Title: Enforcing aquaculture facilities location through remote sensing and in situ techniques in Chilean Patagonia marine region.

Keywords: Aquaculture, Synthetic Aperture Radar (SAR) images, Location enforcement, Compliance.

Authors: Hugo Ramírez[1], Gonzalo Sepúlveda[1], Kay Bergamini[1, 2], Carlos Sierralta[1] & Juan Eduardo Johnson[1].
1: Superintendence of the environment. 2: Environmental consultant

Abstract
Chilean coastal Patagonia has a coastline of 84.000 km long and is a favorable region for salmon and mussel sea farming. These aquaculture activities require environmental licenses to operate due to their potential environmental impact. The Superintendence of the environment is the institution in charge of enforcement and compliance in Chile, including enforcement of aquaculture activities. To accomplish that task, with an industry that has about 3.400 operational facilities in such vast region, the Superintendence has implemented a practical method for detection of location authorization unconformities. The method allowed the Superintendence to efficiently detect 6 cases of unconformities in spatial location, thereby inducing environmental enforcement to the industry.

1. Introduction

In 2010, the Law N° 20.417 created the Superintendence of the Environment (Spanish Acronym: SMA), which is the agency in charge of environmental enforcement and compliance in Chile. SMA enforces commitments and standards listed in an environmental license, which is given to a project proprietor by a Environmental Assessment Committee after impact assessment (IA) is carried out. The environmental licenses are classified according to the type of activities they were given for, and one type of these activities is aquaculture.

In the southern region of Chile, aquaculture industry has found a suitable place for its requirements because of the area's geographical particularities. Chile´s Patagonia coastal region extends from 41.51°S (Reloncaví Fjord) to 55.91° S (Cape Horn), covering 240,000 km^2 and this coastal geography is composed largely by islands, channels and fjords (Pantoja et al. 2011). In this vast region, the aquaculture industry has preponderance and operates mostly salmon and mussel farms.

The aquaculture industry has notorious environmental impacts, including decrease of oxygen concentration in water column and oxygen-reduced sediment affected by fecal material and unconsumed food pellets (Buschmann et al. 2009), structural solid remains (i.e. fish cages, nets and others), fish farm structures, use of cleaning and sterilizing substances and use of other chemical substances for disease and parasite control.
Nowadays, there are around 3.400 aquaculture facilities approved and the number is increasing (SERNAPESCA, 2013), most of them concentrated in southern Chile. Furthermore, it is very expensive to enforce compliance in aquaculture facilities, due to logistics and transportation.

All these projects related to farms implementation and operation require environmental licenses prior to construction, and the SMA could lately inspect their corresponding facilities and activities. One of the most important issues regarding environmental compliance is the location authorization of these farms. Each authorization includes literally the vertexes of the permitted activity area. The SMA is implementing a strategic environmental enforcement approach, being one of its objectives the reduction of high expenses but also the coverage of every particular project in Chile.

Through Synthetic Aperture Radar (SAR) satellite images the SMA is detecting unconformities in salmon farm cages location in an affordable and always possible way, no matter the weather conditions or diurnal and nocturnal period. In just one swath with a SAR scene is possible to detect large numbers of cages as well as the location of the structures, making possible a comparison with authorized polygons using geographic information systems (GIS). This method has been used for similar applications such as inventory and monitoring of coastal aquaculture and fisheries structures, providing important baseline data for decision-making in fisheries planning and development (Travaglia et al. 2004).

Due to geographical area isolation, and difficult logistic procedures the SMA has developed a strategic plan for inspection activities in order to cover this particular industry. With this method, SMA detected spatial location unconformities of several aquaculture facilities. That information was used by the SMA to carry out some *in situ* inspections and also the respective analyses of geographic information for those non visited projects.

In order to validate the strategic plan for inspections, a salmon farm located in Quillaipe, at Reloncaví Sound area, was selected for an *in situ* inspection. The project was situated 35 Km away from the main city of Puerto Montt. The combination of satellite and *in situ* GPS data led to formulation of charges against the permit holder, because of its inappropriate location. The evidences were sufficient to establish new commitments in location.

