Water Productivity Journal

Received: 22 December 2020

Accepted: 2 February 2021

WPJ, Vol. 1, No. 3, Winter 2021

A cross-national analysis of the factors impacting the coastal ecological footprint

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Abstract

Coastal ecological footprint (EF) forms one of the six components of the EF measure. It accounts for the marine area required to sustain current levels of seafood consumption within a nation. It is estimated by drawing on the calculation of net primary production or the amount of solar energy converted into organic matter through photosynthesis needed to support a fishery. Coastal ecosystems, found along continental margins are the regions of extraordinary productivity and accessibility which also makes them vulnerable to degradation. Hence studying their footprint becomes important. This paper seeks to find the driving factors behind the coastal EF using data from 117 countries for a period of two decades from 1992 to 2012. A set of economic, demographic, climatic and trade variables were found to have the biggest impact on coastal EF. Given that temperature has emerged as the most import driving factor coastal EF among the variables examined, policies to protect and restore coastal ecosystems go hand in hand with the policies to combat global warming and ties into the larger narrative of climate change that has sparked debate and controversy in recent times. It is necessary to have the international co-operation through organisations, conventions, agreements and everything in between because we know that the temperature fluctuations at unprecedented levels are a global phenomena. But countries inevitably give different levels of priority to the sustainable development of their coasts depending upon national interests.

Keywords: Coastal Ecological Biocapacity; Coastal Ecological Footprint; Cross-National Analysis; Ecological Footprint

INTRODUCTION

The current state of the planet warrants retrospection into our development activities which has involved indiscriminate exploitation of the ecosystem resources at a rapid speed. This has allowed no time for ecosystems to regenerate and return to its normal functioning. In such a situation, discussions on sustainability and sustainable development gains importance. Sustainability includes, but is not limited to people attaining maximum welfare in their lives but within nature's means. A major portion of the discussions in the early stages have been limited to depletion of non-renewable resources, but overuse and exploitation of renewable resources have also gained attention more recently as it poses a threat to our society (Kitzes *et al*., 2007). Climate change due to greenhouse gas emission, soil erosion due to deforestation and collapsing fisheries are a few examples. This impact of human activities can be measured in terms of the area of biologically productive land and water required to produce the goods consumed and to assimilate the wastes generated. This is what we call Ecological Footprint (EF) (Wackernagel *et al*., 1997).

The EF concept was introduced by Wackernagel and Rees (1994) to measure the biologically productive area necessary to support the current consumption

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patterns, given prevailing technical and economic processes. Later EF was redefined as the measure of the biocapacity fundamental for an economic framework to work, for example the biocapacity ought to have the essential pool of natural resources and it ought to also have the option to absorb the waste produced by the economic framework (Wackernagel and Monfreda, 2004). WWF defines footprint more simply as the amount of the environment necessary to produce the goods and services necessary to support a particular lifestyle.

As countries, organizations and communities have started to recognize the importance of using earth's resources within the range of its productivity, a methodology which addresses the question of how much of nature we use and how much we have, has become a necessity. The EF hence evolved as a science-based methodology that addresses this question by contrasting the ecosystem services utilized every year by mankind with the biosphere's yearly regenerative limit with regards to these services. A footprint can be determined at any scale— from global, national or municipal to that of organizations, products or services. It is measured in global-acres, units of biologically productive area necessary to produce the annual flow of resources that are consumed. Translating different types of resource use into a single common metric makes it easy to benchmark the overall ecological demand associated with any human activity, from a single project to the operation of an entire organization or community. At the same time, the footprint components can be analyzed to determine their relative contribution to the overall demand, and targeted strategies can be developed to maximize Footprint savings.

EF is a composite consisting of six components – the area of cropland required for crop production, the area of grazing land for the production of animal products, the area of forest required for wood and paper production, the area of sea required to produce marine fish and seafood, the area of land required for housing and infrastructure and finally the area of forest required to sequester carbon (Chambers *et al*., 2000).

In the present chapter, I confine myself to one of these six components, namely the coastal EF component which accounts for the marine area required to sustain the current level of seafood consumption within a nation. It can be calculated as the amount of energy from the sun that is converted into organic matter by the process of photosynthesis (i.e. primary production) that is required to maintain fishery output (Clark *et al*., 2018).

