Fisheries Research 143 (2013) 191–200

Contents lists available at SciVerse ScienceDirect

Fisheries Research

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

Carbon footprint analysis of goose barnacle (*Pollicipes pollicipes*) collection on the Galician coast (NW Spain)

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ARTICLE INFO

Article history:
Received 15 October 2012
Received in revised form 14 February 2013
Accepted 17 February 2013

Keywords:
Carbon footprint
Galicia
Goose barnacles
Seafood

ABSTRACT

Goose barnacles constitute an important market product in Spain, where they are considered a top seafood attraction in first-class restaurants. However, their environmental sustainability has not been explored beyond the implementation of co-management schemes to avoid overexploitation. Therefore, the main objective of this article is to understand the environmental implications of goose barnacles in terms of carbon footprint (CF), in the wake of recent studies which have highlighted the importance that fishing systems can have on climate change, as well as to facilitate accountability concerning CF reduction policies for stakeholders and consumers. Results for the six scenarios under analysis showed substantial changes depending on the harvesting area and especially on the means of transport chosen, since this intertidal species can be accessed by land or by sea. The average CF per kg of harvested barnacles ranged from 0.64 kg CO_2 equiv. to over 11 kg CO_2 equiv., showing substantially higher CF values whenever the resource was accessed by sea. The wide CF gap observed between harvesting carried out on foot or by sea suggests that different management schemes should be implemented for each of the two methods in terms of environmental monitoring, as well as different strategies concerning environmental transparency and reporting.

1. Introduction

Goose barnacles (*Pollicipes pollicipes*) are marine pedunculate cirripedes that are found in sessile metacommmunities in intertidal regions of the North Atlantic coast (Barnes, 1996; Molares and Freire, 2003). In particular, these organisms are found between the latitudes of 48°N in France and southern England and 15°N in Dakar (Senegal). Even though these marine organisms are used for human consumption in coastal communities throughout this entire geographical region, it is only in Spain where this species has become an important market product (Bald et al., 2006). In fact, barnacles are considered a delicacy in Spain constituting an essential seafood attraction for top class restaurants (Bernard, 1988; Pérez, 1996). Therefore, prices can reach up to 80 €/kg at the fish auction at certain times of the year, such as Christmas, when roughly 20% of the sales are concentrated (Mercados Municipales, 2011).

Goose barnacles are collected from the intertidal area of rocks by fishermen all along the rugged Galician coast. Fishermen reach the desired harvest area, which due to current management specifications is controlled through strict harvest ground delimitations and daily quotas, by land, using their personal vehicles, or by sea, using conventional artisanal fishing vessels (Molares and Freire, 2003). The collectors usually have a wide range of licenses to fish with different gears depending on the time of the year and on the climatic conditions (Freire and García-Allut, 2000; Cambiè et al., 2012) and barnacle harvesting constitutes only one of many activities they undertake throughout the year. Furthermore, it is important to highlight that in most cases the quality of the barnacles landed by vessels is higher than those gathered by shellfish harvesters, since they target more remote populations, inaccessible for collectors on foot (Eva Iglesias, *Confraría of Baiona*, personal communication, 2010).

Over 90% of goose barnacles harvested in Spain come from Galicia (NW Spain), where entire fish communities specialize in the collection of this invertebrate (Fig. 1). In fact, barnacle sales in Galician fish auctions represent approximately 2.5% of total extractive marine species sales (Pesca de Galicia, 2012). Barnacles are usually consumed fresh, but small percentages are also destined to export frozen to other areas of Spain (Mercados Municipales, 2011) or for canning and pâté production.

The high demand for barnacles in the Iberian Peninsula gave rise to the first overexploitation problems as early as the 1980s and 1990s (Molares and Freire, 2003). Therefore, in 1992 a co-management system for access to this natural resource was

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http://dx.doi.org/10.1016/j.fishres.2013.02.009

Fig. 1. Goose barnacle landings in Galicia (bars) in the period 2001–2011 (t/year) and contribution of the *confraría* in Baiona (%).
Source: Xunta de Galicia (2012a,b).

established, in which the local fishing associations (*confrarías*) and the Galician Regional Government (*Xunta de Galicia*) became co-responsible for barnacle management under a specific system known as *territorial user rights for fishing* – TURFs (Molares and Freire, 2003). TURFs have proved to be relatively successful for guaranteeing the sustainability of small-scale fisheries, such as clams or lobster (Acheson et al., 2000; Gelcich et al., 2007; Sestelo and Roca-Pardiñas, 2007; White and Costello, 2011). In fact, they have provided important benefits in terms of economic and social sustainability (Hentrich and Salomon, 2006; Cambiè et al., 2012). In contrast, in terms of environmental sustainability, and despite the improvement of shellfish stocks in Galicia over the past two decades, these improvements are limited due to the high number of illegal, unreported and unregulated (IUU) landings that still occur in these economically attractive activities. Moreover, these IUU are expected to increase in years to come due to the severity of the economic crisis in Spain (La Voz de Galicia, 2012a, 2012b).

