Linking Salmon Aquaculture Synergies and Trade-Offs on Ecosystem Services to Human Wellbeing Constituents

Luis Outeiro, Sebastian Villasante

Abstract Salmon aquaculture has emerged as a successful economic industry generating high economic revenues to invest in the development of Chiloe region, Southern Chile. However, salmon aquaculture also consumes a substantial amount of ecosystem services, and the direct and indirect impacts on human wellbeing are still unknown and unexplored. This paper identifies the synergies and trade-offs caused by the salmon industry on a range of ecosystem services. The results show that large economic benefits due to the increase of provisioning ecosystem services are also causing a reduction on regulating and cultural services. Despite the improvement on average income and poverty levels experienced in communities closely associated with the sector, this progress is not large enough and social welfare did not improve substantially over the last decade. The rest of human wellbeing constituents in Chiloe region have not changed significantly compared to the development in the rest of the country.

Keywords Salmon aquaculture · Ecosystem services · Synergies and trade-offs · Chile

INTRODUCTION

After 20 years of the first Earth Summit, the vast majority of the world's nations declared that human actions were dismantling the Earth's ecosystems at an alarming rate (Cardinale et al. 2012). In the field of marine social–ecological systems, there is general agreement on what needs

to be achieved (i.e., a sustainable aquaculture, less overfishing, recovery of depleted fish stocks, reduction in by-catch and habitat impacts, increase of jobs and better distribution of food), but specific objectives on how best to achieve them remain contentious and unresolved (Salomon et al. 2011).

Our analysis focuses on the components of nature directly consumed by the salmon aquaculture industry in Southern Chile and how they relate to human wellbeing. Here we consider three types of ecosystem services by following the classification made by the Millennium Ecosystem Assessment (MEA 2005): provisioning (i.e., salmonid production from aquaculture), regulating (biological regulation, human disease control, and waste processing), and cultural (aesthetic quality of seascapes–landscapes) services.

The transformation of multifunctional coastal and marine social–ecological systems (Chiloe before the implementation of the intensive aquaculture system) into monofunctional seascapes (Chiloe after the intensive aquaculture) constitutes an economic benefit in the short term. However, it may also produce a degradation of regulating ecosystem services, coupled with an increase of social vulnerability and a potential loss of human wellbeing in the long term.

The specific objectives of this paper are the following: (a) to identify the relationships between ecosystem services and salmon aquaculture, (b) to identify and analyse the flows of synergies and trade-offs between ecosystem services caused by the salmon aquaculture, and (c) to evaluate the trade-offs on ecosystem services associated with salmon aquaculture and its implications for human wellbeing in the social–ecological system of Chiloe. As far as we know, this is the first study in which such analyses are accomplished with the focus on the use of ecosystem services and its effects on human wellbeing.

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Synergies and Trade-Offs Between Ecosystem Services

While the valuation of ecosystem services has been recognized as a relevant component of environmental public policies, most of these approaches tend to aggregate the different social groups of beneficiaries within a general category of human wellbeing, which limits the applicability of these approaches to questions related to synergies and trade-offs between ecosystem services, stakeholders, and institutions at temporal and spatial scales.

Even though most environmental management decisions recognize the existence of synergies and trade-offs between the benefits of ecosystem services, empirical studies tend to ignore the time–space relationships between ecosystem services and their beneficiaries (Tallis and Polasky 2009). This may lead to excessively simplified economic analysis of ecosystem services and the potential policy implications that may be derived from them.

In spite of the relevant contributions provided from different methodologies commonly used in the environmental economics arena (i.e., contingent valuation, travel cost, or hedonic prices methods) during the last decades, most of them have important limitations in terms of spatial and social disaggregation of ecosystem services and the group of beneficiaries. It is not possible to assume that every hectare provides the same ecosystem services, and that these are valued in every hectare in the same way, because this implies ignoring key aspects such as diversity, spatial configuration, size, habitat quality, and the number and type of groups of beneficiaries (Tallis and Polasky 2009). That is, empirical valuation studies often do not break down the issue in terms of typology and production processes or distinguish between the economic value of ecosystem services among different groups of beneficiaries (Daw et al. 2011).

Under this context, Chile represents one of the global paradigms of an open economy focused on extracting provisioning ecosystem services to obtain *commodities* for export purposes (copper, lithium, seafood products, etc.).

MATERIALS AND METHODS

Study Areas

The Region of Los Lagos has been the principal recipient of aquaculture investment and production in Chile. Since the start of the activity in the 1980s, the companies have concentrated their net pens within the Sea of Chiloé (Fig. 1). This study is focused on the salmon aquaculture developed in 15 of the 30 municipalities of the Los Lagos region (Southern Chile): Ancud, Calbuco, Castro, Chaitén,

Chonchi, Cochamó, Curaco de Vélez, Dalcahue, Hualaihué, Puerto Montt, Puqueldón, Quemchi, Quellón, Quinchao, and Quellón.

From the 15 municipalities included in this study, 3 of them are considered urban ones (Puerto Montt, Ancud, and Castro) whereas the other 12 are rural entities. The salmon aquaculture industry needs three different types of infrastructures to obtain a production unit of salmon ready to be sold at seafood markets: (a) freshwater hatcheries, b) salmon net pens, and (c) processing factories. First in the ranking is the municipality of Puerto Montt with the highest number of jobs created within the salmon industry, and it also contains 18 freshwater factories; second is Hualaihué municipality (13), and finally Cochamó (12). The largest number of net pens is located at Quellón municipality (62), followed by Calbuco and Quemchi municipalities (with 40 and 39 net pens, respectively).

The processing factories of the industry are mostly located in three municipalities: 21 processing factories are located in Puerto Montt (the most populated municipality of the region); 9 are localized in the municipality of Calbuco (West of Puerto Montt); and 7 in Quellón (South of Chiloé island). In 2011, 57 % of the total production of salmon aquaculture in Chile was located within the sea of Chiloé and the surrounding municipalities. According to unpublished data from regional government of Los Lagos and SERNAPESCA (Fisheries Services of Chile), 465 net pen concessions and 113 fresh water hatcheries and 50 processing plants were located within these 15 municipalities.

