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Is it possible to determine the economic impact of jellyfish outbreaks on fisheries? A Case Study – Slovenia

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Abstract

The interdependence between the economy and the environment is becoming a fact of increasing importance. Productive coastal areas have been recognised as one of the most valuable ecosystems from an ecological and socio-economic point of view. In this paper we focus on the massive presence of jellyfish in the northern Adriatic and their effect on the Slovenian economy. Our results indicate that high jellyfish abundance in 2004 resulted in a reduction of fish catch, value added, gross income, and employment in the fishing industry. Moreover, the government and the EU have acknowledged the impact of jellyfish on the fishing industry by allocating financial help to the fishermen involved. We attempted to assess other factors influencing the fishing industry but none were statistically significant. The input-output analysis has not revealed a significant impact on the entire Slovenian economy presumably due to the small contribution of the fishing industry to Slovenian GDP. Our work is a first attempt to relate ecological changes such as jellyfish outbreaks in the northern Adriatic to the wider economy and we suggest that such a methodology can be applied to other countries/regions and to other natural phenomena affecting the economy.

Keywords: jellyfish outbreaks, fishing industry, economy, input-output tables.

Introduction

The economies of the world are inevitably dependent on their surroundings, their environment. To meet the needs of the population, an economy needs a production process. As regards production (and later consumption), natural resources, along with physical and human capital, are included in the production function. Therefore, in order to sustain our production processes, natural resources need to be managed properly. This means that overexploitation and hence degradation of natural resources should be avoided. Natural resources are dependent on the exploitation method and vice-versa: production, consumption – life in general – is dependent on natural resources. This interdependence is becoming a fact of increasing importance in the contemporary world, where ecosystem changes are taking an ever-increasing toll on the economy and our lives. The productive coastal areas of the oceans have been recognised as belonging to the most valuable ecosystems on Earth, from an ecological and socio-economic point of view (Costanza *et al*., 1997); yet, they are also among the most endangered due to a variety of direct and indirect anthropogenic disturbances such as pollution, marine and coastal construction, maritime transport, overfishing, invasive species, and climate change (Halpern *et al*., 2008). Evidence from many coastal areas suggests that major structural and functional changes have occurred in relation to different stressors. Among such changes, jellyfish outbreaks warn of dramatic consequences for the functioning of ecosystems and consequently for humans as well. A recent review of world oceans (Bollmann *et al*., 2010) listed jellyfish as an increasing threat for the future of the oceans, which is also reflected in increased media reports (Condon *et al*., 2012). Evidence suggests that a variety of human activities such as seafood harvesting, eutrophication, the introduction of alien species, coastal and offshore hard substrate infrastructure (ports, rigs, aquaculture) and climate change may benefit jellyfish populations (Purcell, 2012). Therefore, the increase in the jellyfish population appears to be both a symptom of the cumulative deterioration of ecosystems and the outcome of combined climate and anthropogenic stressors (Richardson *et al*., 2009).

While the ecological consequences of jellyfish outbreaks have been increasingly studied recently, limited data is available on the cost to fisheries and other economic sectors. Jellyfish blooms may affect fisheries in several ways either directly by interfering physically with fishing activities and posing health risks for fishermen, or indirectly by affecting fish populations (Quiñones *et al*., 2012 and references cited therein). It was estimated recently that nearly 150 million people are exposed to jellyfish every year (Whiteman, 2008). The Mediterranean region is among those heavily affected, as illustrated by the fact that more than 40,000 people were stung during one summer season in the north-western Mediterranean alone (Purcell *et al*., 2007). Moreover, climate scenarios and overfishing in some traditional Mediterranean fishing grounds may contribute to a further increase in jellyfish outbreaks in this sensitive enclosed sea (Ruiz *et al*., 2012; Mozetič *et al*., 2012). Due to the connectivity between individual Mediterranean sub regions (Millot & Taupier-Letage, 2005), jellyfish blooms may disperse and sustain high jellyfish abundance in several areas (Stopar *et al*., 2010).

