Science of the Total Environment 610–611 (2018) 298–307

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Environmental life cycle assessment of seafood production: A case study of trawler catches in Tunisia

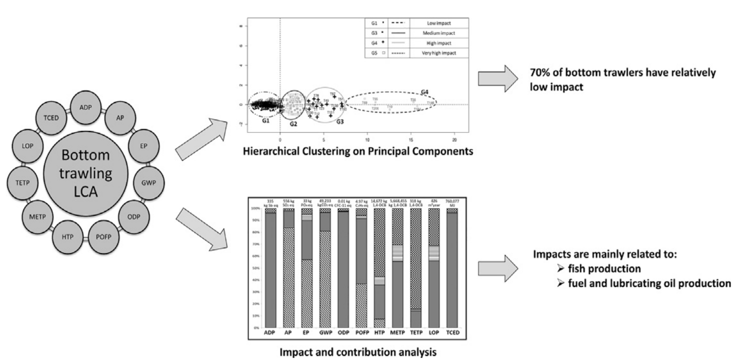
Khaled Abdou [a,b,*], Didier Gascuel [c], Joël Aubin [d], Mohamed Salah Romdhane [a], Frida Ben Rais Lasram [e], François Le Loc'h [b]

[a] UR 03AGRO1 Ecosystèmes et Ressources Aquatiques, Institut National Agronomique de Tunisie (INAT), Université de Carthage, 43 Avenue Charles Nicolle, 1082 Tunis, Tunisia
[b] UMR 6539 Laboratoire des Sciences de l'Environnement Marin (CNRS/UBO/IRD/Ifremer), Institut Universitaire Européen de la Mer (IUEM), Technopôle Brest-Iroise, Rue Dumont d'Urville, 29280 Plouzané, France
[c] UMR 985 Ecologie et Santé des Ecosystèmes, Université Européenne de Bretagne, Agrocampus Ouest, 65 rue de Saint-Brieuc, CS 84215, 35042 Rennes Cedex, France
[d] UMR 1069, Sol Agro et hydrosystème Spatialisation, Institut National de la Recherche Agronomique (INRA), 65 rue de Saint Brieuc, CS 84215, 35042 Rennes Cedex, France
[e] Univ. Littoral Côte d'Opale, Univ. Lille, CNRS, UMR 8187, LOG, Laboratoire d'Océanologie et de Géosciences, F 62930 Wimereux, France

HIGHLIGHTS

- First application of the LCA to fisheries in southern Mediterranean.
- First LCA of demersal trawling in Tunisia and one of few worldwide.
- Provides a complete environmental impact assessment of the production of seafood.
- Considers eleven different impacts of seafood production on the environment.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 July 2017
Received in revised form 7 August 2017
Accepted 8 August 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Life cycle assessment
Demersal trawling
Environmental impact
Gulf of Gabes

ABSTRACT

The Gulf of Gabes is one of the most productive fishery areas in the southern Mediterranean Sea. It is archetypal of an ecosystem in which the effects of fisheries are most pronounced. Demersal trawling is the main fishing activity in the Gulf of Gabes. Life Cycle Assessment (LCA) was applied to assess the environmental performance landing 1 t of seafood with wooden demersal trawlers in the Gulf of Gabes. Impact categories included in the study were abiotic depletion potential (ADP), acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone depletion potential (ODP), photochemical oxidant formation potential (POFP), human toxicity potential (HTP), marine eco-toxicity potential (METP), terrestrial eco-toxicity potential (TETP), land occupation potential (LOP), and total cumulative energy demand (TCED). Demersal trawlers were classified based on their impact intensity. Results showed that 70% of the vessels had relatively low impacts. Impact intensity was proportional to the amount of fuel consumed to land 1 t of seafood. Ships that fished less had the highest impacts per ton, due to lower fishing effort and catch per unit effort. This is likely to typify vessels that target highly valuable species such as shrimp. Onboard vessel activities contributed most to different environmental impacts (AP, EP, GWP and POFP), related to the high energy use of this fishery. Several impacts (ADP, ODP, METP, LOP and TCED) were associated mainly with fuel and lubricating oil production. Therefore, improvements must focus on