Step-by-Step Approach: Ecosystem Services Level and Data Proxy

Here we describe the method we followed to investigate the role of ecosystem services included in the study at different scales by using a step-by-step approach (Villasante et al. 2011):

- Identification of the types of ecosystem services (provisioning, regulating, or cultural) consumed by salmon industry by using the local expert knowledge and on-site observation.
- Disaggregation of each ecosystem services in their respective: (1) categories: food, timber, fuel, biological regulation, human disease control, waste processing, recreation, and aesthetics; (2) dimensions: biophysical–ecological, socio-cultural, and monetary, and (3) values: equity, use value, existence value, non-extractive use value, biodiversity, functional diversity, and landscape multifunctionality.
- Micro and macro-economic dimension of salmon aquaculture: once the ecosystem service consumption has been recognized, then macro and micro-economic

Fig. 1 Localization of salmon net pens in the Sea of Chiloé (Southern Chile). ©Luis Outeiro

indicators were selected in order to use them as proxy indicators to better understand the socioeconomic dimension of salmon aquaculture.

- (d) Aesthetic quality of seascapes: Scenic amenities play an important role in augmenting local economies by attracting visitors who support local businesses. Because scenic beauty is an attribute usually considered to be relevant to people living in coastal communities and for those who visit coastal areas to enjoy the ocean and the marine environment, coastal planners can incorporate measures of visual amenities and/or disamenities into broader policy deliberations and planning exercises. Thus, a spatial model of the viewshed impact on the aesthetic quality of the landscape and seascape has been generated by using the InVEST Aesthetic model (Tallis et al. 2013).
- (e) In the process of collecting data and information, this paper uses data proxies in order to determine the undesirable and desirable outcomes on the whole chain of ecosystem services constituents (types, categories, dimensions, values) derived by the salmon aquaculture activities. Here, undesirable (or negative) outcomes are assumed as decreases of the ecosystem services, and desirable (or positive) outcomes as increases of the ecosystem services. In addition, synergies and trade-offs between different ecosystem services described in (a) and (b) are also included in the analysis. By synergies we mean an increase of at least two ecosystem services, while trade-offs refer to the increase of a given ecosystem service and a decrease on another one at the same spatial and temporal scales (Bennett et al. 2009; Carpenter et al. 2009).
- (f) A set of the most relevant human wellbeing indicators were selected from the socio-economic survey CASEN of the Ministry of Social Development (2011). CASEN (2011) provides data of human wellbeing indicators at the municipality scale from the years 2000, 2005, and 2010. Data and information which covers aspects of marine ecosystem services in the area were also gathered from national reports and published papers included in ISI Web of Knowledge and Latindex databases. In addition, phone and e-mail surveys were carried out between May and June 2013 targeting salmon aquaculture firms mainly located within the selected municipalities in order to find out employment data on each of the three production units. All the interviews were made by contacting the person in charge of the human resources department in each salmon aquaculture firm. The aquaculture firms were randomly chosen to ensure a homogenous representation of the sample in each municipality which then was used to estimate the following structure of direct employment: a net pen generates an average of 30 jobs per year, a processing plant 225 jobs and a hatchery an average of 35 jobs.

The Potential Capacity of Chilean Salmon Aquaculture to Improve Human Wellbeing

Aquaculture is a form of exploitation that takes place in the biophysical environment by making use of the marine ecosystem to achieve its target of intensive fish production with nutritional values important to the welfare of humans (FAO 2012). For the Chilean aquaculture the main species grown in terms of volume is the Atlantic salmon (*Salmo salar*), which is an alien species in the marine social–ecological ecosystem of Chiloe (Thorstad et al. 2008).

For the purposes of the study, it is important to stress that salmon aquaculture is not the sole economic activity in the region (farming, fishing, and tourism develop an important overall role as well), but it has a predominant role providing direct and indirect employment at the municipality scale. The salmon aquaculture invests human and technological capital to generate indirect benefits of ecosystems as stable employment and flexible capital accumulation (Barton and Floysand 2010). Through the use of human, built, and natural capital, aquaculture industry may contribute to the achievement of wellbeing constituents (MEA 2005).

It is important to highlight that a high number of studies that establish conceptual frameworks can be found in the literature to categorize human wellbeing constituents based on the degree of development of the country (Duraiappah 2004; MEA 2005; Smith et al. 2013). Duraiappah (2004) and MEA (2005) use a suitable framework to apply in developing countries, whereas Smith et al. (2013) propose a framework to distinguish human wellbeing constituents suited to developed countries (Australia, European Union, New Zealand, USA, etc.) (see for more detail the [Electronic Supplementary Material](#)).

RESULTS

Provisioning Ecosystem Services

Figure 2 presents the trade-offs generated by the salmon aquaculture industry in the Sea of Chiloé. In terms of provisioning ecosystem services, salmon aquaculture mainly affects food provision by increasing the salmon production, in particular the export production to international markets. The provisioning's category comprises the monetary and social ecosystem services' dimensions. The monetary dimension indicates that Chilean salmon aquaculture shows a huge economic benefit in the short term, while the social dimension of the provisioning ecosystem services presents both desirable and undesirable outcomes.

Salmon aquaculture is also able to cause some trade-offs because is not able to satisfactorily address some ethical

and equity (income and its distribution, labor safety, labor rights) values of the ecosystem services provided to the society. In addition, the most important trade-off occurs between the regulating and provisioning services. The salmon industry generates a strong exchange between the monetary dimension of provisioning services and the biophysical–ecological dimension of the regulating services in the social–ecological system of Chiloé (Fig. 2).

Short-Term Positive Outcomes on the Monetary Dimension of Provisioning Ecosystem Services

The economic revenues were depicted through indicators of secondary variables indirectly related to the provisioning services, namely corporation benefit, tax benefits, production multipliers, poverty index, and employment rate.

