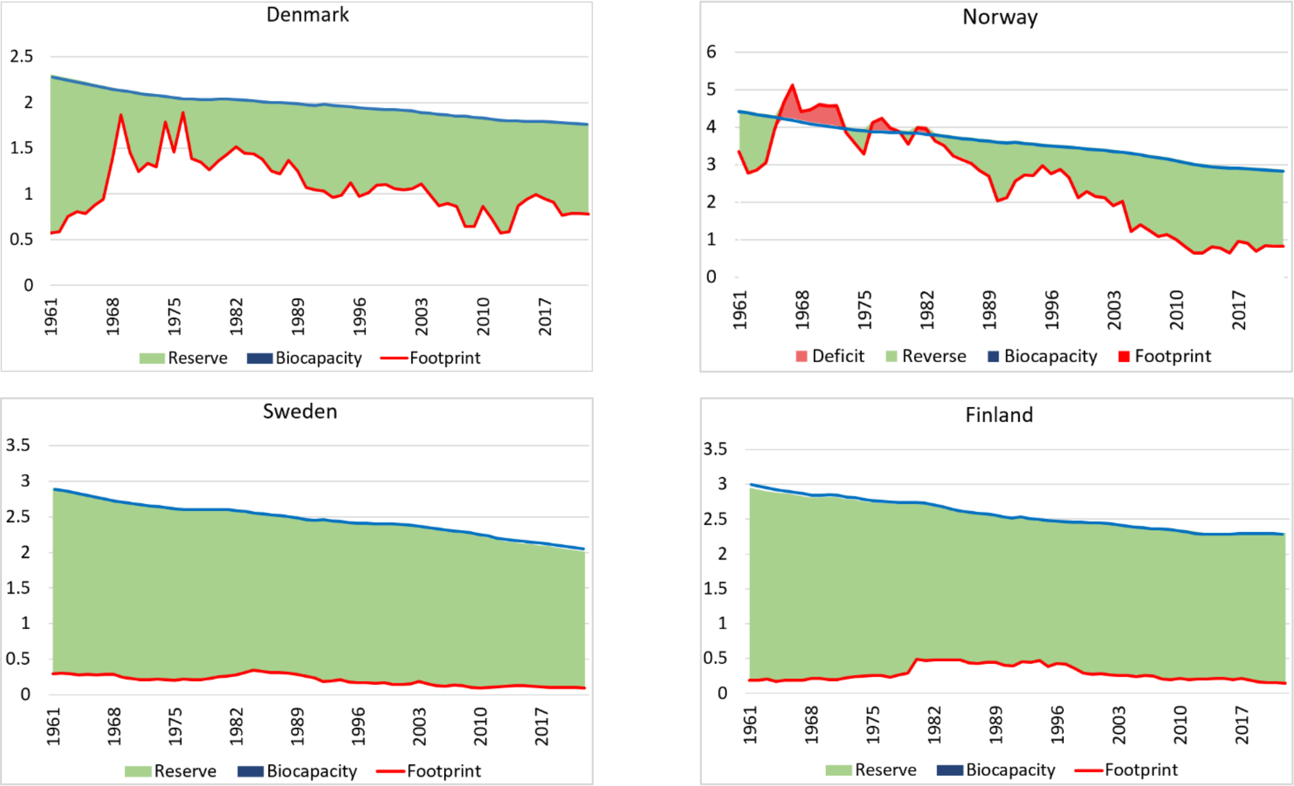
The seas, which have the richest biodiversity in the world, are the habitat of millions of species in trophic levels that form complex food webs. Disruptions in trophic levels in the marine ecosystem can decrease biodiversity and damage the ecological balance (Myers et al. 2007; Estes et al. 2011). One of the most important reasons for the deterioration of trophic levels has been fishing activities, which are considered important in terms of food security and economic importance. Improper fishing methods used in fisheries, poaching, trawling, and overfishing cause degradation in marine ecosystems and destruction of biodiversity (Aish et al., 2003; Dammannagoda, 2018; Worm et al., 2009). In addition, the effects of drought, plastic pollution, overconsumption, global warming, industrialization, etc., on marine ecosystems have been determined by many studies (Scavia, 2002; Gao et al., 2016; Li et al., 2016a; Ivleva et al., 2017; Ullah et al., 2023). For this reason, studies supporting the protection of marine ecosystems directly contribute to the goal of "life in water" (SDG14), which is among the Sustainable Development Goals (SDGs).

Fisheries and aquaculture are seen as important sources of income and jobs worldwide. For the first time in 2022, aquaculture surpassed capture fisheries with a production of 130.9 million tons. Of this production, 89% was for human consumption, demonstrating the growth of aquaculture to meet growing global demand. In addition, the fisheries sector produced a total of 92.3 million tons in 2022, 11.3 million tons from inland catch, and 81 million tons from marine catch. Despite growing aquaculture, capture remains the main source of aquatic animal production (FAO 2024). Unplanned management practices in the fisheries catching sector and increased demands with the growing population have serious environmental impacts on marine and inland water ecosystems. In order to identify and control these environmental impacts and to maintain aquatic sustainability, the "ecological footprint" model has come to the forefront of current studies.

Ecological footprint (EF) is an important tool that can evaluate countries' or regions' economic growth and development by determining the production and consumption of resources in terrestrial and aquatic ecosystems (Gao and Tian, 2016; Solarin et al., 2021). In addition, EF is an important determinant of sustainable development, as it shows the ecological losses in the world's ecosystem (Kong et al., 2021). Researchers have made progress in this field by developing model volution, application scale, and subcomponents and conducting many studies related to EF. They have utilized indicators such as EF or carbon footprint to measure the sustainability of ecosystems, using the consumption of natural resources available for human services and waste data (Bastianoni et al., 2012; Bi et al., 2020; Wang et al., 2021). In addition, with EF, carbon and water footprint indicators, the environmental impacts of countries' economic growth have been evaluated and the relationship between environmental changes and economic development has been tried to be revealed in line with sustainable development goals (Salvo et al., 2015; Sanyé et al., 2019; Galli et al., 2012). In addition to issues such as EF trade and tourism, the relationship between resource use and foreign trade (Wiedmann, 2009; Gao and Tian, 2016) has been used to evaluate the relationship between tourism and ecosystem carrying capacity (Zhang and Yang, 2009; Yang and Li, 2007).