In this paper we focus on the massive presence of jellyfish in the northernmost part of the Mediterranean, namely, the northern Adriatic, and its effect on the Slovenian economy: directly, how it affects the fishing industry, and also indirectly, how it affects the economy as a whole. Specifically, the massive presence of jellyfish can reduce the possibility of catching fish, deteriorate the quality of fished organisms and increase costs, due to increased fuel use, thereby reducing the income of fishermen and, eventually even threatening their employment. Therefore, jellyfish outbreaks do not affect only fishing, but the industry as a whole: employment, wages, and value added. Furthermore, we find it plausible that the effects of this ecological phenomenon stretch beyond the fishing industry, affecting other industries, such as tourism (hotels, restaurants). Fishing industry output constitutes an important input into other industries and, although alternatives (substitutes) are available, we believe that such impact should be recognized. In order to verify the stated hypothesis, both the simple methodology consisting in comparing a period characterised by massive jellyfish appearance to a non- or low-presence period using descriptive statistics and graphical representations are applied, as well as the economy-wide input-output modelling of this effect.

Materials and Methods

Study area, data sets and data analysis

Our study focuses on the northernmost part of the Mediterranean Sea, one of its most productive areas where fishing has traditionally been one of the most important economic activities (Houde *et al*., 1999, Fortibuoni *et al*., 2010). Due to the early establishment of research centres along the northern Adriatic shores, historical data relative to jellyfish are available, which have allowed Kogovšek *et al*. (2010) to reconstruct a two-century time series and analyse the recurrence of jellyfish outbreaks. This information was used as a baseline for jellyfish presence in our study. A more recent study (Malej *et al*., 2012) has provided semi-quantitative data on recent blooms, while a quantitative study of large jellyfish abundance was carried out in 2004-2006 within the framework of an M.Sc. Thesis (Miloš, 2009). Briefly, sampling was carried out approximately monthly, from January 2004 to December 2005 and once in 2006 (May) from commercial fishing vessels, using fishing nets (pelagic trawling nets); the density of medusae was estimated from the volume of sampled water divided by the number of captured individuals.

Fishing industry and effects on the economy

The code of the fishing industry in the NACE rev. 2 classification of activities (within Fishing and aquaculture, A03) is A03.1. On the other hand, Classification of Products by Activity (CPA) classifies product fish in category B (valid for input-output analysis). We have used data on the total marine fish catch in Slovenia, on a monthly basis, for the period 1982-2009, provided by the Fisheries Research Institute of Slovenia (2010). For selected countries (Slovenia, Croatia and Italy), we also used Eurostat (2011a) data for catches in the Mediterranean in the period 2000-2009. Data on the fishing industry, value added, wages, gross mixed income, and employment in the fishing industry in Slovenia were obtained from the Statistical Office of the Republic of Slovenia (2010a, 2010b).

Measuring the economy-wide impact of a change in production in one industry is a formidable task. Different methodologies, ranging from simplistic economic models to complex general equilibrium models can be found. In this paper we have chosen to study the effect of fishing industry changes on the economy as a whole within an input-output analysis. An input-output analysis is based on input-output tables, where every transaction of inter-industry purchases (inputs) and sales (outputs) is recorded and combined in the form of input-output tables. Input-output models are based on the input-output tables and a number of simplified assumptions that define inter-industry transactions (ESA, 1995; 1996, Perman *et al.,* 2003). As presented below, input-output models are mathematically less demanding than other general or multi-sector models – thus making input-output models more attractive. The basis for input-output modelling is the availability of suitable data in the economy, namely the supply and use tables, which are combined to form the input-output tables. Input-output tables provide insight into purchases (inputs) and sales (output) transactions at the industry level. By industry we will refer in our analysis to products of this industry. On the input side, intermediate consumption (purchases from other industries) and imports, and value added (wages, mixed income and consumption of fixed capital) are recorded for each industry (in each column). On the other hand, intermediate consumption (what industries sell to each other) and final consumption (what is sold for consumption to households, government, investment consumption, and exports) comprise the total output and

Intermediate consumption		Final consumption				Total output
Sales/purchases		Households	Government	Investments	Exports	
Imports						
Value added	Wages					
	Mixed income					
	Consumption of fixed capital					
Total input						

Fig. 1: Input-output table. The supply and use tables are combined to form the input-output tables which provide an industry-level insight into purchases - inputs recorded for each industry in each column (intermediate consumption, imports, and value added) and sales - outputs represented in rows of the table (intermediate consumption and final consumption).

are represented in the rows of the table, where the rows represent industries. This is shown in Figure 1**.**

This input-output table is thus an accounting compilation. Therefore, in order to perform an analysis, we need to implement certain assumptions and procedures. Firstly, the assumption is that intermediate inputs are constant proportions of the output of the purchasing industry, which is mathematically represented by:

$$X_{ij} = a_{ij} X_j \quad (1)$$

where X_{ij} represents the sales of a product from industry i to industry j, a_{ij} is a constant by assumption and represents the technical coefficient of production (how many products from industry i are needed (and sold to industry j) to produce a unit of output of industry j, and X_j represents total output of industry j. By assuming that technical coefficients are constant, we clearly do not allow substitution among industries (substitution within industries cannot be taken into account at this level).