Corporation Benefit

The Chilean salmon aquaculture industry generated US\$2500 million according to statistics of seafood exports in 2010 (FAO 2012), while the peak of seafood exports was reached in 2007 with US\$3600 million (Fig. 3). In 2007 the industry was hit by the Infectious Salmon Anemia (ISA) virus which caused a substantial mortality on the salmon net pens in Chiloé (Valdés-Donoso et al. 2013). This demonstrates that aquaculture production is highly vulnerable to adverse impacts of disease and environmental conditions, not only in Chile but also elsewhere (FAO 2012).

The ISA crisis consequently led to a fall in the production volume and consequently in the net benefits (in 2011 the production volume had dropped to 150 000 tonnes and US\$1000 million (Fig. 3), and generated an estimated economic loss of US\$2000 million with more than 25 000 jobs lost in the sector. The recent ISA virus detection in Aysen region in April 2013 was also a new symptom that the effectiveness of the salmon aquaculture industry in achieving a high control and monitoring production system is still fragile (Bravo et al. 2013).

Tax Benefits

The 1991 Chilean Fisheries and Aquaculture Law (Law No. 20.657) was modified in 2013 to ensure the sustainability of fishery resources, whilst taking into account the welfare of those communities depending on marine activities. The new law incorporates the obligation to pay a fee for space occupied by net pen which is US\$820 ha^{−1} year^{−1}. The funds obtained from this fee go directly to the creation of a common fund of the Chilean government, which is redistributed proportionally based on poverty incidence, number of properties exempt from taxation, income per habitant,

Fig. 2 Synergies and trade-offs caused by the salmon aquaculture industry in the Sea of Chiloé. *Source* own elaboration

Fig. 3 Salmon aquaculture (*Salmo salar*, *Oncorhynchus tshawytscha*, *Oncorhynchus mykiss*) production in Chile (1987–2010). *Source* own elaboration from (FAO 2013)

and index of proportional size of the municipality. These funds are put aside for the development of other activities related to the welfare of the society such as public education, which is controlled by the municipality, the satisfaction of social needs and/or the improvement of

infrastructures. The estimated total annual amount collected from this fund in 2012 reached US\$5.4 million. However, in spite of the fee approved by the Law No. 20.657, the contribution of the taxes from salmon net pens on the total amount of public taxes is relatively low (in average 12 %)

compared to the weight of the industry in the economies of the municipalities included in this study (Table 1).

A second type of tax is obtained by the Chilean government from the salmon aquaculture through the creation of employment contracts and it goes directly to the Chilean tax administration. This tax increases with the salary received by the employees and it is applicable to contracts which salaries are above US\$1300 per month. As result, only 20 % of the salmon industry employment is contributing to the common employment tax, generating an average revenue of US\$533 000 per month.

Production Multiplier

The production multiplier measures the capacity of a sector to generate indirect employment. According to FIP (2005), the salmon aquaculture showed the lowest production multiplier of a total of 19 analyzed sectors of the Los Lagos region economy. Therefore the impact of salmon aquaculture to satisfy one of the human wellbeing constituents is not developing any “knock-on” effects on a network and/or cluster of different economic industries in the region.

Employment, Capacity Building, and Poverty Levels

The development of salmon aquaculture industry, almost inexistent 20 years ago, has raised the migration of workers to the Los Lagos region from the rest of the country. The industry attracted professional workers, and it also

generated the creation of different university degrees on aquaculture as well as to offer a range of technical degrees (Montero 2004).

The increase of education and professional proficiency in developing countries is often associated with the potential to reduce inequality and poverty (Baneerjee and Duflo 2011). The advances made within the salmon aquaculture industry in this field could contribute to the decrease the poverty incidence in the salmon municipalities.

According to CASEN (2011), poverty levels have slightly dropped from 14.6 % in 2000 to 12.1 % in 2011 (in 2011, the poverty line was above US\$153 per month). Comparing the evolution of poverty incidence in the region of study and in Chile, Table 2 indicates that although in the year 2000 the region showed a higher poverty incidence than the whole country, the decrease of the poverty incidence was also greater: in the first case the poverty incidence decreased from 25.6 to 13.3 % while in Chile diminished from 20.2 to 15.9 %.

However, some municipalities with high number of direct employees in the salmon aquaculture such as Calbuco (3370 jobs) and Puerto Montt (6539 jobs) still show high level of poverty if compared with other municipalities. On the other side, the rest of municipalities such as Castro (1015 jobs), Curaco de Vélez (180 jobs), Dalcahue (1095 jobs), and Quinchao (1235 jobs) increased the poverty incidence between 2000 and 2011 (Table 2). It is important to highlight that in those municipalities with other rural and urban activities the poverty incidence may also be affected by the trends of these economic activities.

Table 1 Amount of taxes form net pens, total public investment and relative weight of the salmon industry tax on total public taxes

Municipalities	Direct employment		Total public taxes (a) (US\$/year)	Taxes from salmon net pens (b) (US\$/year)	Participation of salmon industry on (a) (%)
	No. Workers	% From salmon industry			
Ancud	500	2.2	6 379 329	49 476	0.8
Calbuco	3 370	19.1	4 344 746	730 596	16.8
Castro	1 015	4.3	5 753 609	116 269	2.0
Chaitén	1 835	45.0	2 163 845	848 513	39.2
Chonchi	2 150	28.9	2 964 510	268 820	9.1
Cochamó	1 470	55.4	1 852 837	171 517	9.3
Curaco de Vélez	180	9.8	4 344 746	63 494	1.5
Dalcahue	1 095	17.2	2 726 278	70 091	2.6
Hualaihué	2 255	48.2	2 028 075	512 077	25.2
Puerto Montt	6 539	5.9	15 880 062	357 052	2.2
Puqueldón	420	18.4	1 781 217	249 029	14.0
Queilén	665	23.1	2 207 313	319 945	14.5
Quellón	3 575	21.1	4 231 311	432 090	10.2
Quemchi	1 910	39.0	2 896 333	677 821	23.4
Quinchao	1 235	25.3	2 824 170	502 181	17.8
Region	28 214	24.2	62 378 382	5 368 971	12.6

Table 2 Poverty incidence in the municipalities of the Sea of Chiloé, Los Lagos region, and Chile