Coastal ecosystems, found along continental margins are regions of extraordinary productivity and accessibility. This made them centres of human activity and the birth place of civilization. From a production standpoint, they are the primary producers of fish (the term 'fish' is used in a broad sense and includes aquatic animals such as fish, crustaceans, molluscs and other aquatic invertebrates) and seaweed for both human and animal consumption. The bulk of the world's marine fish harvest, as much as 95 percent, by some estimates is caught or reared in coastal waters. Only a small percentage comes from the open ocean. Fisheries are also important within the framework of the sustainable development goals of achieving global food security and ending malnutrition. Within this framework, fisheries form an irreplaceable part of local and global food systems and though overlooked and undervalued sometimes, contributes to health and nutrition especially for the poorer sections of the society (Thilsted *et al*., 2015).

Natural resources from oceans and coasts are essential components for human well-being. The world's coastal areas generate a large share of the ocean's services, and their support of coastal economies and livelihoods is particularly important in less developed areas (Costanza, 1999; Martínez *et al*., 2007; Kildow and McIlgorm, 2010; Visbeck *et al*., 2014). But people are also drawn to the coast for recreational, aesthetic, cultural, and spiritual reasons, for the specific sense of place and well-being they attach to coastal environments (Bell *et al*., 2015), or for pursuing “coastal lifestyles” (Green, 2010). For coastal states and island nations, coastal tourism is a complex factor for conservation and economic development. For many Small Island Developing States (SIDS), unique land and seascapes enable tourism as a major economic activity (Division for Sustainable Development, 2015; UNEP, 2009).

Coastal zones are attractive environments to settle and live or pursue economic activities, but this has also led to a growing human footprint on coastal ecosystems, including less charismatic but ecologically highly important ones like seagrass meadows or salt marshes, and become a threat to many species (Duarte *et al*., 2008; Stojanovic and Farmer, 2013). Coastal zones support componded interactions of marine and terrestrial habitats sustaining high biodiversity, complex life cycle and food chain linkages through the water column (Neumann *et al*., 2017). The dynamics of most marine ecological linkages are poorly understood compared to terrestrial ecosystems.

When these ecosystems are exploited leading to a deterioration in their quality, communities that depend upon fisheries as their primary source of income and nutrition become increasingly vulnerable (Clark *et al*., 2018). Large scale degradation can also lead to permanent loss of marine biodiversity. It can result in reduced water filtration and declining quality of coral reefs, both of which can protect humans from exposure to toxins and intensify the coastal storms (Hiddink and Ter Hofstede, 2008). Various studies have also shown that entire oceans are under threat due to human activities and anthropogenic factors have endangered the sustainability of countless marine systems.

The main threats to coastal ecosystems are summarized to be habitat loss or conversion due to coastal development, agriculture, or aquaculture; habitat degradation due to eutrophication, pollution, and contamination; and consequent changes in sediment and water supply due to human activities along the coasts and in the upstream watersheds (Agardy *et al*., 2005; Newton *et al*., 2012). Coastal zones are also typically subject to natural hazards such as river flooding, storms and storm surges, and tsunamis, with serious socio-economic impacts from flooding and erosion in developed coastal areas (Newton and Weichselgartner, 2014). Some of these effects are exacerbated by climate change and sea-level rise (Wong *et al*., 2014).

Hence a look at the EF of coastal ecosystems is a useful exercise from a conservation and restoration standpoint. This paper is intended to explore the coastal EF as few have before it, in order to bring attention to the degradation due to anthropogenic activities using a scientific methodology such as the EF. The objective of this paper is to determine whether economic, demographic, climatic and trade variables have significant impact on coastal EFs of countries in the world.

Results from the analysis will help us categorize countries into groups based on the type of variables which affects its national coastal EF. This is a very important exercise from a policy perspective and can help countries implement tailor-made policies and manage their coastal ecosystems in a more sustainable manner. The study of emerging countries can give policymakers the insight they need to control environmental degradation in terms of EF.

It is also essential to include biocapacity of the coastal ecosystem in our empirical analysis so as to identify biocapacity debtor and creditor countries. “Biocapacity is the amount of biologically productive area available to that population within a defined geographical area” (Kitzes *et al*., 2008). It is comparable to EF and is also divided into five major categories of biologically productive areas like cropland, grazing land, fishing ground, forest land and built-up area.