Secondly, the input-output model (based on the input-output table) is represented in matrix notation by:

$$\boldsymbol{X}=\boldsymbol{AX}+\boldsymbol{Y} \quad (2)$$

where $\boldsymbol{X}$ is an $n \times 1$ vector of outputs, A is an $n \times n$ matrix of technical coefficients a_{ij}, and Y is an $n \times 1$ vector of final consumption. Implementing identity matrix I and some matrix algebra, we obtain the final solution of the input-output model:

$$\boldsymbol{X}=(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{Y} \quad (3)$$

The $n \times n$ matrix $(I-A)^{-1}$ represents the direct and indirect effects of final consumption in industry j on output in industry i – in other words, the level of output in industry i required to meet the direct and indirect needs for a unit of final consumption in industry j.

Within this framework various analyses can be conducted. Firstly, we analyse how the fishing industry is related to other industries, i.e. the values of corresponding technical coefficients. This will show the impact of the fishing industry on the economy as a whole.

Secondly, from the $(I - A)^{-1}$ matrix albeit will be possible to estimate the direct and indirect effect of the fishing industry, i.e. how much production in the fishing industry is required to meet the needs of a unit of final consumption of other industries. Extending this further, using matrix $(I - A)^{-1} Y$ will allow us to estimate what has to take place in the entire economy in order to produce one unit of fishing industry output. Alternatively, this will show how the fishing industry affects the whole economy.

Thirdly, further extending the model in equation (3) to include the connection to value added (matrix $\boldsymbol{D}$), we will estimate how much of total economic value added is built into a unit of final consumption of a fishing industry product. In order to do this, we will follow the model adaptation:

$$\boldsymbol{D} = \boldsymbol{d}\,(\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y} \quad (4)$$

where d is an $n \times n$ vector (values on the diagonal, 0 otherwise) of direct value added coefficients $d_j = D_j / X_j$.

The data used is the input-output table for Slovenia for the year 2005, which is the last combined input-output table available from the national Statistical Office of the Republic of Slovenia (SORS). We have used the input-output table at the 30-industry level, that is, at the level of 30 products, classified according to Classification of Product by Activities (CPA). The data available had values at basic prices in millions of Euros. Moreover, the jellyfish blooms were very severe in 2004-2005. The periods being close are thus appropriate, as we assume that the 2005 input-output table for Slovenia reveals the structure (and interrelation between industries via technical parameters) that is closest to the 2004 real situation in the economy.

Results and Discussion

Jellyfish in the northern Adriatic

The northern Adriatic is among the rarest marine areas for which historical scientific data on marine biota extend back more than 200 years. Scyphozoan jellyfish were among the surveyed organisms, which prompted Kogovšek *et al*. (2010) to analyse long term trends. Information was gathered about historical occurrences of the five most frequently recorded scyphomedusae: *Aurelia aurita* (Linnaeus, 1758), *Chrysaora hysoscella* (Linnaeus, 1766), *Cotylorhiza tuberculata* (Macri, 1778), *Pelagia noctiluca* (Forsskål, 1775), and *Rhizostoma pulmo* (Macri, 1778). Published sources (a complete list of references is available in Kogovšek *et al*., 2010) were complemented by our own (Malej, pers. obs.) observations since the early 1970s. The main objective of the