* Corresponding author at: UR 03AGRO1 Ecosystèmes et Ressources Aquatiques, Institut National Agronomique de Tunisie (INAT), Université de Carthage, 43 Avenue Charles Nicolle, 1082 Tunis, Tunisia.
E-mail address: abdou.khaledfb@hotmail.fr (K. Abdou).

http://dx.doi.org/10.1016/j.scitotenv.2017.08.067

minimizing fuel consumption. LCA is a valuable tool for assessing how to increase environmental sustainability of demersal trawling and it can help stakeholders identify the main operational issues that require improvement.

1. Introduction

Seafood represents a very important source of protein for the world's population. In 2014, seafood accounted for about 17% of the global population's intake of animal protein and 6.7% of all protein consumed (FAO, 2016). Due to the increase in world population and the increasing demand for seafood over the last decades, fishing activities have expanded substantially (Halpern et al., 2008). This expansion is related to technological developments in fishing technologies, increased fishing effort, increased number of fishing units and fishing grounds (Pauly et al., 2002; Swartz et al., 2010). Global production from marine fisheries increased to 86 million tons in 1996 and is now stagnating, and even slightly decreasing, due to the overexploitation of many fish stocks (FAO, 2016). Based on the Food and Agriculture Organization, half of world's fisheries are fully exploited and only 25% are sustainably exploited (FAO, 2016).

The Mediterranean Sea is the widest and deepest semi-enclosed sea in the world (Lotze et al., 2011). It is considered a biodiversity hotspot despite its oligotrophic conditions (Coll et al., 2010). Due to a long history of exploitation, the Mediterranean Sea has experienced several perturbations related to human impacts (Libralato et al., 2008; Tsagarakis et al., 2010). Fishing is the main threat to the Mediterranean ecosystem, in addition to climate change, eutrophication, habitat loss, pollution and introduction of alien species (Coll et al., 2010; Ben Rais Lasram et al., 2015a). The Gulf of Gabes, located on the southeastern coast of Tunisia, has a shallow slope, soft bottom and high fish diversity. The gulf is the main fishing ground in the country (more than 40% of national seafood production) and is one of the most productive areas in the Mediterranean Sea in terms of catches (Halouani et al., 2015; Papaconstantinou and Farrugio, 2000).

Fishing is the only food production activity that relies mainly on extracting organisms from wild ecosystems (Christensen et al., 2003), which risks degrading marine ecosystems (Kaiser and de Groot, 2000). Environmental impacts of seafood production have been studied widely in recent years because of increased worries concerning world fisheries state (World Bank, 2017; Worm et al., 2009). Most studies focused on direct impacts of fisheries on targeted species (Costello et al., 2016; Myers and Worm, 2003; Pauly et al., 2002) by-catch and discarded organisms (Glass, 2000); changes in benthic communities (Guyonnet et al., 2008); seafloor damage due to trawling (Hall-Spencer et al., 2002; Kaiser et al., 2006) and changes in trophic dynamics, structure and functioning of the ecosystem (Jackson et al., 2001; Pauly et al., 2002; Tremblay-Boyer et al., 2011). Most environmental studies focus on these general concerns and overlook important aspects related to the performance of fishing. Few studies include impacts related to energy and material use in the construction and maintenance of fishing vessels (Hayman et al., 2000), supply of gear (Ziegler et al., 2003), gear loss at sea (Derraik, 2002), fuel consumption (Thrane, 2004; Tyedmers et al., 2005), ice, paint and antifouling paint (Hospido and Tyedmers, 2005) and marketing and processing catches (Andersen, 2002).