2. Methodology

The first approach to the Study Area was made using a set of images from ENVISAT ASAR and ALOS PALSAR satellites, both of them in IMAGE MODE to test the usability of SAR technology and to identify the structures involved in Aquaculture industry. As background, monitoring projects were conducted in South East Asia (Steckler, 2003; Travaglia, 2007) using RADARSAT-1. Since the results were satisfactory, in January 2013 the SMA bought three TerraSAR-X scenes of the Chacao Channel and Reloncaví fjord area, both situated in Los Lagos Region in southern Chile.

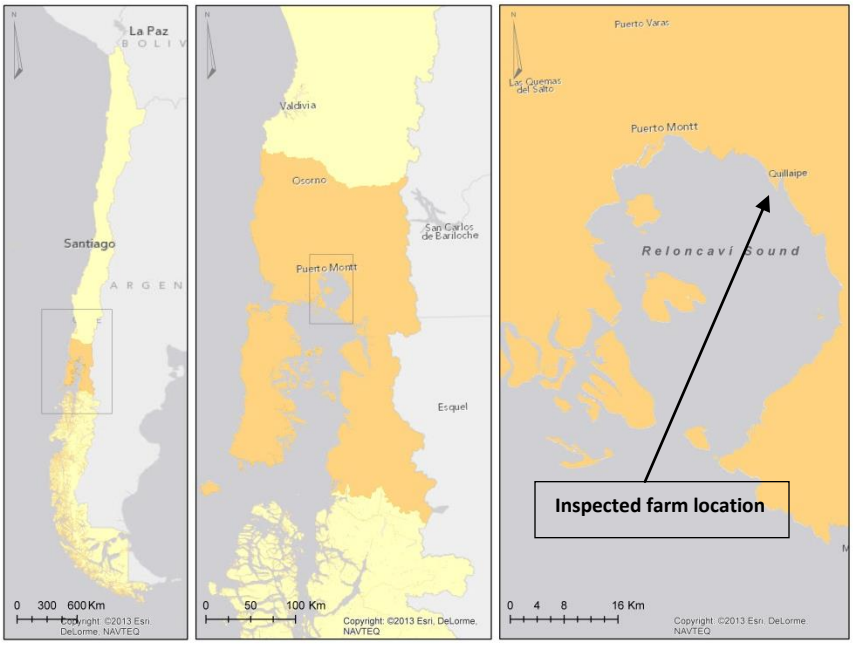
Afterward, aquaculture projects were collected to cross check it with SMA inspection prioritization plan and the projects listed in the corresponding environmental license in order to identify the legitimate marine polygon's vertexes. The information of Approved Area for Aquaculture (SUBPESCA, 2014), which is the marine territory where is permitted to carry out fish and mussel farming, was also reviewed. In order to avoid false positive cases, only records with approved environmental license and presenting infrastructure out of location authorizations limits detected by the SAR images were confirmed.

In situ inspection

In January 2013, on board of a driven vessel, an inspection was carried out at Quillaipe, located 35 km southeast from Puerto Montt, in the Reloncaví fjord area (Figure 1). The inspectors of the SMA used Trimble Nomad GPS 900GXC technology. The tracks recorded where corrected using Pathfinder Office software 5.40. Five (5) previously planned auditing stations where visited in two days of inspection.

Visual spatial analysis was carried out contrasting the geographical and spatial information available and collected in Nepassist GIS system (SMA, 2013), including: site authorized polygons and GPS information taken during the inspection. Figure 1 shows the general and local situation of the inspected fish farm.

Figure 1.- General and local situation of the fish farm inspected in Quillaipe.