Kogovšek *et al*. (2010) study was to assess the periodicity of scyphomedusae occurrences in the northern Adriatic using the wavelet time series technique (Torrence & Compo, 1997). The records for the five scyphomedusae, which covered nearly 200 years, were binary (1 = presence, 0 = absence of a particular species in the northern Adriatic in each year) and for the few years when data was missing, the missing data were treated as 0 (absent). This analysis revealed that the five species have been present regularly in the northern Adriatic over the last 200 years, with two major periods of jellyfish proliferation. The first period at the beginning of 20th century was characterised by a significant periodicity of 8-12 years for each species, while the second period from the 1960s onwards was characterised by a shorter significant periodicity of less than 8 years. These results indicate that the recurrence of jellyfish outbreaks (massive presence) has increased in the last few decades compared to the long-term time series particularly in the case of three species: barrel jellyfish (*Rhizostoma pulmo*), moon jellyfish (*Aurelia aurita*) and the mauve stinger (*Pelagia noctiluca*). Among the studied jellyfish species, barrel jellyfish reach the largest size (bell diameter up to 62 cm and wet weight up to 19.5 kg) and therefore have the greatest impact on fishing operations (Fig. 2). Moon jellyfish (bell diameter up to 33 cm and wet weight less than 1 kg) and the mauve stinger (max bell diameter: 8.5 cm) are significantly smaller (Kogovšek, 2011), break-up more easily and thus interfere less with fishing.

In contrast to long-term qualitative data about the presence of jellyfish in the northern Adriatic, limited quantitative abundance estimates are available. After rather high abundances of barrel jellyfish in 2003, the Piran Marine Biology Station (MBS) started a more systematic survey in 2004. These jellyfish were numerous during cold months, from December to February, decreased from summer 2005 onwards (Table 1), and was < than 10 ind./km^3 in May 2006. Our regular quantitative survey ended in May 2006 but semi-quantitative observations are ongoing: barrel jellyfish have been recorded till now but in lower abundances than during 2004-2005. Abundances of the mauve stinger were the highest in autumn 2004 – spring 2005 (Table 1) but were not observed in the northern Adriatic from spring 2007. On the other hand, moon jellyfish reached high abundances in the period from the late 1990s onwards, forming large blooms every year since 2002 (Malej *et al*., 2012).

Fig. 2: 'Fish' catch in February 2004 in the Gulf of Trieste.

The fishing industry

Data on the total marine fish catch in Slovenia, on a monthly basis, reveal that the total fish catch steadily declined from 1982 to 2009 (Fisheries Research Institute of Slovenia, 2010), thus significantly reducing both the scope and variability after 1991, when Slovenia became independent; prior to that, Slovenia was part of Yugoslavia and no borders between Slovenia and Croatia also meant no limits for Slovenian fishermen to catch fish in what are now Croatian waters. With this in mind we turn to Figure 3 for a shorter 10-year period (2000 – 2009), where the beginning of 2004 clearly indicates an all-period low value – stressing the fact that jellyfish presence, mentioned in the previous section, had a direct impact on the fish catch.

Figure 3 also shows that every year there were monthly variations as regards fish catch. However, the all-period (1982-2009) minimum was observed in February 2004. Furthermore, based on data provided by the Fisheries Research Institute of Slovenia (2010), indices were calculated for a month to month comparison and February 2004 was especially critical. Before proceeding and for reasons of comparison, a large amount of data was obtained on neighbouring countries that also exploit the northern Adriatic fishery, namely Croatia and Italy, in order to establish whether those countries have suffered similar impacts due to the phenomenon under study. The comparison reveals

Table 1. Density of two scyphozoan jellyfish species: barrel jellyfish (*Rhizostoma pulmo*) and mauve stinger (*Pelagia noctiluca*) in the northern Adriatic during 2004 and 2005.

Date	**Jellyfish density (no. ind. / km^3)**	
	Rhizostoma pulmo	***Pelagia noctiluca***
January 2004	99.7 – 265 x 10^3	absent
April 2004	8.1 x 10^3	absent
July 2004	3.7 x 10^3	0.1 x 10^3
October 2004	0.4 – 1.9 x 10^3	0.8 – 2.2 x 10^3
November 2004	0.5 – 2.1 x 10^3	3.1 – 11 x 10^3
December 2004	122 – 2120 x 10^3	93.7 x 10^3
February 2005	11.1 – 87.4 x 10^3	99.3 – 133 x 10^3
June 2005	0.3 x 10^3	Present (no quantitative data)
September 2005	0.1 x 10^3	Present (no quantitative data)
November 2005	0.3 – 1.6 x 10^3	Present (no quantitative data)
December 2005	0.2 – 0.5 x 10^3	0.3 – 0.4 x 10^3