Footprint accounts released by the Global Footprint Network shows that the world is currently operating in a state of overshoot with demand for resources exceeding nature's regenerative capacity by a huge measure. Overshoot is unsustainable and will Kitzes *et al*. (2008) erode the planet's resources leading to depletion and degradation. Hence it is useful to perform a similar analysis as we have proposed earlier by replacing coastal EF with coastal biocapacity with all of the independent variables remaining the same. This will help us answer more questions about the driving factors of footprint. We will also be able to see which countries are operating in a state of overshoot and which countries (if any) are not. This will give us valuable insight into their developmental and environmental policies and how well they are functioning. The ecological sustainability of a country is very much dependent on its capacity to absorb the pollution and also regenerate from the perspective of SDGs. This makes this exercise timely.

LITERATURE REVIEW

To date, research has demonstrated that EFs are driven by a variety of economic, political, ecological and demographic factors. The most notable among them for our purposes is Marquart-Pyatt (2010) paper. It investigated the driving forces of EF and its six sub-components using a cross-national data set of over a 100 countries and found that structural factors driving EFs differ across EF's components. Marquart-Pyatt used variables like GDP per capita, service sector as a percentage of country's GDP and GINI index to gauge domestic inequality and also used a host of other variables like liberal democracy score to account for political factors. She categorized countries into arctic, temperate and tropical to account for climatic conditions.

Results from the above study confirmed that national footprints are shaped by a combination of economic factors, natural conditions and political measures. But the standard set of predictors used by Marqurt-Pyatt performed the least well for fisheries or what we are calling coastal EF. This means that we need to bring in more relevant variables that might affect coastal EF exclusively and also exclude variables that might have no significant impact. In the present study I would also like to overcome the limitations of Marquart-Pyatt's study by examining the processes over time using a panel dataset instead of cross-sectional data.

Population size and affluence are the principal drivers of anthropogenic environmental stressors which affect EF (York *et al*., 2003; Dietz *et al*., 2007). For EF - the composite measure, these factors accounted for 95 percent of the total variance in national EF (York *et al*., 2003). For coastal EF, it stands to be tested whether such factors hold such a large explanatory power. A fixed-effects regression for 162 nations over the 1961 to 2012 period, also found that population and affluence are central drivers of nations' fisheries footprint and seafood consumption (Clark *et al*., 2018). Hence including these variables in the present analysis makes perfect sense. We use GDP per capita as a measure of economic development as did Marquat-Pyatt (2010) in hers. We also include the population size as our demographic variable. Some other widely postulated drivers such as urbanization, economic structure, age distribution were found to have little effect (Dietz *et al*., 2007) even on EF. Hence it is safe to ignore these variables in our present analysis of coastal EF.

To account for different climates having varied impacts, we use annual temperature and precipitation data for all the countries included in the study. Another factor that has been proved to have an impact on EF is trade openness. This impact can be positive or negative. The level of development and industrialization in a nation determines this direction of the impact. For developed and industrialized countries who can afford to develop or import clean technologies and production processes, trade openness exerts the "technique effect" on the environment. As a consequence of this effect, the quality of the environment is improved during production processes. On the other hand, during early stages of development in a country, governments may be willing to substitute the environmental quality for economic growth. Therefore, cheap and polluting technologies are imported in those nations to boost the production, and in the process, the technique effect exerted by trade openness leads to a decrease in environmental quality (Destek and Sinha, 2020). This analysis was conducted in the context of OECD countries. Al-Mulali and Ozturk (2015) also found that trade openness causally impacts the EF. The variable is also important as it can be considered as a "proxy for economic growth and is an enabler of economic growth" (Destek and Sinha, 2020). Therefore we also include trade openness as one of our independent variables. It should be noted that seafood is a highly traded good exceeding the combined trade value of sugar, maize, coffee, rice, and cocoa (Asche *et al*., 2015). Thus including trade variables is necessary to our analysis. The trade related variables we have included are: production quantity, export quantity, import quantity, stock variation and domestic supply quantity of various categories of seafood.