Municipalities	Poverty incidence (%)		
	2000	2006	2011
Ancud	21.3	7.8	15.4
Calbuco	18.5	14.4	14.7
Castro	11.7	12.7	15.9
Chaiten	n/d	10.6	n/d
Chonchi	15.5	9.2	9.5
Cochamó	14.0	8.1	n/d
Curaco de Vélez	4.5	n/d	12.8
Dalcahue	6.9	6.1	9.0
Hualaihué	20.0	6.9	11.9
Puerto Montt	21.4	12.5	14.1
Puqueldon	n/d	n/d	7.8
Queilén	n/d	n/d	14.2
Quellon	n/d	18.6	11.4
Quemchi	16.2	n/d	5.8
Quinchao	10.9	9.0	14.9
Average	14.6	10.5	12.1
Region	25.6	11.8	13.3
Chile	20.2	14.0	15.9

Source own elaboration from CASEN (2011) and Ministry of Social Development

Long-Term Trade-Offs on the Social Dimension of Provisioning Ecosystem Services

Income Distribution

As already described, the provisioning ecosystem services generate a substantial amount of economic capital with the use of human, manufacture, and natural capital. The human capital of the social–ecological system in Chiloé obtains a direct economic and social return in terms of income. This economic service has the potential to impact positively on the social cohesion of the population by creating equitable wages and redistributing wealth, thereby relieving conflicts between different classes (Rupasingha et al. 2006).

According to the Chilean's National Institute of Statistics (INE) (2008), a high number of the jobs are concentrated among factory base workers, egg hatchery operators, refrigerator workers, and feeding center workers. The rest of the jobs are also distributed in administrative personnel, divers and harvesting supervisors (Table 3).

In terms of salaries, 80 % of the workers receive a salary below US\$500 per month of which almost 30 % are usually subjected to a high variability due to the fact that the workers can receive a production bonus depending on the development of the economic activity. As a result, the salary is often below US\$330 per month (Díaz 2009). The other 20 % of the

Table 3 Total number of jobs in the salmon industry for the study area and their average salaries

Categories	No. jobs	% Jobs	Salaries (US\$)
CEO	28	0.1	14 460
Managers	256	0.9	6 772
Harvesting supervisor	138	4.9	3 020
Processing factory administrative	187	0.7	2 425
Line supervisor of processing	776	2.8	1 435
Administrative	2 802	9.9	924
Diver level 3 (>40 m)	105	0.4	850
Diver level 2 (20–40 m)	9	0.0	565
Diver level 1 (<20 m)	1 138	4.0	507
Feeding centers operators	3 115	1.0	456
Egg hatchery operator	3 859	13.7	426
Factory base worker	1 133	40.2	369
Refrigerator worker	3 221	11.4	394
Total	28 206	100	

Source Instituto Nacional de Estadística de Chile (2008)

total workers are office and administration positions whose average salary is around US\$900 per month. Salaries for technical employees amount to US\$2300 per month and managers to US\$10 650 per month.

Labor Rights and Equality

According to Melillanca and Díaz (2007), 13–15 % of the total working force of the salmon aquaculture industry belonged to unions in 2007. The current structure of the sector includes a high number of contractors and subcontractors, and a precarious control of the labor rights. In the Chilean legislation there is also a fine system to punish the lack of compliance of labor rights. However, in spite of this important initiative, the fine system is unable to promote labor rights compliance among the companies, as the law does not allow sanctioning the same company more than once a year (Ernesto Morales, pers. comm., Inspector of Labour Direction, Ministry of Public Work).

According to Montero (2004) the most expensive cost is concentrated on the feeding process of the value chain where 49 % of the cost in an average salmon net pen is usually destined to the cost of fishmeal supply, while 27 % of the total costs is dedicated to labor cost. The labor force of this industry is one of the labor sectors in which employees spend more hours at work, where 1 of 5 workers works 50 h per week (Gillet and Olate 2010).

Regulating Ecosystem Services

The salmon aquaculture industry mainly affects three categories of regulating ecosystem services (biological

Chilean jack mackerel (*Trachurus murphyi*), Common sardine (*Strangomera bentincki*), and Peruvian anchovy (*Engraulis ringens*), among other pelagic species ([5] in Fig. 4). Tacon et al. (2009) also found that the Chilean salmon aquaculture requires between 20 and 40 % more volume of fish to produce one tonne of salmonids. In fact, Chile is the third largest producer of fishmeal and fish oil for aquaculture, which is supported by the pelagic species of marine ecosystems (Deutsch et al. 2007).

Human Disease Control

High volumes of antibiotics used by the industry started to be issued since the ISA virus outbreak in 2007 with inefficient results (Bravo et al. 2013). Despite of this, salmon aquaculture in Chiloé still uses 8000 times more antibiotics than the Norway salmon aquaculture (Millanao et al. 2011). This intensive and excessive usage of antibiotics may lead to harmful human diseases and harm the biological equilibrium of the marine environment (Rozas and Asencio 2007; Tett 2008; Sapkota et al. 2008; Millanao et al. 2011). Tetracyclines (used for protein inhibition) and quinolones (fast bactericide action) have been found ([6] in Fig. 4) in native species surrounding the salmon net pens of the Chiloe Sea (Soto and Norambuena 2004).

Several chemicals are used to treat sea lice outbreaks, and the indiscriminate use in Chile of some of these products appears to have the potential to increase resistance levels in the lice (Mordue-Luntz and Pike 2002). These products can also affect other crustaceans (copepods) potentially exacerbating the food web disruptions and the risk of HAB (Tett 2008).

Waste Processing

It is estimated that salmon net pens produce an average of 9.5 kg of phosphorous (P) and 78 kg of nitrogen (N) per day per every 1000 kg of salmon in a given cage. From that total amount 60 % of N (46 kg) and 12 % of P (1.1 kg) is transformed in dissolved nutrients ([7] in Fig. 4), and 15 % of N (11.7 kg) and 65 % of P (6.1 kg) is transformed into solid matter sediment ([8] in Fig. 4). The other 25 % of N (19.5 kg) and 23 % of P (2.1 kg) are stored in salmon mass which is then harvested ([9] in Fig. 4). It is well established in the scientific literature that organic waste from salmon farms alters the physiochemical properties and changes the micro-flora biodiversity of benthic sediments (Chopin et al. 2008).