Source: Data recalculated from Miloš (2009) the already mentioned drop in 2004 for Slovenia, a slight decrease in total catch in Italy, yet not in Croatia. The reason for this probably lies in the fact that both Croatia and Italy fish in waters that stretch way beyond the northern Adriatic, which significantly reduced their sensitivity to the northern Adriatic jellyfish outbreak. This is best illustrated from the data on value added, gross mixed income or employment in the fishing industry, which does not show a drop in 2004 in Croatia or Italy, as in Slovenia, as shown in Table 2 (Eurostat, 2011b; CBS, 2010). From this perspective it is not possible to study the jellyfish outbreak in the northern Adriatic for Croatia and Italy, due to the lack of detailed data for the region. Therefore our research is focused on Slovenia alone.

Detecting the impact of jellyfish outbreaks on the economy

The fishing industry

Firstly, we analysed available annual fishing industry data. Annual data confirms the drop in fish catch in 2004, and at the same time an increase in farmed fish, substituting for the loss of captured fish on the market (and thereby somewhat reducing the impact of jellyfish occurrence on the total economy) – as depicted in Table 2. The fish-catch drop was also partially offset by a rise in the price of fresh fish: the price indices for fresh fish reveal that prices increased by 14% in 2004 prices, whereas in 2003 the rise was over 5 per cent and in 2005 the figure was less than 1 per cent (SORS, 2000, 2005b, 2010).

The presented downward trend in fish catch in the studied period also affects (in the long run) other aspects of the fishing industry, specifically employment, value added, wages, etc., which are further detailed in Table 2. However, it is clear that 2004 was a particularly negative year with respect to all the indicators in the table – which can (at least partly) be attributed to the aforementioned jellyfish occurrence in the northern Adriatic. At this point we also stress that values for 2008 are also negative in this respect; however, that was the year of the economic crisis and we have thus refrained from analysing year 2008 in order to avoid mixed effects. Furthermore, this data has been used to measure the impact of jellyfish outbreaks on the fishing industry as a whole. We followed examples from the several studies conducted on the effect of fishing and fish catch on the industry (and/or the economy). Goulding *et al.* (2000) report that a 1000 tonne reduction in annual catch means a job-loss of 46.6 jobs; Eide & Heen (2002) also stress that fisheries are of great importance for the North Norwegian economy. Moreover, GSGislason & Associates (2010) stress that a reduction in fish harvesting would have a serious impact on business and the community (and economy) as a whole. Although some evidence suggests that reduced catch reduces employment, other reports state that about 75% of the decline in the number of employed persons is due to the structural adjustment of the fleet (Goulding *et al.*, 2000). Moreover, as Hannesson (2011) points out, the fishing industry is normally only a small part of the national economy, making a partial analysis justified. This is especially true in our case, the case of Slovenia, but not for the North Norwegian economy as shown by Eide & Heen (2002). Nevertheless, the fishing industry needs to be placed in a wider context and caution is needed, given that other factors might have an influence on value added, employment and/or the earnings drop in the fishing industry. In turn, this could mean that reported lower earnings in the fishing industry are not the result of jelly-

Table 2. Fishing industry in Slovenia during 1995-2008: FC - fish catch (tonnes), FF - fish farming (tonnes), T - fish total (tonnes), VA – value added (M €), W - wages (total, M €)), GMI - Gross mixed income (M€), Em - Employment, Ed - Employed, SE - Self-employed.

Year	FC	FF	T	VA	W	GMI	Em	Ed	SE
1995	1795	49	1845	1.70	1.17	0.63	328	162	166
1996	2063	75	2137	1.92	1.27	0.77	336	169	167
1997	2038	90	2128	1.52	1.43	0.16	312	195	117
1998	1926	109	2035	2.38	1.55	0.97	303	182	121
1999	1755	66	1820	2.49	1.62	1.02	300	178	122
2000	1597	72	1669	2.29	2.04	0.22	289	180	109
2001	1482	66	1548	2.43	2.04	0.35	281	171	110
2002	1405	37	1442	3.14	2.25	0.86	401	171	230
2003	1016	71	1087	3.88	2.43	1.47	406	176	230
2004	***749***	***113***	***862***	***3.33***	***2.44***	***0.97***	***316***	***166***	***150***
2005	931	26	957	3.67	2.56	1.20	298	173	125
2006	870	30	900	3.61	2.57	1.28	286	173	113
2007	818	15	833	3.31	2.53	1.50	281	163	118
2008	637	50	687	3.10	2.61	0.74	265	160	105