Some researchers have investigated the role of political institutions in fostering environmental sustainability, arguing that democracy may promote greater environmental sustainability by providing protective barriers to environmental depletion (Ehrhardt-Martinez *et al*., 2002; York *et al*., 2003). To test this claim, an index of freedom status which categorizes countries into free, not free and partly free based on a score of their political rights and civil liberties is incorporated in our study.

MATERIALS AND METHODS

Dependent variables

The coastal EF or the fishing grounds footprint data is collected from the National Footprint Accounts published by Global Footprints Network. It is calculated according to the GFN by "dividing the amount of primary production consumed by an aquatic species over its lifetime by an estimate of the harvestable primary production per hectare of marine area. This harvestable primary production is based on a global estimate of the sustainable catch of several aquatic species (Pauly and Christensen, 1995). These sustainable catch figures are converted into primary production equivalents, and divided by the total area of continental shelf. This same calculation is currently used for inland fish as well". It includes all wild caught fish and production through aquaculture. The second dependent variable used in a separate regression is the coastal biocapacity data which is also released by the GFN. Both are measured Global hectares (GHA). Per capita measurements are also available. We make use of these estimates in our regressions.

Independent variables

The GDP per capita and population size data is collected from the World Bank's database. The World Bank uses a de facto definition of total population, meaning that it counts all residents within a nation, regardless of legal status or citizenship for a nation's total population. Gross domestic product (GDP) per capita in constant US 2010 dollars allows us to consider the effect of economic development levels on a nation's consumption of seafood and ecological demands.

Temperature and precipitation data is collected from NASA's power single point database. Trade openness data is also collected from the World Bank's database. Data for all other trade-linked variables are collected from the FAO's statistical data base. The FAO database on marine fisheries landings is the most complete data set at the global level. But, according to the Pilot Analysis of Global Ecosystems' report on coastal ecosystems, FAO's catch statistics may be biased as a result of unreported discarding, misreporting of harvests, and exclusion of all information on illegal fishing, still we continue to use this database due to necessity and lack of an alternative. The database is primarily based on the official statistics submitted by member countries, but these are complemented or replaced with data from other sources as and when the need arises (Ye *et al.*, 2017). In our analysis we use, production quantity, export quantity, import quantity, stock variation and domestic supply of twelve separate coastal species and products identified in the FAO database namely, aquatic animals, aquatic plants, cephalopods, crustaceans, demersal fish, fish meal, fish body oil, fish liver oil, freshwater fish, marine fish, molluscs and pelagic fish. The freedom status data is collected from the annual freedom in the world survey published by Freedomhouse.org. Freedom House was founded on the core conviction that freedom flourishes in democratic nations where governments are accountable to their people. In our analysis, we will test whether this is a significant driver of coastal EF.

All the variables are considered over a period of 2 decades from 1992-2012. We have taken the liberty to exclude countries which do not have data for all the variables under consideration. The period till 2012 is considered because our trade data from FAO Stat is only available till 2013. And the year 2013 itself has incomplete data points. So 2012 is the final year in our analysis.

The following OLS regressions are run as follows:

$$\log CF = a + b\,GDP + c\,Popl + d\,Temp + e\,Prec + f\,Prod + k\,To + l\,Fs + E \quad (1)$$

Since the trade related variables like production quantity, export quantity, import quantity, stock variation and domestic supply quantity are highly correlated, the regression is run separately. Including them in a single model would result in multicollinearity and omission of variables might lead to no results or conclusion.

For comparison and to identify which countries are on a more sustainable path, we also run the following regressions by replacing the dependent variable with coastal biocapacity instead of coastal EF:

$$\log CB = a + b\,GDP + c\,Popl + d\,Temp + e\,Prec + f\,Prod + k\,To + l\,Fs + E \quad (2)$$

where, CF represents the coastal EF per capita
CB represents the coastal biocapacity per capita.
GDP represents the gross domestic product per capita
Popl represents the population
Temp represents the average annual temperature
Prec represents the average annual precipitation
Prod represents the production quantity
To represents the trade openness and
Fs represents the freedom status.

117 countries are considered in the analysis excluding all the countries that were missing key data points that are necessary for our analysis.

RESULTS AND DISCUSSION

The regression results show a consistently high R squared value and p value (with few exceptions) which means that the model does not explain much variation in the data but is still significant. The coefficients of all the variables had small values in general indicating that we have not succeeded in isolating the variables that are the strongest drivers of coastal EF. The models which used coastal biocapacity as the dependent variable instead of coastal EF performed worse. Our set of independent variables did not seem to explain much of the variation in coastal biocapacity. Nevertheless a comparison between the effectiveness of the two models is still worthwhile.