These studies are consistent with those from the Northern hemisphere suggesting that inputs of waste material disrupt benthic ecosystems beneath salmon culture pens (Buschmann and Fortt 2005). Recent improvements in feeding technology have reduced the amount of food waste

introduced to benthic environments, but such advances will be less effective at reducing metabolic waste because the assimilation capacity of salmon is finite (Buschmann et al. 2009).

Long-Term Trade-Offs on the Socio-economic Dimension of Cultural Ecosystem Services

Cultural ecosystem services (i.e., aesthetic, cultural heritage, educational, inspirational, recreation and tourism, sense of place, and spiritual and religious) are impacted by the salmon aquaculture in at least the recreation and aesthetic categories. Here, recreation mainly encompasses the monetary dimension and aesthetical category the socio-cultural dimension.

The monetary dimension includes the non-extractive use value of the seascape which is able to attract tourism, which ultimately may lead to the improvement of social welfare of the population. On the other hand, the socio-cultural dimension embraces the existence value of the seascape/landscape of the indigenous communities and local people who desire to keep a pristine seascape as a legacy for present and future generations.

The coastline and 'seascape' is an important economic asset that attracts visitors for tourism and recreation which may contribute to the general quality of life for people living near the coast. Near- and offshore development projects often raise considerable concern within the local communities that value the natural seascape for its inherent beauty.

The coastal areas of Chiloé hold an amazing and varied scenic beauty with rugged land forms around bays, channels, and fiords with volcanoes in the background. Salmon net pens within the Chiloé Sea are located not far from the shore within bays, channels, and fiords. The salmon net pens occupy an important amount of sea space, which normally degrades the aesthetic value of the seascape or landscape. Location of the net pens has neither been regulated in terms of scape impact, nor minimized the visual impact searching for areas where the topography may provide a viewshed.

Figure 5 shows the visual impact of the salmon net pens in Chiloé by using the InVEST Aesthetic Quality model (Tallis et al. 2013). We used the classification of Jenks natural breaks (see the [ESM](#) for detailed definition), which ArcGIS is able to optimize automatically. The viewshed was delineated with a 5 km buffer from the shore to land. Each pixel within the viewshed represents 0.4 km², giving a total area of 5690 km². The results of using the InVEST model indicates that 44.8 % of net pens had no visual impact, 20.7 % belong to low visual impact, 12.2 % to low-medium visual impact, 11.8 % to medium-high visual impact, and 10.5 % to high visual impact. Overall, the

Fig. 5 Aesthetic quality impact on landscape and seascape in the coastal fringe of the Sea of Chiloé. The visual impact is measured as follows: the visual impact ranges from low visual impact to high visual impact 0 to 4, being low visual impact scored between 1 and 2 for net pens, low-medium visual impact with an score between 2 and 4 net pens, medium-high 4 to 7 net pens, and high visual impact 7 up to 54 net pens. *Source* own elaboration from the InVEST Aesthetic Quality model

amount of viewshed degraded is 55.4 %, and it is a noticeable higher intensity of impact on the Reloncaví Sound, Hornopirén, and Chaitén communities, which is the area holding higher degree of natural seascape quality (Fig. 5).

Spatial Analysis at Municipality Scale of Human Wellbeing Indicators

Data available at the municipality scale from the survey of socio-economic characterization (CAsEN) of the Ministry

of Social Development has been used to spatially map some selected indicators to measure the level of human wellbeing at municipality scale in the 2000–2010 period. The selected indicators of human wellbeing represent 3 of the 5 constituents of human wellbeing: safety and security, living standards, health and freedom of choice and opportunity¹. It is important to highlight that while the living standards constituents (average income, precarious sanitation, and precarious housing) has been improved in almost all the municipalities, the safety and security (criminal complaints and socio-economic vulnerability) and freedom of choice and opportunity (average years of schooling and income inequality) constituents has experienced a deterioration in all municipalities.

Safety and Security

Intense socio-economic vulnerability is high in Calbuco, Cochamó, and Quemchi municipalities where the percentage of direct employment from salmon aquaculture is 19, 55, and 17 %, respectively in 2010 (Fig. 6). As a result, the contribution of the salmon aquaculture industry to improve the safety and security conditions of people is still low. This vulnerability can also lead into poverty in the case of any ecological or financial crisis, as the ISA outbreak occurred in 2007. The likelihood of a new crisis is high due to the lack of human and technological capacity to control such type of abrupt (but predictable) social–ecological change, together with the shrinkage of regulating ecosystem services.

In addition, data of total criminal complaints is also used to evaluate physical security and safety of the population. According to data from the Ministry of Social Development (2010), the total number of criminal complaints in 13 of 15 (Hualaihué has the same level of criminal complaints in both years) municipalities analyzed increased between 2005 and 2010 (Fig. 6).

Living Standards

Three components of living standards have improved during the 2000–2009 period. In terms of precarious sanitation, apart from Calbuco, Castro, Dalcahue, Puerto Montt, and Quinchao's municipalities which did not improve their standards, the rest of them (8) did improved significantly in the these years. Precarious housing follows a similar pattern with most (9) of municipalities improving their standard, Castro and Puerto Montt shows no changes and Calbuco and Cochamó presents worse conditions over

time. The average income has also increased in all the municipalities (except Quemchi which remains at the same level).² However, this increase seems not to be far enough to reduce the poverty level and the criminal complaints in all municipalities of the region.

Freedom of Choice and Opportunity

In order to analyse this human wellbeing constituent, we consider data of income inequality by estimating the Gini coefficient in all of the municipalities during the 2000–2009 period. Table 4 shows that the inequality increased in the last decade for the municipalities selected, therefore decreasing the freedom of choice and opportunities in the region.

DISCUSSION

Temporal trade-offs of ecosystem services caused by the salmon aquaculture are manifested by (a) growth of provisioning ecosystem services, (b) shrinking of regulating ecosystem services, (c) reduction of supporting ecosystem services and biodiversity, and (d) decrease of cultural ecosystem services.