Source: Statistical Office of Republic of Slovenia (2010a, 2010b), own calculations

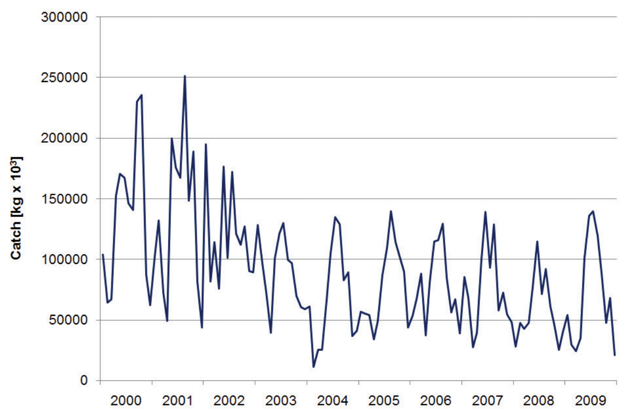

Fig. 3: Total fish catch in Slovenia during 2000-2009. *Source: Fisheries Research Institute of Slovenia (2010), own calculations.*

fish presence alone. For proper determination of the proposed impact of jellyfish we therefore need to take other factors into account. Factors influencing the fishing industry include specific conditions and control or general economic conditions. The first, fishing industry specific conditions include factors such as the costs, e.g. price changes of energy resources, number of vessels, and the demand for fish and related products (e.g. restaurants). Moreover, GSGislason & Associates (2010) would also consider increased market competition and growing public demand for eco-certification as factors influencing the fishing industry. Last but not least, as is the case in this paper, certain ecological or other phenomena need to be accounted for by implementing variables to measure them, i.e. dummy variables. On the other hand, the general economic conditions in the country (e.g. GDP per capita), determine the general dynamics of all industries in the economy, thereby influencing the fishing industry as well. Besides the economic impacts, studied in the paper, there are also other environmental and social externalities associated with the industry (Derek Murray Consulting Associates, 2006), but these are not considered in this paper.

The proposed model used to include all the factors would be as follows:

$$EMPL = f\,(catch,\ price_{ENERGY},\ vessels,\ demand_{fish},\ ecocertification,\ competition,\ GDP,\ D_{Jellyfish=1},\ldots)$$

In order to properly, i.e. methodologically correctly, estimate the presented model, a strong data basis is needed. For the majority of research and analysis studies, this has been done using various survey and interview data, along with secondary data on the fishery and the economy (e.g. Eide & Heen, 2002; Knapp, 2006; Gunderson & Kreag, 2011). The data available for Slovenia, however, greatly reduces the chances of proper methodological testing of the various factors. First of all, there is an absence of in-depth survey and interview data collection tools and data itself. Secondly, in most cases, annual time series data is only available from 1995 onwards, providing only 14 units. Last but not least, the data is not consistently available for all the issues stated (e.g. only data for vessels for 2003-2006 was available – SORS 2004; 2005a; 2006 and MFFF 2011) or we could not obtain data at all (restaurants and private consumption of fresh fish). Thus, methodologically speaking, the model could not be properly tested and only an illustration is presented at this stage. This comprises the following model:

$$EMPL = f\,(catch,\ price_{ENERGY},\ GDP,\ D_{Jellyfish=1},\ldots)$$

where *EMPL* represents employment (and employed alternatively) in the fishing industry, *catch* is fish catch, $price_{ENERGY}$ is a (chain, i.e. year-to-year) price index of energy (costs), *GDP* represents gross domestic product per capita and $D_{Jellyfish=1}$ is a dummy variable, with a value of 1 in the year 2004, when the jellyfish outbreak occurred.