While these developments continue, new research on the fishing ground footprint (FGF) is being conducted. The fishing ground footprint, one of the components of EF, reveals the current conditions of aquatic ecosystems and defines the area of water used to consume marine fish (Solarin et al., 2021). Factors affecting marine ecosystems and biodiversity negatively affect FGF (Adalı et al., 2023). Studies on FGF in the literature have remained limited. Jennik et al. (2012) found that only a small fraction of the total trawl area and effort greatly impacts FGF management. Ulucak and Lin (2017) examined the effects of policy shocks on EF components in the United States and found that FGF is non-stationary. Clark and Longo (2019) argue that FGF strongly impacts economic development in less rich countries, while rich countries are unaffected. Yilanci et al. (2019), In 25 OECD countries, EF and its six subcomponents were used as ecological indicators, and it was stated that the effects of policy shocks on FGF were persistent in the long run, which was non-stationary only for FGF. Solarin et al. (2019) identified ten convergence clubs for EF and two convergence clubs for FGF using the club convergence approach for EF and its six subcomponents, including FGF, in 92 countries. Ulucak et al. (2020) examined the ecological footprint and its subcomponents and the club integration approach for Sub-Saharan Africa. Solarin et al. (2021) determined that most of the series were non-stationary and did not revert to the mean using fractional integration in the FGF analysis of 90 countries with upper-middle and high-income groups. Kassouri (2021) investigated the FGF dynamics in the Gulf of Guinea and Congo Basin region and recommended that a common areal fisheries policy could be implemented as the convergence structure is not uniform and the capture effect is partial. Karimi et al. (2022) stated that monetary freedom, business freedom, government integrity, and tax burden indices among economic factors in Asia-Pacific countries increase FGF, while investment freedom and trade freedom indices have negative effects on FGF. Yıldırım et al. (2022) proved that human capital reduces FGF and human capital reduces environmental pollution in Mediterranean countries. Amin et al. (2022), By analyzing data from 17 Asia-Pacific countries between 2000-2017, found that cumulative effects in the form of aggregate economic freedom index have a positive effect on FGF and lead to increased extraction from fisheries resources. Adalı et al. (2023) analyzed the stochastic behavior of the FGF of the top 10 fish-producing and catching countries using unit root tests (URT) and found that the FGF of Bangladesh, China, India, and the Philippines deviated from any changes due to fisheries and maritime policies.

Fisheries and aquaculture are important sectors in the Nordic countries (Denmark, Faroe Islands, Finland, Iceland and Sweden). These countries are ahead of other countries in terms of their sustainable fisheries strategies and management policies. Although Asian countries account for most of the production in terms of aquaculture and capture, Norway is particularly prominent with its Atlantic salmon production. According to data from the FAO (2022), Norway ranks 9th among other countries with 2.4 million tons of aquaculture and 7th with 1.5 tons of aquaculture. Denmark, which stands out with its herring and haddock fisheries in the Baltic Sea, plays an active role in commercial fishing. Although Sweden and Finland have small-scale fisheries, deep management policies are implemented to protect biodiversity and natural resources. In Nordic countries, it is important to monitor biological capacity (BC), which shows ecological sustainability as well as FGF per capita. Graph 1 shows the time path graphs of FGF per capita and BC, deficit, and/or reserve per capita of FGF per capita for the Nordic countries. Denmark has a per capita biocapacity reserve of FGF, while Norway had a biocapacity deficit of FGF in the 1960s and early 1970s. Finland and Sweden have consistently maintained a biocapacity reserve per capita of the FGF.



Graphic 1. Fishing grounds footprint per capita, biocapacity (gha) per capita, biocapacity deficit, and/or reserve per capita for the Nordic countries

In order to optimize ecosystem sustainability, well-thought-out fisheries management policies need to be developed. For this reason, it is important to evaluate the ecological resources of the Nordic countries, which are making rapid progress in aquaculture, and to determine development strategies based on these evaluations in order to maintain their sustainability. For these reasons, when the literature was examined, several studies were found using criteria such as ecological footprint and carbon footprint of these countries (Ziegler et al., 2013; Li et al., 2016b; Nielsen et al., 2017; Georgescu et al., 2024; Eriksson et al., 2015). In this respect, this study will be the first study to reveal the FGF stochastic dynamics of marine resource conservation and sustainable fisheries in the Nordic countries.

The aim of the study is to examine the stochastic properties of the ecological footprint of fishing grounds in Nordic countries, which can play a key role in reducing ecological problems and providing insights into the dynamics of sustainable development. Thus, it will be sufficient for policymakers to put forward micro-practices for environmental regulations and restrictions, first from a regional and then a global perspective. Following the introduction, the second section provides a brief overview of the empirical findings in the literature. The third section defines the scope of the study and introduces the dataset, followed by a methodology section summarizing the empirical process. The fourth section reports and discusses the empirical findings. The last section presents the conclusions and policy recommendations of the study.

2. Literature Review

Upon reviewing the relevant literature, it is evident that a limited number of studies are available. Clark and Longo (2019) investigated how economic growth, geography, and historical periods impacted countries' fisheries footprints. The study's data was examined from 1961 through 2010. To better understand how the impact of economic development differs depending on the degree of national economic prosperity, the geography, and the time period, they concentrate their investigation on the fisheries footprint of less developed countries. According to the study's findings, the fisheries footprint in less developed countries is gradually driven more by economic growth.

The stochastic behavior of the fishing grounds footprint of the top 10 fishing nations was evaluated by Adalı et al. (2023). The series on China, Indonesia, India, Peru, Japan, the Philippines, Vietnam, and the United States spanned 1961–2018, while the series on Bangladesh and Russia covered 1992–2018 and 1971–2018, respectively. Due to data availability, the series' time periods vary. Most URTs verify the presence of stationary patterns for Russia, while the fishing grounds footprint of China, India, and the Philippines was rigorously shown to exhibit non-stationarity stochastic patterns when all URT findings were considered.