The strict management control that barnacle extraction suffers along the Galician coast involves the use of certain production methods which resemble aquaculture practices (Valderrama and Anderson, 2007; Klinger et al., 2013). For instance, the intertidal harvesting areas for barnacles are plotted, and a rotation system which resembles the one implemented in agricultural systems is adopted to guarantee the recovery of the barnacle clusters. It is important to note that barnacle extraction in Galicia, therefore, cannot be considered a pure fishing system, since it incorporates practices that are not in accordance with traditional fishing techniques that hunt for a natural resource. Hence, a recent concept named *hybrid seafood production* has arisen to define these types of production systems (Klinger et al., 2013).

Concerning environmental sustainability in the seafood sector, impact assessment has traditionally been limited to the direct effects on stock abundance, whereas other environmental concerns, linked to the industrial activities that support fishing performance have been disregarded (Hospido and Tyedmers, 2005). However, recent developments in the environmental management of seafood have focused on reporting the carbon footprint of fishing products as a means to inform, analyze and improve the environmental burdens of these products in terms of greenhouse gas (GHG) emissions (Vázquez-Rowe et al., 2012a; Avadí and Fréon, 2013). In fact, recent studies have highlighted the important effect that fishing systems can have on climate change (Tyedmers et al., 2005). For instance, total direct GHG emissions due to fuel combustion in fisheries worldwide are comparable to that of the Netherlands (Tyedmers et al., 2005) and recent estimates reflected that fishing and aquaculture activities represent circa 3% of Galician GHG emissions (Iribarren et al., 2011; Verdegaia, 2010).

Given the importance of goose barnacle harvesting in Spain from a cultural, economic and social perspective, as well as the increasing interest shown by the Galician regional government and certain stakeholders in the supply chain to improve the marketing strategy of Galician seafood products (Mar de Silleiro, 2012; Xunta de Galicia, 2012a), the implementation of carbon footprint (CF) schemes in this sector may entail important benefits (Iribarren et al., 2010a, 2010b, 2011; Vázquez-Rowe et al., 2013; Ziegler et al., 2013). These advantages include the accessibility of markets with a strong demand for environmentally certified products or the knowledge that public opinion has acquired regarding global warming, making CF an easily understood indicator (Weidema et al., 2008).

Nevertheless, environmental assessment for artisanal fishing activities using life cycle methodologies, such as Life Cycle Assessment (LCA) or CF, has been limited to two single studies in literature (Iribarren et al., 2010a; Ziegler et al., 2013), due to the small holding characteristics of these fleets. Moreover, these two publications presented the environmental profile of two very specific species (mussels and shrimp), limiting the extrapolation of the results to other fish and shellfish species captured by artisanal mechanisms. Therefore, the main aim of this article is to understand the environmental implications from a CF perspective of high economic value coastal seafood, in this case, goose barnacles, as well as to facilitate accountability concerning CF reduction policies for stakeholders and consumers. Finally, environmental sustainability comparison in terms of mass and energy content with respect to other marine species is provided.

2. Materials and methods

2.1. Goal and methodological framework

As mentioned in Section 1, the main aim of the current study is to obtain the environmental profile of goose barnacles harvested in Galicia in terms of GHG emissions. Therefore, CF methodology was the selected life-cycle approach to report the results, due to its proliferation in the food sector (Weidema et al., 2008; Roy et al., 2009). It should be noted that despite its extensive use as a sole environmental indicator, it may provide a myopic vision of the environmental profile of a specific production system, since it obviates a wide range of environmental dimensions, such as toxicity, acidification or eutrophication (Laurent et al., 2012). Nevertheless, CF has proved to be an adequate indicator for reporting environmental results in the seafood sector, due to its strong penetration in public opinion and stakeholders (Vázquez-Rowe et al., 2012a). Moreover, fuelling of vessels in fishing systems has proved to be the overwhelming carrier of environmental impact in most