As a consequence of shrinking of supporting ecosystem services, the resilience of the social–ecological system is reduced as well as the ability of the community to deal with the three fundamental components of human wellbeing. Thus, the social–ecological system becomes more vulnerable to any change or crisis that might take place in the future.

Potential Contribution of Ecosystem Services to Human Wellbeing by Socio-economic Factors

The Increase of Provisioning Ecosystem Services

In theory, provisioning ecosystem services are the most important services to effectively deliver human wellbeing because of their potential to contribute to the improvement of the socio-economic conditions of a given coastal area. In terms of management and planning, it is crucial to only allow activities that produce provisioning goods and services with effective contribution to human wellbeing by socio-economic factors.

When increasing provisioning services, a given public policy may improve the standards of living and health as well as the security level of the population. Moreover, the potential contribution due to socio-economic necessities (economic revenues, increase employment, etc.) could be

¹ A detailed explanation of the concepts and relationships among ecosystem services and human wellbeing constituents is given in Fig. S1 of the Electronic Supplementary Material.

² See detailed results in Fig. S2 of the ESM.

Fig. 6 Human wellbeing indicators: safe and security constituents. *Source* own elaboration from data of Ministry of Social Development

high in terms of safety-security and standards of living, and it would have also a low potential to deliver good social relations. However, as described previously, safety and security indicators (poverty incidence and criminal complaints) showed that general improvement of average income seems to be not high enough to reduce the poverty incidence in all municipalities. In addition, the region still remains below the reported average of the country.

On the other hand, the observed socio-economic vulnerability is high for the whole studied area and the criminal complaints indicator increased in almost all municipalities. Nevertheless, in terms of standards of living the spatial results obtained in this study also indicate that the improvement of the average income at least allows the population to diminish the precarious sanitation and the housing sanitation.

Table 4 Gini Coefficient at the municipality scale, and the variation from the two selected years

Municipalities	Gini coefficient		$\Delta 09 - 00$
	2000	2009	
Ancud	0.461	0.401	−0.060
Calbuco	0.470	0.407	−0.063
Castro	0.400	0.414	0.014
Chonchi	0.465	0.543	0.078
Cochamó	0.459	0.603	0.144
Curaco de Vélez	0.427	0.514	0.087
Dalcahue	0.377	0.330	−0.047
Hualaihué	0.414	0.469	0.055
Puerto Montt	0.480	0.517	0.037
Quemchi	0.457	0.527	0.070
Quinchao	0.451	0.492	0.041
Average	0.442	0.474	0.032

Source own elaboration from CASEN (2011)

The Decrease of Regulating Ecosystem Services

The decrease of regulating ecosystem services may impact the potential contribution to the improvement of socio-economic conditions of coastal communities. The study area suffered a biological crisis in 2007, which also triggered a dramatic socio-economic crisis (Gillet and Olate 2010). Thus, the capacity of regulating ecosystem services to improve access to human wellbeing by socio-economic factors can be impacted when regulating ecosystem services decrease.

Regulating ecosystem services are key to deliver human wellbeing constituents in the long term. When the activities of any aquaculture enterprise are decreasing regulating services, the natural capacity of the ecosystem to deliver human wellbeing is being lost. From this trade-off between ecosystem services, it is highly advisable to strongly increase the control of these activities that unbalance the relationship of regulating ecosystem services with provisioning ecosystem services.

The Decrease of Cultural Ecosystem Services

More than half of the coastal landscape and seascapes where the salmon aquaculture is located have been impacted aesthetically. In terms of security and good social relations, seascape aesthetic quality is also important to deliver human wellbeing (Sander and Polasky 2009). Tourism activities depend on the quality of seascape and landscapes to attract local and foreign visitors. Therefore, a reduction of aesthetic quality can put their economic security under siege, also because of degraded landscapes and seascapes are less attractive for investors on spiritual

and natural values (Haggett 2011). In order to efficiently manage resources and avoid the degradation of aesthetic seascape and landscape's viewshed quality, it is crucial to identify hotspots that provide topographically natural view shades to locate the salmon net pens or any other aquaculture infrastructure.

In this study we found that salmon aquaculture is an important consumer of ecosystem services compared to other economic activities in the region such as tourism (Jordan et al. 2012) or traditional small-scale fishing activities.

The consumption of ecosystem services by salmon aquaculture activities creates great wealth opportunities, but the distribution of this wealth is undermining the delivery of human wellbeing. Salmon aquaculture has indeed contributed to improve the material constituents of the human wellbeing, especially in terms of average income, poverty alleviation, precarious sanitation, and precarious housing.

Besides, the cost on regulating ecosystem services may limit the access to other ecosystem services and goods, and may also create conflicts with other important economic activities such as artisanal fishing or eco-tourism.

The conceptual approach adopted in this study elucidates where it is necessary to concentrate the planning and management efforts in order to transform the weak Chilean regulatory framework in a more equal, sustained and fair legal one. Taking into account that municipalities hold a substantial amount of responsibility to deliver wellbeing, the Chilean local administration has the opportunity to level up taxation and at the same time redistributing the socio-economic benefits derived from aquaculture. This measure may influence positively on the improvement of human wellbeing constituents at the municipality scale.

We accept the hypothesis previously launched, confirming that regulating and cultural ecosystem services have been degraded in change of provisioning services at the local scale. It is important to highlight that the environmentalist paradox³ (Raudsepp-Hearne et al. 2010) need to be address at the finer scale (Duraiappah 2011). This study provides a context-specific and local scale contribution to untangling the environmentalist paradox, confirming that at the local scale (municipality), ecosystem services are degrading while the human wellbeing is also declining (apart from living standards).

Finally, it is important to highlight some limitations of the study related to the availability of accurate data. Firstly, although most of the relevant socio-economic impacts of the provisioning ecosystem services have been quantified at the municipal scale, the valuation of the socio-economic

³ Which is commonly known as the improvement of human wellbeing while, at the same time, ecosystem services are being degraded.

impact on regulating and cultural ecosystem services is far from being fully understood. Secondly, while employment data was used to show the role of salmon aquaculture in the labor market, indirect multiplier effects of the activity is at this moment difficult to quantify. Thirdly, the temporal available series of data used for some of the human well-being constituents may be not large enough to have a full understanding of the contribution of salmon aquaculture in the Sea of Chiloé. However, the qualitative information from the interviews made to the representatives of the sector accurately confirms the results presented in the study.