Fractional integration was used by Solarin et al. (2021) to examine the fishing ground footprint in 89 nations. Although they discover that the majority of the series are nonstationary and non-mean reverting, their findings vary greatly throughout nations, with the majority falling into the upper-middle and high-income ranges.

The dynamics of fishing footprints in the Congo Basin and Gulf of Guinea area were investigated by Kassouri (2021). Between 1990 and 2017, they track the changes in fishing ground footprints in twelve nations in the Congo Basin and the Gulf of Guinea. In fishing ground imprints, they discover modest evidence of convergence, suggesting that the catching-up effect is only partially present.

Kong et al. (2021) investigated the spatial-temporal variation characteristics of marine fishery ecological footprint and decoupling effects associated with the fishing economy of 11 coastal provinces in China from 2010 to 2019 using the Tapio elastic decoupling model and the modified ecological footprint model. The findings demonstrated that the ecological footprint of marine fisheries in 11 Chinese coastal provinces rose sporadically between 2010 and 2019.

Karimi et al. (2022) looked at the economic aspects affecting the fishing industry's ecological footprint using 17 collections of data from Asia-Pacific nations between 2000 and 2017. Although its squared form coefficient is negative, the results support the EKC hypothesis in the fishing grounds footprint, showing that GDP per capita increase has a positive and substantial impact.

The convergence hypothesis of the ecological balance of fisheries in 20 African nations between 1961 and 2018 was studied by Adalı et al. (2024). Different nations have different results from the panel URTs on the stochastic features of the fishing balance.

In their study, Solarin et al. (2019) looked at the convergence of fishing ground footprints across 92 nations between 1961 and 2014. The results show that two convergence clubs for fishing ground footprint can be observed.

Caglar et al. (2021) investigated the fishing ground footprint's resilience to shocks (political, economic, epidemics, etc.) in the EU-5 nations between 1961 and 2016. They used the newly developed SOR URT, which takes into account both sharp and smooth breaks to provide reliable findings, after first using the conventional and one-break URTs to accomplish their goal. The econometric results show the presence of unit roots in fishing ground footprints.

Pata et al. (2024) assessed how Malaysian fishing grounds are impacted by democracy, economic growth, and the use of fisheries products. The research used data from 1961 to 2018 to do an ARDL analysis. As a result of the analysis, it was determined that the EKC is not valid for the footprint of Malaysian fisheries. Additionally, the fishing footprint is increased by economic expansion and the consumption of fisheries products. Democracy doesn't affect fishing footprints.

Whether the impact of shocks on the fishing grounds footprint in the Big Ten developing economies is temporary or not was the goal of Yilanci et al. (2022). On yearly data from 1961 to 2017, they used the newly developed fractional URT with a Fourier function (FUR) and the Fourier augmented Dickey-Fuller URT with a fractional frequency (FADF). According to their research, this is not the case for the Big Ten nations, and changes to fishing ground footprint policies will only have short-term impacts.

3. Data and Methodology

3.1. Data

This study aims to investigate the stochastic dynamics of the ecological footprint of the fishing grounds of the Nordic countries from a sustainability perspective. For this purpose, the fishing grounds of the Nordic countries are spread over a large geographical area, including the North Sea, the Barents Sea, the Baltic Sea, and parts of the Atlantic Ocean. The fishing grounds of these countries are fertile and food-rich, with cold sea waters and freshwater resources. In addition, thanks to national and regional cooperation in this region, seasonal restrictions, quotas, and Marine Protected Areas (MPAs) are aimed at sustainable management with a focus on conserving fish stocks and ecological balance. The Nordic countries included in the study are Denmark, Finland, Iceland, Norway, and Sweden (Iceland and the Faroe Islands were excluded from the empirical analysis due to the lack of data on these countries). Global hectares of FGF per capita (gha) covering the data range 1961-2022 were used. The FGF data of the countries are taken from the Global Footprint Network and several URTs are used to investigate the stationarity of these series.

Graphic 2 presents historical per capita FGF data for four countries. Norway's FGF per capita was higher by far for most of the data period but has shown a significant downward trend in recent years. Following Norway, Denmark has a higher FGF per capita. On the other hand, Finland and Sweden have similar levels of FGF per capita. For more information on the series of countries, descriptive statistics are given in Table 1.

Graphic 2. FGF (gha) series per capita for the Nordic countries

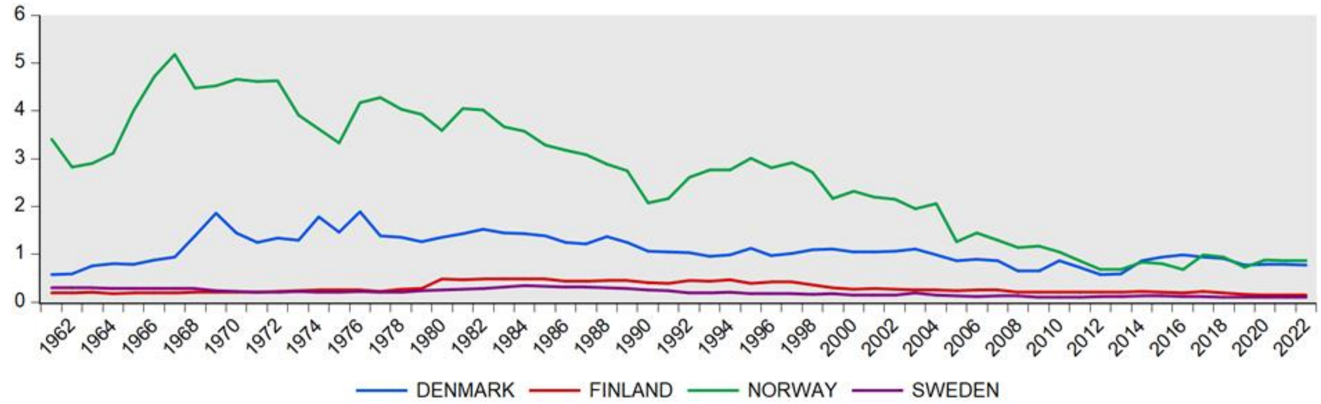


Table 1. Descriptive Statistic

Country	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	JB	JB Prob	Obs.
Denmark	1.077	1.036	1.890	0.570	0.312	0.531	2.917	2.931	0.231	62
Finland	0.287	0.246	0.488	0.149	0.110	0.684	1.909	7.912	0.019	62
Norway	2.649	2.785	5.185	0.675	1.319	-0.033	1.813	3.653	0.161	62
Sweden	0.201	0.205	0.344	0.094	0.074	0.165	1.731	4.439	0.109	62