Among the variables that we have included in our model, the average temperature clearly emerged as the variable which affected the coastal EF the most. The trade openness variable did the second best job while the other trade related variables such as production quantity, export quantity, import quantity, domestic supply and stock variation did a marginally alright job at affecting the coastal EF to varying degrees in case of different countries. The GDP, precipitation and population variables showed negligible effect on the dependent variable in the vast majority of cases. They show a marginal effect for a few countries which may be considered as outliers. The freedom status variable showed no effect at all for some countries while still showing a modest effect on the dependent variable for some others.

The clear indication from our analysis that the average annual temperature has the most effect on coastal EF is consistent with the scientific consensus that the rise in global average temperature has the biggest impact on the oceans. The change, over the study period of 20 years in average atmospheric temperature also reflects the change in temperature of the waters. The warming of the oceans and the resultant threat to coastal ecosystems is an area that warrants immediate attention. The International Panel on Climate Change (IPCC) Fifth Assessment Report estimates that the upper ocean (surface to 750m deep) has warmed by 0.09 to 0.13°C per decade over the past 40 years. Scientists also agree that up to 90 percent of the carbon dioxide that is emitted due to human activity is absorbed by the world's oceans which imply that the oceans are warming at a higher rate than previously thought.

Warming of the oceans is the driver behind massive coral bleaching events around the world and has also led to expansion in volume of ocean waters leading to global sea level rise. While these are separate issues which we don't concern ourselves with in this paper, the underlying problem also impacts local coastal ecosystems for example by forcing species to migrate to cooler waters. In the worst case scenario, it leads destruction of habitats and the dying out of several species. Breeding grounds of fish and other aquatic mammals are also lost. In summary, increasing temperature of the seas has wide ranging impacts on the physical, chemical and biological characteristics of the seas (Yao and Somero, 2014).

Compared to terrestrial species, organisms in the seas tend to experience a relatively stable temperature which makes them more sensitive to fluctuations in temperature. Within these organisms, species that have historically evolved to survive in cold waters are threatened by small rise in temperature. From our analysis, in countries bordering the Arctic Ocean like Russia, Iceland, Norway and Canada, temperature is indeed the largest factor that affects coastal EF. If temperatures continue to rise, the vulnerable organisms will need to move to cooler waters or may face local extinction.

In Polar Regions and the southern ocean, fish are adapted to narrow temperature ranges for over 15 million years. In the face of an increase in ocean temperature, they have very little potential of adaptation at a genetic level (Patamello *et al.*, 2011). They also don't have refuges to move to. The result is that their population substantially declines. There will also be distributional shifts of some fish to higher latitudes and greater depths (Dulvy *et al.*, 2008) Evidence also points to an invasion of warm water species in case of moderate warming (Simpson *et al.*, 2011). This will negatively affect the natural composition of the original coastal ecosystem. This can in turn affect the sea food production, import, export and domestic supply at a national level. Therefore we can say that the increase in temperature has far reaching economic effects as well.

Fluctuation in temperature is also affecting aquatic mammals despite them being endothermic homeotherms that possess a high capacity to regulate body temperature. The effect is often indirectly through food webs. The food resources of these mammals are altered due to the shifts in temperature. For example, repeated fluctuations in anchovy populations play an important role in the biology of the coastal dusky dolphin (*Lagenorhynchus obscurus*) (Harlin-Cognato *et al*., 2007). A continuing northward shift in Pacific walrus (*Odobenus rosmarus* divergens) distribution has been observed since average temperature of the oceans began to increase (Maccracken, 2012).