Under these circumstances, future research efforts need to be intended to tackle the mentioned limitations as well as to integrate other types of aquaculture (mussels, abalone, and seaweed) on the ecosystem services framework, to quantify biophysical pressures and aesthetical impact on landscape and seascape and to model the impacts of climate change on the entire value chain of the aquaculture industry.

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REFERENCES

Asencio, G., J. Carvajal, and M.T. González. 2008. Following in Colaco Bay: Searching for environmental indicators. In *7th International Sea Lice Conference*, Puerto Varas, Chile, 7 pp.

Baneerjee, A., and E. Dufflo, E. 2011. *Poorer economics: A radical rethinking of the way to fight global poverty*, 303 pp. New York: Public Affairs.

Barton, J., and A. Floysand. 2010. The political ecology of Chilean salmon aquaculture, 1982–2010: A trajectory from economic development to global sustainability. *Global Environmental Change* 20: 739–752.

Bennett, E.M., G.D. Petterson, and L.J. Gordon. 2009. Understanding relationships among multiple ecosystem services. *Ecology Letters* 12: 1394–1404.

Bravo, S., M. Nuñez, and M.T. Silva. 2013. Efficacy of the treatments used for the control of *Caligus rogercresseyi* infecting Atlantic salmon, *Salmo salar* L., in a new fish-farming location in Region XI Chile. *Journal of Fish Diseases* 36: 221–228.

Buschmann, A., and A. Fortt. 2005. Efectos ambientales de la acuicultura intensiva y alternativas para un desarrollo sustentable. *Revista Ambiente y Desarrollo* 21(3): 58–64.

Buschmann, A.H., V.A. Riquelme, M.C. Hernández-González, D. Varela, J.E. Jiménez, J.A. Henríquez, P.A. Vergara, R. Guíñez, et al. 2006. A review of the impacts of salmonid farming on marine coastal ecosystems in the southeast Pacific. *ICES Journal of Marine Science* 63: 1338–1345.

Buschmann, A., F. Cabello, K. Young, J. Carvajal, D.A. Varela, and L. Henríquez. 2009. Salmon aquaculture and coastal ecosystem health in Chile: Analysis of regulations, environmental impacts and bioremediation systems. *Ocean Coastal Management* 52: 243–249.

Cardinale, B.J., J.E. Duffy, A. González, D.U. Hooper, C. Perrings, P. Venail, A. Narwani, G.M. Mace, et al. 2012. Biodiversity loss and its impact on humanity. *Nature* 486: 59–67.

Carpenter, S.R., H.A. Mooney, K. Agard, D. Capistrano, R.S. De Fries, S. Díaz, T. Dietz, A.K. Duraipappah, et al. 2009. Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proceedings of the National Academy of Sciences of the United States of America* 106(5): 1305–1312.

CASEN. 2011. Ministerio de Desarrollo Social, División Social, Encuesta CASEN. Retrieved March 11, 2013, from <http://www.ministeriodesarrollosocial.gob.cl/observatorio/casen/>.

Chopin, T., S.M.C. Robinson, M. Troell, A. Neori, and A.H.J. Fang. 2008. Mariculture waste management. In *Ecological engineering. Encyclopedia of ecology*, vol. 3, ed. S.E. Jørgensen, and F.B. Fath, 2211–2217. Oxford: Elsevier.

Daw, T.K., S. Rosendo Brown, and R. Pomeroy. 2011. Applying the ecosystem services concept to poverty alleviation: The need to disaggregate human well-being. *Environmental Conservation* 38(4): 370–379.

Deutsch, L., S. Graslunda, C. Folke, M. Troell, M. Huitric, N. Kautsky, and L. Lebel. 2007. Feeding aquaculture growth through globalization: Exploitation of marine ecosystems for fishmeal. *Global Environmental Change* 17: 238–244.

Díaz, E. 2009. Operarios y operarias de las plantas de proceso de la industria del salmón: Estudio de remuneraciones. Dirección del Trabajo. Gobierno de Chile. Santiago de Chile, Chile, 73 pp.

Duraipappah, A.K. 2004. *Exploring the Links: Human well-being, poverty and ecosystems*, 44 pp. Nairobi, Kenya: United Nations Environment Programme.

Duraipappah, A.K. 2011. Ecosystem services and human well-being: Do global findings make any sense? *BioScience* 61(1): 7–8.

FAO (The Food and Agriculture Organization of the United Nations). 2012. *State of the World's Fisheries and Aquaculture 2012*, 209 pp. Rome, Italy: FAO.

FIP (Fondo de Investigación Pesquera). 2005. Diagnóstico económico y social de la acuicultura en Chile N°2002-24. Final report I Coquimbo, Chile, 783 pp.

Gillet, J., and C. Olate. 2010. *La crisis del salmón y el desempleo en la décima región*. Seminario de título Ingeniero comercial. Mención economía Facultad de Economía y negocios. Santiago de Chile, Chile: Universidad de Chile, 121 pp.

Haggett, C. 2011. Understanding public responses to offshore wind power. *Energy Policy* 39: 503–510.

INE (Instituto Nacional de Estadística). 2008. Estudio de mercado acuícola. Región de Los Lagos. Dirección Regional INE, Unidad Técnica. Puerto Montt, Chile, 95 pp.

Jordan, S.J., T. O'Higgins, and J.A. Dittmar. 2012. Ecosystem services of coastal habitats and fisheries: Multiscale ecological and economic models in support of ecosystem-based management. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 4: 573–586.

Krkosek, M., J.S. Ford, A. Morton, S. Lele, R.A. Myers, and M.A. Lewis. 2007. Declining wild salmon populations in relation to parasites from farm salmon. *Science* 318: 1772–1775.

Melillanca I., and I. Díaz. 2007. Radiografía a la industria del salmón: bajo la mirada de estándares de RSC. Documentos Red Puentes Chile, Puerto Montt, Chile, 38 pp.