Table 1 presents descriptive statistics for the FGF per capita series. The country with the highest average FGF per capita is Norway, followed by Denmark. The countries with the lowest average FGF per capita are Sweden and Finland, respectively. Except for the Finnish series, the series is normally distributed according to the JB test statistic.

3.2. Methodology

In this study, determining the stochastic structure and linearity of the series is an important point in investigating the stationarity of the series. This is because incorrect identification of the stochastic structure of the series and the use of tests that do not consider nonlinearity may lead to erroneous results regarding the UR process. For this reason, it would be appropriate to test linearity in the first step of the empirical strategy. To test linearity, Harvey et al. (2008) proposed a linearity test when stationarity is unknown.

$$y_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 y_{t-1}^2 + \beta_3 y_{t-1}^3 + \beta_4 \Delta y_{t-1} + \beta_5 (\Delta y_{t-1})^2 + \beta_6 (\Delta y_{t-1})^3 + \varepsilon_t \quad (1)$$

$$H_0 : \beta_2 = \beta_3 = 0$$

$$H_1 : \beta_2 \neq \beta_3 \neq 0$$

Equation 1 estimates the AR process and tests the joint significance of the nonlinear terms β_2 and β_3 with the null hypothesis H_0 representing linearity and the alternative hypothesis representing nonlinearity.

In the stochastic structure of the series, three structures emerge according to the presence or absence of intercept and deterministic trend. There are three structures in the series: (i) no intercept term and deterministic trend, (ii) no deterministic trend in the presence of an intercept term, and (iii) the presence of intercept and deterministic trend terms. When the truncation and/or deterministic trend is modeled incorrectly in the data-generating process of the series before applying the URT, a specification error is made in the URT, and the power of the test is reduced. In this case, the URT will tend to fail to reject the null hypothesis. Sims et al. (1990) proposed a method that investigates the stochastic structure of the series by testing the AR(1) process, which includes the intercept and trend term in the data-generating process of the series, using standard t-test and F-test. Accordingly, by testing from the most general model (with intercept and trend) to the most specific model (without intercept and trend), which is defined as a sequential process approach, a practical approach is presented to determine whether the stochastic structure of the series includes intercept and deterministic trend in the data generating process. Therefore, in the second stage, the stochastic structure of the series will be determined and URT models appropriate to the stochastic structure will be applied.

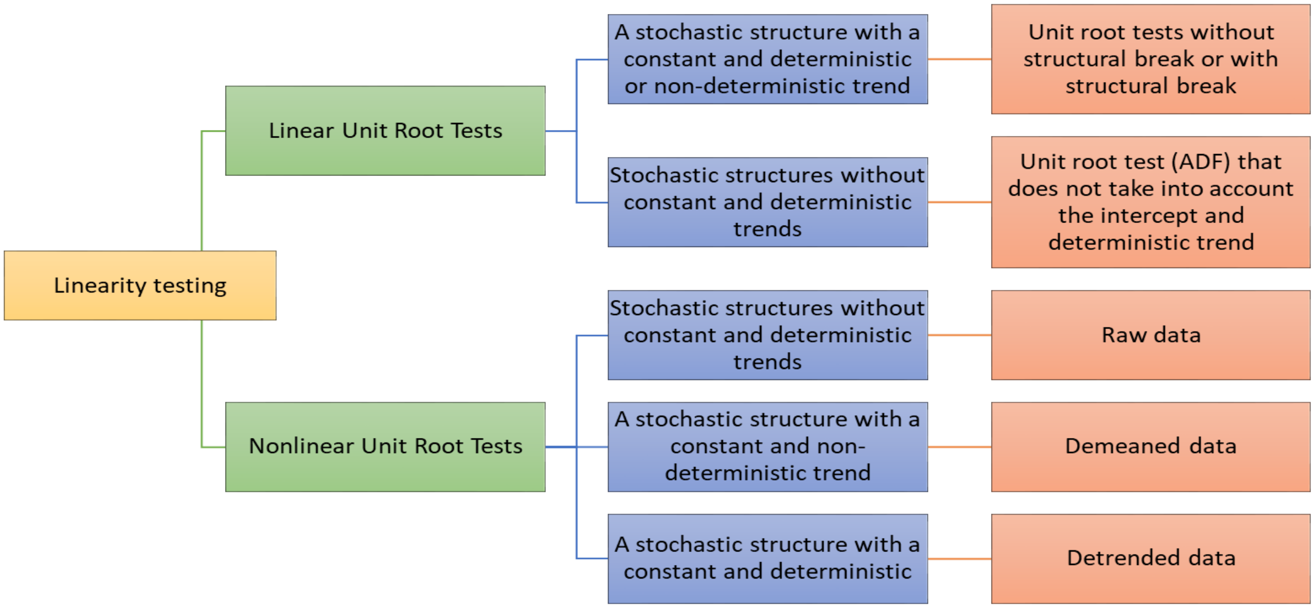


Figure 1. Empirical Process

As can be seen in Figure 1, which summarizes the empirical process, linear or nonlinear URTs will be applied to the series as a result of the linearity tests. In linear URTs, if the stochastic structure of the series includes intercept and trend, three different URTs are applied. The first one is the LM test proposed by Schmidt & Phillips (1992), which investigates the presence of a unit root in the presence of deterministic trends.

$$u_t = \rho u_{t-1} + \varepsilon_t \tag{2}$$

$H_0: \rho = 1$

$H_1: \ \rho < 1$

The u_t series in Equation 2 is the residuals obtained from the y_t series with deterministic components. For the LM test statistic obtained here, the null hypothesis is the unit root, and the alternative hypothesis is stationarity.