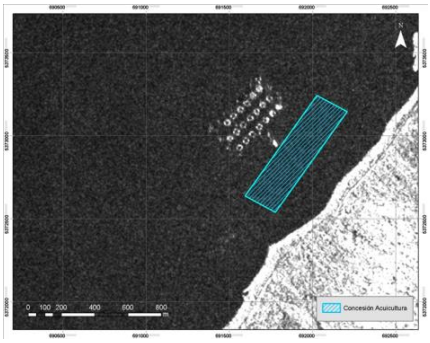
3. Results

Satellite image and location authorizations

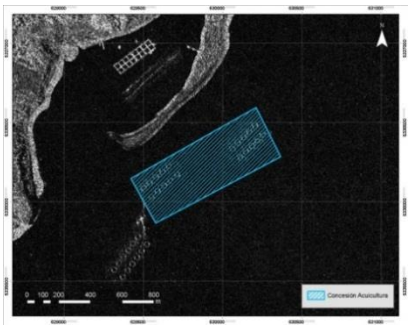
From the identification of legitimate marine polygon's vertexes, a number of eleven projects, including fish farms and mussel farms, presented differences between actual spatial location and location authorizations. Such unconformities are related to infrastructure situated out of permitted limits, corresponding mostly to fish cages (Table 1). In cases 3 and 6 none of the cages where actually inside the polygon. Furthermore, in terms of area coverage, in cases 1, 5 and 6 the detected total area used by the structures was larger than the approved areas. The Fisheries Office of Chile (SERNAPESCA) has implemented a category system to group the farms in an environmentally perspective; using the tons of biomass produced and cages depth. That categorization enforces environmental follow up monitoring under farming operations (e.i. oxygen concentration, sediment Red-ox index, benthic community ecology index, and others; SERNAPESCA, 2013). It is important to point out that inspected fish farms were currently under operation and most of them are situated in areas less than 60 m depth presenting sedimentary benthic substrate (listed as Category 3). Cases 3 and 6 consist in farms situated in areas over 60 m depth (Category 5), and cases 1 and 2 contain mussel farms also.

Another detected unconformity was the distance found between the polygon limits and the farm structures (i.e. cages, pontoon or buoys), confirmed later using GIS. Examples of detected cases are shown in Figure 2. The images help to understand the level of unconformity in terms of distance, area coverage and number of structures or platforms. The distance range detected by the method presented varies from 100 m to 800 m long.

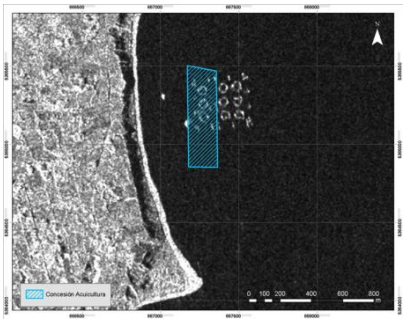
Figure 2.- Cases detected post filtering. The polygons in blue are the areas of concession approved by authorities.



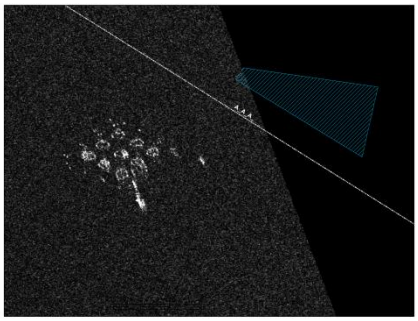
a. Case 3



b. Case 5



c. Case 1



d. Case 6

Table 1.- Main unconformities detected after examination of SAR images and GIS or GPS data .

Aquaculture Concession	Environmental Information Category	Fish Cages Approved (N°)	Fish Cages out of limits (N°)	Area Approved (m^2)	Total Used Area Detected (m^2)	Mussel Lines out of limits (N°)	Farthest distance to polygon (m)	Platform out of limit (N°)
1	3	20	6	154	471	-	204	1
2	1 & 3	76	18	527.200	62.203	-	136	-
3	3 & 5	20	20	148.200	47.864	-	260	2
4	2	-	-	37.500	-	4	200	-
5	3	40	12	28.274	85.053	-	382	2
6	5	9	9	113.900	139.265	-	800	2