Temperature changes may affect concentration of dissolved gases in the water as temperature affects the solubility of oxygen and carbon dioxide in the water. Low concentrations of oxygen can prove lethal to many fish and molluscs in particular. Higher temperatures may also lead to a higher amount of rainfall increasing surface runoff affecting the salinity of coastal waters (Yao and Somero, 2013) and hence the survival of the organisms that live in them. However, we find that precipitation is not a major driver of coastal EF according to our analysis. Except for a few countries like Argentina, Azerbaijan, Belarus, Botswana, Cyprus, Egypt, Georgia, Jordan, Madagascar, Morocco, Mozambique, Namibia, New Zealand, Niger, Portugal, Senegal, Tunisia, Turkey and Zimbabwe which had a small value for the coefficient of the variable precipitation, in all the other countries in the analysis, the coefficient of the precipitation variable was negligible. Even among these countries, we notice that a majority of them geographically lie in dry zones which receive very little annual rainfall. This is likely to be the reason behind the effect of precipitation however small it may be.

We find that import quantity, export quantity, production quantity, domestic supply and stock variation show marginal impact on coastal EF. Import quantity showed the biggest impact among the variables in the model in Benin, Gambia,

Table 1. Countries in which precipitation had an impact on Coastal EF

Country	Coefficient of variable - Precipitation
Argentina	0.001084 (0.000411)
Azerbaijan	0.001282 (0.000996)
Belarus	0.004377 (0.001771)
Botswana	-0.00265 (0.003786)
Cyprus	0.001062 (0.000324)
Egypt	-0.06615 (0.056157)
Georgia	0.015302 (0.0101)
Jordan	-0.0027 (0.001814)
Madagascar	-0.00229 (0.002391)
Morocco	-0.00222 (0.004081)
Mozambique	-0.00315 (0.004658)
Namibia	0.009161 (0.00583)
New Zealand	0.002545 (0.001096)
Niger	0.002371 (0.005912)
Portugal	-0.0005 (0.000271)
Senegal	0.002559 (0.001132)
Tunisia	0.001235 (0.000837)
Turkey	0.002591 (0.002243)
Zimbabwe	0.024498 (0.011871)

Iceland, Turkmenistan and Vanuatu. Export quantity in Barbados, Haiti, Hungary, Nigeria and Saint Lucia. Production quantity showed the biggest impact in Armenia, Austria, Slovenia and Zimbabwe. Domestic supply did in Brazil, Burkina Faso, Grenada, Guinea and Kyrgyzstan. Stock variation did only in

Australia. This seems like a random assortment of countries and no obvious pattern emerge. We also note that among the 12 coastal species whose import, export, production, domestic supply and stock variation we use in the analysis, fish body oil and fish liver oil seem to have the largest impact on the coastal EF in general though there are exceptions.
Trade openness is the biggest driving factor in Namibia. This is only in comparison; the actual coefficient of the variable is small even in these cases. For most countries in our analysis, trade openness explains at least a small portion of the coastal EF. The coefficient of this variable is found to be the second highest in many cases. The coefficients of the GDP per capita and population variables are found to be also negligible but non zero. In comparison, in Azerbaijan, Belize, Benin, India, Kiribati, Niger, Sierra Leone and Zimbabwe, the GDP coefficient had a marginally bigger value. Population coefficient had a marginally bigger value in Saint Vincent and Grenadines (Similar to the case of precipitation, this could be due to the small population of the island). However, these two variables were not the biggest driving factor even in these countries.

Table 2. Countries in which Import Quantity is the variable having the most impact on Coastal EF

Country	Coefficient of variable –Import Quantity
Benin	-0.20955 (0.05086)
Gambia	-0.20257 0.105228
Iceland	0.076483 (0.067572)
Turkmenistan	0.560317 (3.164876)
Vanuatu	0.178957 (0.092403)

Table 3. Countries in which Export Quantity is the variable having the most impact on Coastal EF

Country	Coefficient of variable –Export Quantity
Barbados	0.254095 (0.172053)
Haiti	-0.54493 (0.571289)
Hungary	-0.40512 (0.313558)
Nigeria	0.176073 (0.152355)
Saint Lucia	0.321595 (0.172534)

Table 4. Countries in which Production Quantity is the variable having the most impact on Coastal EF

Country	Coefficient of variable –Production Quantity
Armenia	-0.46294 (0.602967)
Austria	-0.22292 (0.104392)
Slovenia	0.075324 (0.038069)
Zimbabwe	-0.52808 (0.136711)

Table 5. Countries in which Domestic Supply is the variable having the most impact on Coastal EF

Country	Coefficient of variable –Domestic Supply
Brazil	0.00158 (0.000458)
Burkina Faso	0.209968 (0.328531)
Grenada	0.789307 (1.874651)
Guinea	-0.42924 (0.193955)
Kyrgyzstan	0.414159 (0.261276)