The model estimated according to the LM principle of the minimum LM URT under one structural break proposed by Lee & Strazicich (2013) and the URT under two structural break proposed by Lee & Strazicich (2003);

$$y_t = \delta' Z_t + \varepsilon_t \tag{3}$$

$$\Delta y_t = \delta' Z_t + \phi \tilde{S}_{t-1} + \varepsilon_t \tag{4}$$

$H_0: \phi = 1$

$H_1: \ \phi < 1$

The Z_t series here refers to breaks as a vector of exogenous variables. These breaks are $Z_t = [1, t, D_t]$ for a single break in the intercept and $Z_t = [1, t, D_t, DT_t]$ for a break in the trend as suggested by Lee & Strazicich (2013). For the Lee & Strazicich (2003) test, Z_t is constructed as a two break, where $Z_t = [1, t, D_{1t}, DT_{1t}]$ for two break in the constant and trend, and $Z_t = [1, t, D_{1t}, D_{2t}, DT_{1t}, DT_{2t}]$ for a double break in the trend. The null hypothesis H_0 indicates a unit root and the alternative hypothesis indicates stationarity.

Finally, if there are no deterministic components of truncation and trend under linearity in the data-generating process of the series, the Augmented Dickey-Fuller (ADF) test proposed by Dickey & Fuller (1979, 1981) is used as a conventional URT.

$$\Delta y_t = \delta y_{t-1} + \textstyle\sum_{i=1}^{k} a_i \Delta y_{t-i} + \varepsilon_t \tag{5}$$

$$\Delta y_t = \mu + \delta y_{t-1} + \textstyle\sum_{i=1}^{k} a_i \Delta y_{t-i} + \varepsilon_t \tag{6}$$

$$\Delta y_t = \mu + \beta T + \delta y_{t-1} + \sum_{i=1}^{k} a_i \Delta y_{t-i} + \varepsilon_t \tag{7}$$

$H_0: \delta = 0$

$H_1: \ \delta < 0$

The ADF tests in Equations 5, 6, and 7 represent models without intercept and trend, with intercept and trend, and with intercept and trend. While the null hypothesis states the presence of a unit root, the alternative hypothesis states the absence of a unit root, in other words, stationarity.

As a result of the Harvey et al. (2008) test, two different nonlinear URTs were applied in the study against the weakness of linear URTs in case the data generation process of the series exhibits nonlinear characteristics. The first one is the first Taylor expansion under the assumption of the first-order exponential smooth transition autoregressive process (ESTAR) proposed by Kapetanios et al. (2003), and the following test regression is proposed.

$$\Delta y_t = \delta y_{t-1}^3 + \textstyle\sum_{i=1}^{k} a_i \Delta y_{t-i} + \varepsilon_t \tag{8}$$

$H_0: \delta = 0$

$H_1: \ \delta < 0$

The null hypothesis of the test proposed by Kapetanios et al. (2003) is a unit root and the alternative hypothesis is nonlinear ESTAR stationarity. Kruse's (2011) test is an improved version of the Kapetanios et al. (2003) test. Accordingly, the test regression is proposed as follows.

$$\Delta y_t = \delta_1 y_{t-1}^3 + \delta_2 y_{t-1}^2 + \sum_{i=1}^{k=1} a_i \Delta y_{t-i} + \varepsilon_t \tag{9}$$

$H_0: \delta = 0$

$H_1: \ \delta < 0$

Similarly, this test's null and alternative hypotheses are unit root and nonlinear ESTAR stationarity, respectively. In nonlinear URTs, components such as constant and deterministic trends are not included. Instead, depending on the data-generating process of the series, raw data is used if there is no truncation and trend; demeaned data is used if there is a truncation and trendless component; and detrended data is used if there is a truncation and trend component.

3. Empirical Results

Empirical results before investigating the stationarity of the FGF series of the Nordic countries Denmark, Finland, Norway, and Sweden, the series' deterministic components and linearity tests were performed by following the empirical process in Figure 1. Table 2 shows that according to the sequential process approach, the deterministic components of the series have intercept and trend components for Denmark and Norway, while there are no intercept and trend deterministic components for Finland and Sweden.

Table 2. Deterministic component structures of series

Country	Deterministic Structure of the Series
Denmark	C+T
Finland	non(C+T)
Norway	C+T
Sweden	non(C+T)

In the process of making the series' data, C+T, C+nonT, and non(C+T) stand for the deterministic structure with a constant and a trend, a constant and no trend, and a structure without a constant and no trend, accordingly.

Table 3 presents the linearity test results of Harvey et al. (2008). Accordingly, the linearity test results for Denmark, Finland, and Norway W_λ Since the test statistic is smaller than the critical values, the null hypothesis cannot be rejected. It is understood that the series for these countries exhibit linear behavior in the data generation process. Therefore, linear URTs should be applied to investigate the stationarity of the FGF series for these countries. On the other hand, the results for Sweden W_λ Since the test statistic is greater than the critical value at least at the 1% probability level, the null hypothesis of linearity is strongly rejected. The Swedish FGF series exhibits nonlinear behavior in the data-generating process. Hence, it would be appropriate to apply URTs that consider nonlinearity.

Table 3. Linearity Test Results

Seri	W_λ	Decision
Denmark	0.14	Linearity
Finland	0.4	Linearity
Norway	0.21	Linearity
Sweden	18.62^{***}	Nonlinearity

Table 4 presents the results of the LM URT without structural breaks, with one and two structural breaks for the Danish FGF series. The URT equations appropriate to the truncated and trended structure identified as the deterministic component of the Danish FGF series were used. For all three tests, the alternative hypothesis is against the existence of a URT stationarity. The alternative hypothesis indicates stationarity under structural breaks in the tests with structural breaks. While the FGF series contains a unit root according to the test result without structural breaks, the null hypothesis expressing the existence of a unit root is rejected in the one-break and two-break tests, and the series is stationary under structural breaks.