The long-term sustainability of fishing is a major concern from environmental and ecological viewpoints. Social groups (e.g. authorities, stakeholders, consumers, skippers) require a complete evaluation of environmental impacts of seafood products, which is reflected in recent developments and policies, such as increasing consumer awareness (FAO, 2016; Luten, 2006). To better understand environmental impacts and ensure the sustainability of fishing, it is necessary to develop an integrative science-based approach to impact assessment. In this context, Life Cycle Assessment (LCA) has emerged as a robust method to estimate potential environmental impacts associated with seafood production throughout the supply chain (Pelletier et al., 2007).

LCA assesses potential environmental impacts associated with a product or service by compiling an inventory of inputs (resources required) and outputs (pollutants emitted) throughout the entire life cycle of the product, "from cradle-to-grave", i.e. from the extraction of raw materials, through production, construction, use, and when appropriate, waste management and disposal or recycling (Consoli et al., 1993; Guinée et al., 2002). It is an ISO-14000 standardized method (ISO (The International Organization for Standardization), 2006a, 2006b). LCA of fisheries and seafood products began in the 2000s (Avadí and Fréon, 2014) and has been applied to a wide range of seafood products (Tyedmers, 2000; Ziegler et al., 2003, 2011; Hospido and Tyedmers, 2005; Iribarren et al., 2010; Vázquez-Rowe et al., 2010, 2012a; Ramos et al., 2011; Fréon et al., 2014; Avadí et al., 2015; Abdou et al., 2017a, 2017b).

Demersal trawling is the dominant fishing practice worldwide for catching demersal and benthic species. It is also considered to have the most destructive fishing gear because it damages bottom habitats and perturbs benthic communities, in addition to its non-selectivity (Kumar and Deepthi, 2006). Using the wooden demersal trawlers operating in the Gulf of Gabes as a case study, the main objective of this study was to assess environmental impacts of trawler subfleets to analyze the environmental performance of extracting seafood using this fishing method and to identify hotspots that need to be improved to increase its environmental sustainability. To the best of our knowledge, this study represents the first fishery LCA study in the southern Mediterranean.

2. Materials and methods

2.1. Study area

Located in the south-central Mediterranean Sea, the Gulf of Gabes covers approximately 35,900 km^2 (Fig. 1). The gulf is highly sensitive to atmospheric changes (Natale et al., 2006) due to the shallowness of its basin: it remains only 50 m deep 110 km offshore. Its tidal amplitude can reach 1.8 m high (Sammari et al., 2006). Its water temperature ranges from 13 to 29 °C (Ben Ismail et al., 2010). The Gulf of Gabes shelters one of the world's largest *Posidonia oceanica* seagrass beds (Batisse and Jeudy de Grissac, 1998), which serves as a nursery, feeding and breeding habitat for many marine species (Hattour, 1991). The ecosystem offers suitable shelter for approximatively 247 fish species (Bradai et al., 2004). Human activities are a great threat to the Gulf (Lamon et al., 2014), along with changes in its biodiversity and functioning (Ben Rais Lasram et al., 2015b). Despite its oligotrophic conditions, the Gulf of Gabes is one of the most productive ecosystems in the Mediterranean (Papaconstantinou and Farrugio, 2000; Halouani et al., 2015). Most of its seafloor has a soft bottom (Brahim et al., 2003), resulting in the prevalence of demersal trawling. Due to intense fishing activity since the early 1980s, several stocks have been identified as highly or over exploited (Fiorentino et al., 2008), and total production has substantially decreased since the 1990s. Seafood production from demersal trawlers in the Gulf of Gabes was 10,208 t in 2015, supplying approximately 41 million € (DGPA, 2015). Demersal trawling is the main fishing method in the Gulf of Gabes (Hattab et al., 2013; Mosbah et al., 2013), with 226 fishing units in 2015, of which most (184) were wooden vessels (DGPA, 2015) that target shrimp and demersal finfish (Sparidae (*Diplodus annularis*, *Sparus aurata*), mullets (*Mullus barbatus*,