A linear regression was run on this model, where the number of employed persons was used rather than total employment (which, as shown in Table 2 was rather well-balanced by an increase in self-employment in the critical year of 2004). This revealed that none of the variables has a significant impact (Table 3). Yet, the indications are as expected: catch and *GDP* have a positive impact, as has the jellyfish presence dummy variable, whereas the price index for energy has a negative impact, meaning, *ceteris paribus*, the higher price increase means a reduction in employment (Table 3). This is a brief attempt to control for other variables, factors influencing the fishing industry, and to assign the 2004 drop in fishery production and consequently, employment, to the jellyfish outbreak. The results are indicative, as the data constraints (the number of observations and variables included) proved to be too important for proper conclusions. Given the results, factors other than the jellyfish outbreak alone apparently had an impact on fishing-industry employment; other measures, data- and methodology-wise need to be taken. Based on this we can assume that the jellyfish

Table 3. Impact on fishing industry (EMPL – employed): results of linear regression model.

EMPL	Coefficient	Standard error	t-test	*P-value*
Constant	162.8	70.01	2.33	0.045
Catch	0.00003	0.00002	1.32	0.220
$Price_{energy}$	-0.423	0.483	-0.88	0.403
GDP	0.0009	0.0011	0.81	0.439
$D_{Jellyfish=1}$	5.138	11.731	0.44	0.672
N=14	F=1.38	Adjusted R^2=0.104		

Source: Fisheries Research Institute of Slovenia (2010), Statistical Office of Republic of Slovenia (2010a, 2010b, 2010d), own calculations outbreak had an impact on employment in the fishing industry given the fact that none of the other factors turned out to be statistically significant and therefore more important than the jellyfish outbreak.

From the presented data we can conclude that the jellyfish presence in 2004 had an impact on the fish catch and on the fishing industry as a whole: reduced value added, mixed income and employment. Moreover, the fishing industry did not recover over the following years. In the next section we deal with the economy as a whole and the possible effects of the jellyfish outbreak in Slovenia.

Total economy

The results of the fishing industry effect on the Slovenian economy as a whole are discussed in this section. Before studying the results, one needs to bear in mind that the fishing industry in Slovenia represents a small fraction of the Slovenian Gross Domestic Product (GDP). In 2004 and 2005 the figures were 0.01 per cent of total GDP (SORS, 2010b), which clearly indicates that the total impact of the fishery on the national GDP is potentially very limited. Furthermore, the data reveal that imports in the fishing industry amount to over half of the total supply of that industry in Slovenia (SORS, 2010c), which further reduces the total impact of domestic production in the fishing industry on an economy-wide level. Nevertheless, the results are as follows.

First of all, the technical coefficients were calculated using domestic production only; imports were not taken into account as they are clearly not affected by the presence of jellyfish in Slovenian waters. Additionally, import data are only detailed for the fishing industry as a whole and not broken down within the fishing industry by other lower-level industries. However, in other respects the whole economy (imports and exports) has been used to model the economy properly (as Slovenia is a small and rather open economy). What is important for us at this point is the level of involvement of the fishing industry (their product) in products of other industries. The total effect is given by the sum of technical coefficients of production (how many products from industry *i* are needed (and sold to industry *j*): $\sum_i a_{ij}$

Thus, summing up the technical coefficients in row *i* (fishing industry products) across all columns *j*, gives the amount of fishing industry products needed for the production of one unit in the total economy. This amount is 0.04, which provides evidence that the fishing industry (their products) is of very limited importance in the total economy. This is somewhat anticipated, as it is in line with the aforementioned figure i.e. the share of the fishing industry in the total GDP of Slovenia.

Furthermore, elements from the $(I - A)^{-1}$ matrix give us the quantity (directly and indirectly) of the production in one industry required for a unit of final consumption of a product form another industry. As before, summing the row for fishing-industry product over all other industries gives us the amount of production needed in the fishing industry (directly and indirectly) for the final consumption of all the products in the economy. This figure is 1.05, which, again, means that the fishing industry in Slovenia is related to other industries to a very limited extent. The structure of this sum reveals that 99 per cent of the value comes directly from the same industry. This means that elements from this matrix connecting the fishing industry to other industries are practically inexistent, thus further establishing the nearly negligible impact of the fishing industry on the economy as a whole.