Table 4. Unit Root Results for the Denmark FGF Series

Tests	statistics	critical values			Date Break(s)
		1%	5%	10%	
Schmidt & Phillips (1992)	-0.728	-3.507	-2.904	-2.616	
Lee & Strazicich (2013)	-4.350***	-4.236	-3.639	-3.358	[1984]
Lee & Strazicich (2003)	-6.600***	-5.176	-4.444	-4.088	[1976] [2010]

Symbols *, **, and *** denote the rejection of the null hypothesis at significance levels of 10%, 5%, and 1%, respectively, while the numbers in brackets represent the break dates.

Table 5 shows that the stationarity of the Finnish FGF series is investigated. Since the Finnish series exhibits linear behavior in the data-generating process and there are no intercept and deterministic trend components, and therefore investigating structural breaks in the absence of deterministic components would yield erroneous results, the traditional ADF test is used as a linear URT without deterministic components. According to the results of the ADF test, the null hypothesis expressing the existence of a unit root cannot be statistically rejected at a probability level of at least 5%. Accordingly, it is concluded that the Finnish FGF series is non-stationary.

Table 5. Unit Root Result for the Finland FGF Series

Tests	statistics	critical values		
		1%	5%	10%
ADF	-0.533	-2.603	-1.946	-1.613

Table 6 presents the URT results for the Norwegian FGF series. As in the Danish series, the Norwegian FGF series exhibits linear behavior and has intercept and deterministic trend components, so the intercept and trend models of the LM URTs were used. According to the LM test results without structural breaks, the series contains a unit root, but when structural breaks are considered, it is concluded that the series is stationary under structural breaks.

Table 6. Unit Root Results for the Norway FGF Series

Tests	statistics	critical values			Date Break(s)
		1%	5%	10%	
Schmidt & Phillips (1992)	-1.476	-3.560	-2.957	-2.668	
Lee & Strazicich (2013)	-4.633**	-4.777	-4.207	-3.915	[1981]
Lee & Strazicich (2003)	-4.937**	-4.988	-4.360	-4.071	[1978] [2008]

Symbols *, **, and *** denote the rejection of the null hypothesis at significance levels of 10%, 5%, and 1%, respectively, while the numbers in brackets represent the break dates.

Table 7 displays the URT results for the Swedish FGF series. Tables 2 and 3 indicate that this series demonstrates nonlinear characteristics in the data generation process and is devoid of deterministic elements such as intercept and trend. Consequently, the nonlinear URTs are incorporated. Raw data is utilized for both tests due to the absence of an intercept and trend as the deterministic component of the series. The URT in the test proposed by Kapetanios et al. (2003) is lower than the critical values in absolute terms and the null hypothesis of the existence of a unit root cannot be rejected. Similarly, in the Kruse (2011) test, the null hypothesis cannot be rejected since the test statistic is smaller than the critical values. Accordingly, it is concluded that the Swedish FGF series is non-stationary.

Table 7. Unit Root Result for the Sweden FGF Series

Tests	statistics	critical values		
		1%	5%	10%
Kapetanios et al. (2003)	-1.296	-2.82	-2.22	-1.92
Kruse (2011)	2.752	13.15	9.53	7.85

As reported in Tables 4, 5, 6, and 7, several conclusions have been reached over different URTs. Table 8 summarizes the findings obtained in three stages in accordance with the empirical process. The URT results for the FGF series are statistically conclusive at the 5% probability level in testing the null hypotheses. Accordingly, while Denmark and Norway are stationary in the FGF series of the four Nordic countries, Finland and Sweden exhibit non-stationary behavior.

Table 8. Summary URT Results

Country	**URT Result**
Denmark	Stationary
Finland	Non-stationary
Norway	Stationary
Sweden	Non-stationary

4. Discussion and conclusion

Although countries' development level is associated with more production and consumption, today, opinion leaders in society, policymakers, and scientists have started to focus on a better living environment and the sustainability of these conditions. Discussions have increased over the last few decades at national and international meetings on environmental issues, climate change, and whether future generations will have a livable and sustainable world heritage. The main point is to combat climate change caused by development dynamics in developed and developing or underdeveloped countries and to implement policies and regulations that reduce greenhouse gas and carbon emissions. In this context, the sub-components of EF, as an important indicator of climate change, need to be carefully examined, and more micro-level regulations, restrictions, quotas, and policy constructions should be made from the perspective of these sub-components as well as macro-level policies.

The seas, which constitute a critical and important pattern of the world ecosystem, constitute the habitat of many species in trophic levels. Any disruption in the ecosystem pattern here can lead to the disruption of the entire ecological balance. For this reason, in addition to primary aquatic environmental degradation factors such as improper fishing methods, poaching, trawling, and overfishing in water areas, larger but secondary factors such as plastic pollution, overconsumption, global warming, industrialization, etc., cause the destruction of biodiversity and the deterioration of the marine ecosystem. SDG14, labeled as the SDG for life in water, provides a holistic perspective for the protection of this aquatic ecosystem.

In this study, FGFs per capita as an environmental indicator of the aquatic areas of the Nordic countries, which have an important position in the marine ecosystem, are considered, and it is aimed to provide insights to policymakers by examining the stochastic behavior of these data. In the empirical process of analyzing the stochastic structures of time series, it is important to determine the linearity and deterministic component structures of the series correctly according to the purposes and advantages of the URTs in the literature in order to reach the correct results. For this purpose, the URT results obtained in three stages provide statistically robust evidence without any specification error.

The stochastic behavior of FGF in the data generation process in the Nordic countries seems to provide important clues to policymakers and researchers in understanding the short-term and long-term responses of FGF to policy shocks as an indicator of environmental degradation in aquatic areas and in forward projections. Accordingly, among the four Nordic countries analyzed in this study, the FGFs of Denmark and Norway are stationary, while the FGFs of Finland and Sweden are non-stationary. Accordingly, policy shocks in Denmark and Norway tend to return to their long-run averages and trend path. It is understood that policy shocks to reduce the FGF in these countries will be ineffective in the long run despite their short-run effect. On the other hand, the non-stationary behavior of the FGFs of Finland and Sweden indicates that policy shocks will occur in these countries.