Table 6. Countries in which Stock Variation is the variable having the most impact on Coastal EF

Country	Coefficient of variable –Stock Variation
Australia	-0.06862 (0.026642)

The freedom status variable had no impact (the coefficients were zero) in some countries but ended up being the biggest driver of coastal EF in Argentina, Azerbaijan, Bangladesh, Belarus, Republic of Congo, Cote d'Ivoire, Ghana, Guyana, Kazakhstan, Kenya, Mali, Niger, Oman, Paraguay, Philippines, Romania, Sierra Leone, Thailand, Tunisia, Uganda and Ukraine. The variable also had a marginally bigger non zero value in some more countries though it was not the biggest driving factor. Here, we noticed that the most of the countries in the above list have historically been politically unstable regions where democracy has been under threat. Only as the precipitation variable performed marginally better in geographically dry zones, the freedom status variable does better in regions which are historically known to have less political freedom.

Our analysis also revealed that the models performed worse in advanced and developed nations like Denmark, South Korea, France, Italy, USA, Switzerland, Sweden etc. The indication is that economic, political, demographic, trade and climatic variables that we have included in our analysis are not enough. There are other factors like pollution for example that could have more impact on the dependent variable.

Table 7. Countries in which Trade Openness is the variable having the most impact on Coastal EF

Country	Coefficient of variable –Trade Openness
Namibia	-0.03806 (0.014631)

Table 8. Countries in which GDP had an impact on Coastal EF

Country	Coefficient of variable –GDP
Azerbaijan	-0.00072 (0.000156)
Belize	0.004192 (0.005782)
Benin	0.002312 (0.000946)
India	0.001011 (0.000926)
Kiribati	-0.0014 (0.001281)
Niger	0.002198 (0.003911)
Sierra Leone	-0.00571 (0.001597)
Zimbabwe	0.001924 (0.000642)

Table 9. Countries in which Population had an impact on Coastal EF

Country	Coefficient of variable – Population
St. Vincent & Grenadines	-0.00153 (0.001843)

Table 10. Countries in which Freedom Status is the variable having the most impact on Coastal EF

Country	Coefficient of variable – Freedom Status
Argentina	-0.32239 (0.094683)
Azerbaijan	0.206436 (0.208377)
Bangladesh	-0.2299 (0.09076)
Belarus	-0.48475 (0.214464)
Congo (Republic of)	-0.2099 (0.130945)
Cote d'Ivoire	0.073779 (0.046473)
Ghana	0.293314 (1.85933)
Guyana	-0.41317 (0.576502)
Kazakhstan	0.190174 (0.308761)
Kenya	-0.52557 (0.120231)
Mali	0.450944 (0.138257)
Niger	0.434824 (0.21502)
Oman	0.311084 (0.279134)
Paraguay	0.333627 (0.08775)
Philippines	-0.13019 (0.046699)
Romania	0.54113 (0.238329)
Sierra Leone	-0.59384 (0.368011)
Thailand	-0.13161 (0.108949)
Tunisia	0.152741 (0.124392)
Uganda	-0.46432 (0.146756)
Ukraine	0.240152 (0.140601)

The second set of regressions performed using biocapacity as the dependent variable performed worse than the models with the coastal EF. The values of the coefficients were too small to draw any useful conclusions. This indicates that biocapacity cannot be bundled with EF at least when we are taking a sub component like the coastal EF. It likely has a whole set of separate variables that act as it's driving forces.

POLICY IMPLICATIONS

The growing human and environmental pressure on coastal ecosystems prompted its inclusion in the 2030 Agenda for Sustainable Development. Sustainable development goal (SDG) 14 of the 2030 Agenda for Sustainable Development aims for conservation and sustainable use of the oceans, seas, and marine resources, explicitly considering coastal areas in two of its targets (14.2 and 14.5). These promote a strong sustainability concept by addressing protection, conservation, and management of coastal ecosystems and resources.

Coastal tourism, fisheries and the many other aspects of coastal economies and livelihoods rely strongly on "healthy" coastal ecosystems for a sustained provisioning of the desired services (Agardy *et al*., 2005; UNEP, 2009; Division for Sustainable Development, 2015). Sustainable provision of the services delivered by the seas, coasts and oceans are important for the concept of blue growth. Countries in Europe and Small Island developing nations have put much focus on development of "blue economy". Hence the discussion is relevant.