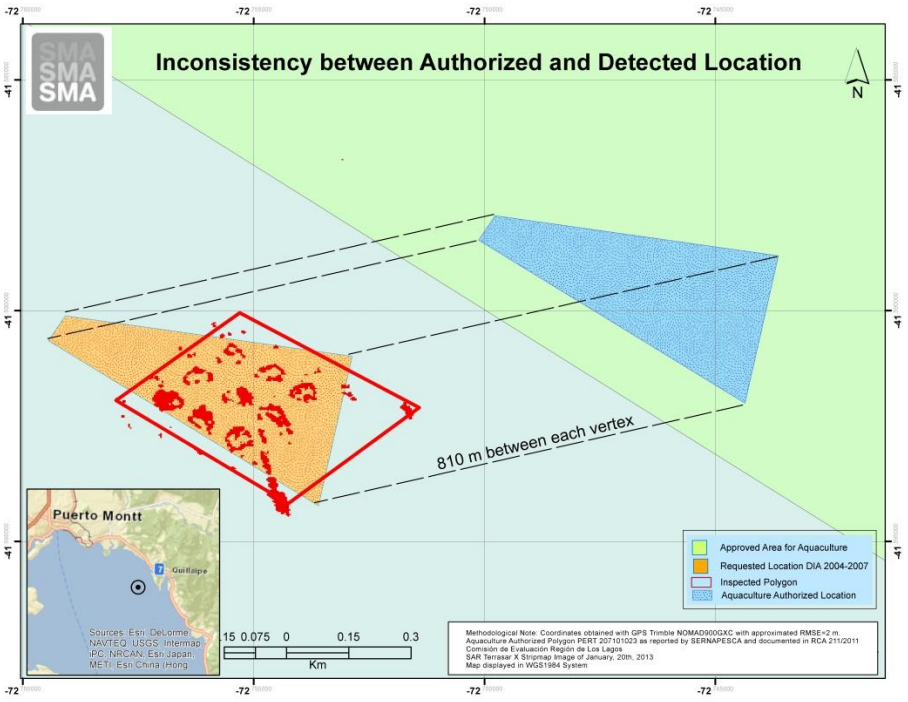
In situ inspection

The inspection at Quillaipe (Case 6 in Table 1) confirmed a fish farm facility composed of 9 circular cages covering 20 m depth and 40 m in diameter, a pontoon of 40 m long and mortality storing platform facilities. The amount of total fish biomass is 4.428 tons and at the moment of the inspection the fish were harvested.

This project originally was environmentally assessed at a mean depth of 160 m (maximum of 196 m) and the area of the concession required to operate was 110.390 m^2. After the inspection, the depth was measured between 220 m and 277 m, and the farm area coverage was confirmed to be 139.265 m^2. The project was

situated 810 m away from the authorized concession area and also was located outside the limits of the Approved Area for Aquaculture (AAA). The spatial analysis is detailed in Figure 3.

Figure 3.- Inconsistency detected between authorized location (blue polygon) and the fish farm structure spatial situation (red square).



Sanctions and penalization

The SMA Sanctions Processes Unit (UIPS) determined through the approval of a Compliance Program that: (i) The fish cages, platforms and other structures must be relocated to the approved area, and (ii) the permit holder must provide a final report of the relocation as a corroboration standard, immediately after the operations take place.

4. Conclusions:

The methodology used by the Superintendence of the Environment (SMA) demonstrated that combining the work of strategic environmental compliance and remote sensing technology, such as Radar images, GIS and GPS *in situ* data, has strong capabilities in terms of enforcing compliance in large and difficult access areas. The method also brings new data for further environmental analysis, such as water and sediment quality conditions, hydrodynamic prediction models of fecal and non-consumed food pellets deposition, and other impacts related to aquaculture activities (oxygen depletion, pesticides and other chemicals use in the industry).

With the applied methodology, the Superintendence provides a strong dissuasive power to the institution. This concept has been evidenced by the articles publish by the Chilean press, after sanctions processes held in 2013 (Aqua 2013; La Tercera 2013).

5. References

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