Have long-run effects. The URT results for these countries do not show a tendency for policy shocks to revert to the mean. Although Finland and Sweden have smaller fisheries than the other two countries, their fisheries governance and strategies are more developed. Therefore, there is no need to develop additional policies to reduce environmental degradation in aquatic areas. However, the stochastic structure of the FGF suggests that a negative policy shock - a policy change that increases environmental degradation - may be effective in the long run.

The fight against environmental degradation is certain to be a topic of conversation and policymakers' policy choices for decades to come. States that are actors of environmental degradation need to implement more international cooperation and global regulations. The results of this study make a unique contribution to the literature in terms of showing that countries with similar development levels and geographical areas, such as the Nordic countries, may have different policy preferences at the national level and the effects of this policy. We highlight the significance of micro-scale policies and practices within the sub-dimensions of the SDGs. Furthermore, we note that global paradigms for addressing environmental degradation may vary from the policy design and nature of efforts at the national level.

References

Adalı, Z., Toygar, A., & Yıldırım, U. (2023). Assessing the stochastic behavior of fishing grounds footprint of top ten fishing countries. Regional Studies in Marine Science, 63, 103015.

Adalı, Z., Toygar, A., & Yıldırım, U. (2023). Assessing the stochastic behavior of fishing grounds footprint of top ten fishing countries. *Regional Studies in Marine Science, 63*, 103015.

Adalı, Z., Toygar, A., Karataş, A. M., & Yıldırım, U. (2024). Sustainable fisheries and the conservation of marine resources: A stochastic analysis of the fishery balance of African countries. *Journal for Nature Conservation*, 126653.

Aish, A., Trent, S., & Williams, J. (2003). *Squandering the seas: How shrimp trawling is threatening ecological integrity and food security around the world*. Environmental Justice Foundation, London, UK.

Amin, S., Li, C., Khan, Y. A., & Bibi, A. (2022). Fishing grounds footprint and economic freedom indexes: Evidence from Asia-Pacific. *PLOS One, 17*(4), e0263872.

Bastianoni, S., Niccolucci, V., Pulselli, R. M., &

Marchettini, N. (2012). Indicator and indicandum: “Sustainable way” vs “prevailing conditions” in the ecological footprint. *Ecological Indicators, 16*, 47–50.

Bi, M., Xie, G., & Yao, C. (2020). Ecological security assessment based on the renewable ecological footprint in the Guangdong-Hong Kong-Macao Greater Bay Area, China. *Ecological Indicators, 116*, 106432.

Caglar, A. E., Balsalobre-Lorente, D., & Akin, C. S. (2021). Analysing the ecological footprint in EU-5 countries under a scenario of carbon neutrality: Evidence from newly developed sharp and smooth structural breaks in unit root testing. *Journal of Environmental Management, 295*, 113155.

Clark, T. P., & Longo, S. B. (2019). Examining the effect of economic development, region, and time period on the fisheries footprints of nations (1961–2010). *International Journal of Comparative Sociology, 60*(4), 225–248.

Dammannagoda, S. T. (2018). Sustainable fishing methods in Asia Pacific region. *Sustainable Aquaculture*, 95–122.

Dickey, D. A., & Fuller, W. A. (1979). Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association, 74*(366a), 427–431.

Dickey, D. A., & Fuller, W. A. (1981). Likelihood ratio statistics for autoregressive time series with a unit root. *Econometrica: Journal of the Econometric Society*, 1057–1072.

Eriksson, M., Strid, I., & Hansson, P. A. (2015). Carbon footprint of food waste management options in the waste hierarchy–a Swedish case study. *Journal of Cleaner Production, 93*, 115–125.

Estes, J. A., Terborgh, J., Brashares, J. S., Power, M. E., Berger, J., Bond, W., Carpenter, S. R., Essington, T. E., Holt, R. D., Jackson, J. B. C., Marquis, R. J., Oksanen, L., Oksanen, T., Paine, R. T., Pikitch, E. K., Ripple, W. J., Sandin, S. A., Scheffer, M., Schoener, T. W., Shurin, J. B., Sinclair, A. R. E., Soule, M. E., Virtanen, R., & Wardle, D. A. (2011). Trophic downgrading of planet Earth. *Science, 333*(6040), 301–306.

FAO. (2024). *The state of world fisheries and aquaculture*. Retrieved from https://www.fao.org/publications/home/fao-flagship-publications/the-state-of-world-fisheries-and-aquaculture/en

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., & Giljum, S. (2012). Integrating ecological, carbon and water footprint into a “footprint family” of indicators: Definition and role in tracking human pressure on the planet. *Ecological Indicators, 16*, 100–112.

Gao, J., & Tian, M. (2016). Analysis of over-consumption of natural resources and the ecological trade deficit in China based on ecological footprints. *Ecological Indicators, 61*, 899–904.

Georgescu, I., & Kinnunen, J. (2024). Effects of FDI, GDP and energy use on ecological footprint in Finland: An ARDL approach. *World Development Sustainability, 4*, 100157.

Harvey, D. I., Leybourne, S. J., & Xiao, B. (2008). A powerful test for linearity when the order of integration is unknown. *Studies in Nonlinear Dynamics & Econometrics, 12*(3).

Ivleva, N. P., Wiesheu, A. C., & Niessner, R. (2017). Microplastic in aquatic ecosystems. *Angewandte Chemie International Edition, 56*(7), 1720–1739.

Jennings, S., Lee, J., & Hiddink, J. G. (2012). Assessing fishery footprints and the trade-offs between landings value, habitat sensitivity, and fishing impacts to inform marine spatial planning and an ecosystem approach. *ICES Journal of Marine Science, 69*(6), 1053–1063.

Kapetanios, G., Shin, Y., & Snell, A. (2003). Testing for a unit root in the nonlinear STAR framework. *Journal of Econometrics, 112*(2), 359–379.