The Rio+20 outcome document The Future We Want acknowledges the critical role of "oceans, seas and coastal areas" in sustaining the "Earth's ecosystem", and emphasises the need for "conservation and sustainable use of the oceans and seas and of their resources" (United Nations, 2012). It commits to "protect, and restore, the health, productivity and resilience of oceans and marine ecosystems" by effectively applying "an ecosystem approach and the precautionary approach in the management […] of activities having an impact on the marine environment, to deliver on all three dimensions of sustainable development" (United Nations, 2012). The 2030 Agenda for Sustainable Development (henceforth the 2030 Agenda) commits to these aspirations through a specific sustainable development goal (SDG) on the conservation and sustainable use of the oceans, seas and marine resources (SDG 14) among the newly established 17 SDGs (United Nations, 2015). SDG 14 explicitly addresses coastal areas and ecosystems in two of its main targets (14.2 and 14.5). Further targets under SDG 14 as well as targets under other goals, though not explicitly referring to coastal areas, are implicitly relevant for coastal areas and for the protection, conservation and management of coastal ecosystems and resources.

Given that temperature has emerged as the most import driving factor coastal EF among the variables examined, policies to protect and restore coastal ecosystems go hand in hand with policies to combat global warming and ties into the larger narrative of climate change that has sparked debate and controversy in recent times. It is necessary to have the international co-operation through organisations, conventions, agreements and everything in between because we know that the temperature fluctuations at unprecedented levels are a global phenomena. But countries inevitably give different levels of priority to the sustainable development of their coasts depending upon national interests. Hence international compliance is a challenge in many scenarios.

CONCLUSION

Coastal zones are the regions of high biodiversity and species richness. They are hence the providers of a large number of resources for human consumption. But the increasing pressure on this unique and delicate ecosystem has put the organisms in these regions at risk. Theoretically, we identify that increasing human population is a huge threat to coastal ecosystems as they use more resources and pollute more. But our analysis did not show evidence for the impact of population on coastal EF. We also don't find the other economic and trade factors to be having much impact on the coastal EF. The most important driver among the variables in our analysis is the climatic variable temperature. This is consistent with scientific consensus that the rising temperatures due to global warming have a massive impact on the oceans compared to terrestrial ecosystems. The organisms in the seas are much more sensitive to temperature changes and are hence at the risk of extinction in the absence of policies to combat the rising temperatures. Results show that the indicators we have chosen do not perform very well at least for the coastal EF component of the EF. This means that they may be other factors like pollution that affect the coasts more specifically that needs to be included. A general set of economic, demographic, climatic and trade variables are not enough to explain the variability in coastal EF. The lack of proper distinction in what entails the coast of one country and how far is it from the shoreline as well as the special nature of the coastal ecosystem makes it very difficult to identify and narrow down the important factors that drive its footprint.

APPENDIX

The countries included in the analysis are Albania, Antigua and Barbuda, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahamas, Bangladesh, Barbados, Belarus, Belize, Benin, Bolivia, Botswana, Brazil, Brunei, Burkina Faso, Cameroon, Canada, Chile, Colombia, Congo (republic of), Costa Rica, Cote d'Ivoire, Cuba, Cyprus, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Finland, France, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Grenada, Guinea, Guyana, Haiti, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kiribati, Kyrgyzstan, Laos, Lebanon, Macedonia, Madagascar, Malawi, Malaysia, Mali, Malta, Mauritius, Mexico, Morocco, Mozambique, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Portugal, Romania, Russia, Rwanda, Senegal, Sierra Leone, Slovenia, Solomon Islands, South Korea, Spain, Sri Lanka, St. Lucia, St. Vincent & Grenadines, St. Kitts & Nevis, Sweden, Switzerland, Tajikistan, Tanzania, Thailand, Togo, Tunisia, Turkey, Turkmenistan, Uganda, United Kingdom, Ukraine, United States, Vanuatu, Venezuela, Vietnam, Zambia and Zimbabwe.

Acknowledgement

The authors are grateful to their parent institute, which provided them the infrastructural facility to conduct the research work.

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