In calculating direct value added coefficients, d_j, we have again used domestic output alone. The coefficient for the fishing industry amounts to 0.46, establishing the fact that value added in the fishing industry represents 46 per cent of (domestic) fishing industry product(ion) – output. This is somewhat in line with other primary and secondary sectors in the economy, whereas, for instance, in educational services the value added adds up to 80 per cent of their product. Furthermore, elements in the $d(I - A)^{-1}$ matrix indicate how much value added is needed/integrated in the production of one industry (row) for a unit of final consumption of a product from another industry (column). Summing up the row for the fishing industry we obtain the figure of 0.49, which means that for a unit of final consumption of the total economy, the fishing industry (directly and indirectly) produces 0.49 units of value added. For comparison purposes, the average coefficient is nearly 1, rising to over 4 in real estate, renting, and business services. Again, 99 percent of this figure is contributed from the fishing industry alone, further pointing to the very limited scope of the fishing industry in the Slovenian economy.

On this basis we would normally be able to study how the changes in production of one industry (e.g. fishing) would affect other values: other industries, value added in this industry, etc. However, the effect in our case is negligible, as the results have indicated, strongly supported by the near-zero values of coefficients relating the fishing industry to other industries in the aforementioned matrices. Thus we can say that, although the fishing industry was affected by the presence of jellyfish, the Slovenian economy as a whole did not suffer significantly.

Concluding remarks

Our data indicates that the high jellyfish abundance in 2004 negatively affected the fish catch. Furthermore, on a yearly level we found reduced value added, mixed income, and employment in the fishing industry. Moreover, year 2004 appears to be the turning point in the fish catch in Slovenia (Table 2). The government acknowledged the impact on the fishing industry by allocating financial help to the fishermen involved (Government of the Republic of Slovenia, 2005); the latter was approved by the European Commission, and a sum of nearly EUR 150,000 was allocated to help the fishing industry. This clearly signals an appreciation of the ecological phenomena that can have a direct effect on the fishing industry. Thus, although other explanations are possible, the data presented (reduced fish catch, value added, mixed income and employment, and at the same time no reduction in wages and number of fishing vessels) leads us to believe that jellyfish outbreaks play a role in the observed impact on the fishing industry. In this paper we have also combined the data from neighbouring countries that also fish commercially in the northern Adriatic i.e. Croatia and Italy, where negative impacts seemed to be negligible. A possible and plausible reason is that both Croatia and Italy have vast fishing grounds extending beyond the northern Adriatic, thus making them less vulnerable to local ecosystem changes.

The use of input-output analysis to assess impact on the fishing industry and on the Slovenian economy as a whole (case study) indicated no significant reduction. We believe that this is due to the relative insignificance of the fishing industry in Slovenia – the fishing industry represents only a small fraction of Slovenian GDP (0.01 per cent). Moreover, with input-output analysis one needs to keep in mind that the assumptions stated and the simplicity of the matrix algebra, albeit posing an attractive and easy-to-use tool, also requires caution when interpreting the results obtained. Nevertheless, input-output analysis is a powerful tool and further research and upgrading can improve its validity in particular.

In addition to these direct economic losses there are other, indirect, effects on the use of marine goods and services. Jellyfish blooms have been shown to impact marine food webs (Malej *et al.,* 2007) including the microbial loop (Tinta *et al*., 2012), limiting food for fish through competition (Pucell & Arai, 2001), harming farmed fish (Baxter *et al*., 2011), and exacerbating eutrophication phenomena (West *et al*., 2009). Although jellyfish abundance typically exhibits large inter-annual and decadal fluctuations (Condon *et al*., 2013), some recent studies have convincingly shown that several anthropogenically mediated factors stimulate the proliferation of jellyfish (Richardson *et al*., 2009; Purcell, 2012). Among the key drivers of increasing jellyfish blooms, overfishing, eutrophication and marine constructions, i.e. substrate additions, can be controlled by adequate policy and management measures. The artificial structures offering substrate for the settlement of polyps are increasing rapidly and stimulating jellyfish proliferation (Duarte *et al*., 2013). In contrast to policies and measures to reduce eutrophication and to protect fishery resources, comprehensive marine construction policy is still missing.

In view of the above, our work is a first attempt to relate ecological changes in the northern Adriatic to the wider economy, and not only the fishing industry. The results are certainly indicative of the way in which an activity with a high impact or footprint in an economy could have a higher overall impact, and needs to be taken into account when planning development, employment, and even environmental policies. In other countries where the fishing industry represents a much larger sector of the economy, the results of jellyfish outbreaks might be more significant. Moreover, ecological impacts affecting other industries, such as tourism, can bring about more detrimental changes in production, wages, and employment. Thus, our methodology can be applied to other countries and regions, and even other natural phenomena affecting industries.

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