Karimi, M. S., Khezri, M., Khan, Y. A., & Razzaghi, S. (2022). Exploring the influence of economic freedom index on fishing grounds footprint in environmental Kuznets curve framework through spatial econometrics technique: Evidence from Asia-Pacific countries. *Environmental Science and Pollution Research, 29*(4), 6251–6266.

Kassouri, Y. (2021). Exploring the dynamics of fishing footprints in the Gulf of Guinea and Congo Basin region: Current status and future perspectives. *Marine Policy, 133*, 104739.

Kong, F., Cui, W., & Xi, H. (2021). Spatial–temporal variation, decoupling effects and prediction of marine fishery based on modified ecological footprint model: Case study of 11 coastal provinces in China. *Ecological Indicators, 132*, 108271.

Kruse, R. (2011). A new unit root test against ESTAR based on a class of modified statistics. *Statistical Papers, 52*(1), 71–85.

Lee, J., & Strazicich, M. C. (2003). Minimum Lagrange multiplier unit root test with two structural breaks. *Review of Economics and Statistics, 85*(4), 1082–1089.

Lee, J., & Strazicich, M. C. (2013). Minimum LM unit root test with one structural break. *Economics Bulletin, 33*(4), 2483–2492.

Li, W. C., Tse, H. F., & Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. *Science of the Total Environment, 566*, 333–349.

Liu, Y., Rosten, T. W., Henriksen, K., Hognes, E. S., Summerfelt, S., & Vinci, B. (2016). Comparative economic performance and carbon footprint of two farming models for producing Atlantic salmon (*Salmo salar*): Landbased closed containment system in freshwater and open net pen in seawater. *Aquacultural Engineering, 71*, 1–12.

Myers, R. A., Baum, J. K., Shepherd, T. D., Powers, S. P., & Peterson, C. H. (2007). Cascading effects of the loss of apex predator sharks from a coastal ocean. *Science, 315*(5820), 1846–1850.

Nielsen, M., Hoff, A., Nielsen, R., & Waldo, S. (2017). Nordic fisheries and aquaculture: Socio-economic importance of nitrogen nutrient load in the environment. *Nordic Council of Ministers*.

Pata, U. K., Erdogan, S., Solarin, S. A., & Okumus, I. (2024). Evaluating the influence of democracy, financial development, and fishery product consumption on fishing grounds: A case study for Malaysia. *Marine Policy, 168*, 106301.

Sanyé-Mengual, E., Secchi, M., Corrado, S., Beylot, A., & Sala, S. (2019). Assessing the decoupling of economic growth from environmental impacts in the European Union: A consumption-based approach. *Journal of Cleaner Production, 236*, 117535.

Scavia, D., Field, J. C., Boesch, D. F., Buddemeier, R. W., Burkett, V., Cayan, D. R., ... & Titus, J. G. (2002). Climate change impacts on US coastal and marine ecosystems. *Estuaries, 25*(2), 149–164.

Schmidt, P., & Phillips, P. C. (1992). LM tests for a unit root in the presence of deterministic trends. *Oxford Bulletin of Economics and Statistics, 54*(3), 257–287.

Sims, C. A., Stock, J. H., & Watson, M. W. (1990). Inference in linear time series models with some unit roots. *Econometrica: Journal of the Econometric Society, 58*(1), 113–144.

Solarin, S. A., Tiwari, A. K., & Bello, M. O. (2019). A multi-country convergence analysis of ecological footprint and its components. *Sustainable Cities and Society, 46*, 101422.

Solarin, S. A., Gil-Alana, L. A., & Lafuente, C. (2021). Persistence and sustainability of fishing grounds footprint: Evidence from 89 countries. *Science of the Total Environment, 751*, 141594.

Ullah, I., Nuta, F. M., Levente, D., Yiyu, B., Yihan, Z., Yi, C., ... & Kumar, R. (2023). Nexus between trade, industrialization, and marine pollution: A quantile regression approach. *Ecological Indicators, 155*, 110992.

Ulucak, R., & Lin, D. (2017). Persistence of policy shocks to ecological footprint of the USA. *Ecological Indicators, 80*, 337–343.

Ulucak, R., Kassouri, Y., İlkay, S. Ç., Altıntaş, H., & Garang, A. P. M. (2020). Does convergence contribute to reshaping sustainable development policies? Insights from Sub-Saharan Africa. *Ecological Indicators, 112*, 106140.

Wang, X., Dong, Z., Wang, W., Luo, Y., & Tan, Y. (2021). Stochastic grey water footprint model based on uncertainty analysis theory. *Ecological Indicators, 124*, 107444.

Wiedmann, T. (2009). A first empirical comparison of energy footprints embodied in trade—MRIO versus PLUM. *Ecological Economics, 68*(7), 1975–1990.

Worm, B., Hilborn, R., Baum, J. K., Branch, T. A., Collie, J. S., Costello, C., ... & Zeller, D. (2009). Rebuilding global fisheries. *Science, 325*(5940), 578–585. https://doi.org/10.1126/science.1173146

Yang, G., & Li, P. (2007). A discussion on tourist ecological footprint and its theoretical significance. *Tourism Science, 22*(2), 54–58.

Yıldırım, D. Ç., Yıldırım, S., Bostancı, S. H., & Turan, T. (2022). The nexus between human development and fishing footprint among Mediterranean countries. *Marine Pollution Bulletin, 176*, 113426.

Yilanci, V., Gorus, M. S., & Aydin, M. (2019). Are shocks to ecological footprint in OECD countries permanent or temporary? *Journal of Cleaner Production, 212*, 270–301.

Zhang, Y., & Yang, G. (2009). The touristic ecological footprint study of man-made scenic spot: Taking Kunming World Horti-Expo Garden as a case. *Journal of Beijing International Studies University, 31*(1), 51–58.

Ziegler, F., Winther, U., Hognes, E. S., Emanuelsson, A., Sund, V., & Ellingsen, H. (2013). The carbon footprint of Norwegian seafood products on the global seafood market. *Journal of Industrial Ecology, 17*(1), 103–116.