- Millanao, A., M. Barrientos, C. Gómez, A. Tomova, A. Buschmann, H. Dölz, and F. Cabello. 2011. Uso inadecuado y excesivo de antibióticos: Salud pública y salmonicultura en Chile. *Revista Médica de Chile* 139: 107–118.
- Millennium Ecosystem Assessment (MEA). 2005. *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press.
- Montero, C. 2004. *Formación y desarrollo de un clúster organizado. El caso de la industria del salmón en Chile*. Comisión Económica para América Latina y Caribe. Red de reestructuración y productividad. Naciones Unidas, Santiago de Chile, 75 pp.
- Mordue-Luntz, A.J., and A.W. Pike. 2002. Salmon farming: Towards an integrated pest management strategy for sea lice. *Pest Management Science* 58: 513–514.
- Raudsepp-Hearne, C., G.D. Peterson, M. Tengö, E.M. Bennett, T. Holland, K. Benessaiah, G.K. MacDonald, and L. Pfeifer. 2010. Untangling the environmentalist's paradox: Why is human well-being increasing as ecosystem services degrade? *BioScience* 60: 576–589.
- Rozas, M., and G. Asencio. 2007. Evaluación de la situación epidemiológica de la caligiasis en Chile; hacia una estrategia de control efectiva. *SalmoCiencia* 2: 43–59.
- Rupasingha, A., S.J. Goetz, and D. Freshwater. 2006. The production of social capital in US counties. *Journal of Socio-Economics* 35(1): 83–101.
- Salomon, A.S., S. Gaichas, O. Jensen, V. Agostini, N. Sloan, J. Rice, T.R. McClanahan, M.H. Ruckelshaus, et al. 2011. Bridging the divide between fisheries and marine conservation science. *Bulletin of Marine Science* 87: 251–274.
- Sander, H.A., and S. Polasky. 2009. The value of views and open space: Estimates from a hedonic pricing model for Ramsey County, Minnesota, USA. *Land Use Policy* 26(3): 837–845.
- Sapkota, A., A.R. Sapkota, M. Kucharski, J. Burke, S. McKenzie, P. Walker, R. Lawrence, et al. 2008. Aquaculture practices and potential human health risks: Current knowledge and future priorities. *Environment International* 34: 1215–1226.
- Smith, L., J.L. Case, H.M. Smith, L.C. Harwell, and J.K. Summers. 2013. Relating ecosystem services to domains of human well-being: Foundation for a US index. *Ecological Indicators* 28: 79–90.
- Soto, D., and F. Norambuena. 2004. Evaluation of salmon farming effects on marine systems in the inner seas of southern Chile: A large-scale mensurative experiment. *Journal of Applied Ichthyology* 20: 493–501.
- Soto, D., F. Jara, and C.A. Moreno. 2001. Escaped salmon in the inner seas, southern Chile: Facing ecological and social conflicts. *Ecological Applications* 11: 1750–1762.
- Tacon, A., M. Metian, and M.R. Hasan. 2009. Feed ingredients and fertilizers for farmed aquatic animals. Sources and composition. FAO Fisheries and Aquaculture technical paper No. 540. FAO, Rome, Italy, 210 pp.
- Tacon, A., M. Metian, G.M. Turchini, and S.S. De Silva. 2010. Responsible aquaculture and trophic level implications to global fish supply. *Reviews in Fisheries Science* 18: 94–105.
- Tallis, H., and S. Polasky. 2009. Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. *Annals of the New York Academy of Sciences* 1162: 265–283.
- Tallis, H.T., T. Ricketts, A.D. Guerry, S.A. Wood, R. Sharp, E. Nelson, D. Ennaanay, S. Wolny, et al. 2013. InVEST 2.5.5 User's Guide. The Natural Capital Project, Stanford, California, 352 pp.
- Tett, P. 2008. Fish farm wastes in the ecosystem. In *Aquaculture in the ecosystem*, ed. M. Holmer, K. Black, C.M. Duarte, N. Marbán, and I. Karakassis, 46 pp. The Netherlands: Springer.
- Thorstad, E.B., I.A. Fleming, P. McGinnity, D. Soto, V. Wennevik, and F. Whoriskey. 2008. Incidence and impacts of escaped farmed Atlantic salmon (*Salmo salar*) in nature. NINA Special Report 36, 110 pp.
- Valdés-Donoso, P., F.O. Mardones, M. Jarpa, M. Ulloa, T.E. Carpenter, and A.M. Perez. 2013. Co-infection patterns of infectious salmon anaemia and sea lice in farmed Atlantic salmon, *Salmo salar* L., in southern Chile (2007–2009). *Journal of Fish Diseases* 36: 353–360.
- Villasante, S., F. González-Laxe, M.C. García-Negro, and G. Rodríguez-Rodríguez. 2011. Overfishing and the Common Fisheries Policy: (un)Successful results from TAC regulation? *Fish and Fisheries* 12(1): 34–50.

AUTHOR BIOGRAPHIES

Luis Outeiro (✉) is a postdoctoral researcher (PhD in Physical Geography) from the CONICYT-Chile at the Universidad de Los Lagos, Osorno, Los Lagos. His research interests include ecosystem services, marine resources management, marine ecology, marine and coastal socio-economics, landscape and seascape management and planning, spatial modeling, global and climate change impact. Address: Universidad de Los Lagos, Campus de Osorno, Pabellón Lago Yelcho, Osorno, Los Lagos, Chile. e-mail: loureiro@gmail.com

Sebastian Villasante is a Researcher and Professor (PhD in Economics) at University Santiago de Compostela and and Researcher Associated at CENPAT (CONICET). Address: Faculty of Economics and Business Administration, University of Santiago de Compostela, Av. Burgo Naci3ns s/n, 15782 Santiago de Compostela, A Coruña, Spain. Address: Campus do Mar, International Campus of Excellence, Vigo, Spain. Address: Centro Nacional Patag3nico (CENPAT), CONICET, Puerto Madryn, Argentina. e-mail: sebastian.villasante@usc.es