Life Cycle Assessment of southern pink shrimp products from Senegal. An environmental comparison between artisanal fisheries in the Casamance region and a trawl fishery off Dakar including biological considerations.

A. Emanuelsson[1, 2] (ae@sik.se), A. Flysjö[1], M. Thrane[3], V. Ndiaye[4], J. L. Eichelsheim[5], F. Ziegler[1,*]

1) SIK, Swedish Institute for food and Biotechnology 2) University of Gothenburg, Sweden 3) Aalborg University, Dep. of Development and Planning 4) CRODT, Senegalese Oceanic Research Centre 5) IDÉE Casamance, NGO, Senegal

Keywords: Artisanal, carbon footprint, developing country, discard, *Penaeus notialis*, Senegal, trawl.

Abstract

Life Cycle Assessment of two Senegalese seafood products exported to Europe was performed based on the functional unit (FU) of one kilogram of product (frozen whole shrimps) plus the accompanying package at the point of import to Europe. One product is produced by on-board processing demersal trawlers based in Dakar. The other production chain starts with the fishery in the Casamance river in southern Senegal were fishing is conducted by two different artisanal fisheries. Major differences between the three fisheries included (trawl, mujas and félé-félé) were shown using both classical environmental impact categories and extended biological ones, related to the FU (bycatch, discard, undersized target catch and seafloor disturbance). For the product originating from trawling, the fishing stage was the most important activity for all the investigated impact categories with high values for all biological categories except the undersized target catch. For the product originating from the artisanal fishery, processing and storage dominated most environmental impact categories, but with an overall lower impact load than the industrial trawl. However, high rates of smallsize target catch and lower but significant bycatches were documented for the artisanal fisheries. Finally, improvements options are discussed, and authors conclude that an increased traceability and labelling is desirable to make active consumer choices possible

Introduction

The main aim of the present study was to quantify the environmental impacts caused by a Senegalese shrimp product from fishing to market by performing a Life Cycle Assessment (LCA) of the artisanal fishery for southern pink shrimp (*Penaeus notialis*) in the Casamance region. Secondary aims were to compare the different fishing methods (artisanal and industrial) from an environmental point of view. Biological effects of the different fishing methods were included in the analysis and an additional goal was to attempt to quantify a few socio-economic indicators. This study was carried out as a collaboration between the Fisheries and Aquaculture Department at the Food and Agricultural Organization of the United Nations (FAO), the Swedish Board of Fisheries, the Swedish Institute for Food and Biotechnology (SIK), IDEE Casamance and Centre de Recherches Oceanographiques Dakar-Thiaroye (CRODT). The biological part of the study also resulted in a B.Sc. thesis where that part is presented in more detail Emanuelsson (2008).

The southern pink shrimp (*Penaeus notialis*) occurs in estuaries and coastal waters of West Africa from Mauretania to Angola, where it inhabits muddy sand bottoms at depths ranging from 2-100m. The shrimp stock occurring in the Casamance estuary has its spawning grounds in the sea off the coast of Senegal and Guinea Bissau. After hatching and metamorphosis to various larval stages in the sea, juveniles migrate upstream in shallow areas of the river to feed and grow in the nutrient-rich mangrove areas that are found along the entire river. Three months later, adult shrimps migrate back to the sea in the central and deepest part of the river to spawn. (Lhomme 1984). While the fishery takes place all year round, landings peak in September-November after the rainy season in June to September.

There are mainly two artisanal fishing methods in use today:

Félé-félé. Drift nets used in intermediate parts of the river, around 120 m long and 1-2 m deep with 12 mm meshes (24 mm when stretched), trailed by canoes and actively managed by three men.

Mujas. Stow net pairs of filtering trawl-like nets placed by one man on each side of an anchored canoe in the deepest part of the river during low tide, i.e. the fishery is powered by the tidal current that brings in the large shrimps migrating towards the sea.

The shrimp fishery in the Casamance is theoretically regulated by a system of fishing permits, by a minimum stretched mesh size of 24 mm and by a ban on pull nets and the capture, possession and trading of shrimps smaller than >200 individuals /kg. The Dakar-based fisheries are more large-scale. Vessels are diesel-driven and demersal trawls are used by the around 30 trawlers active in this fishery. The boats are out fishing for about 25 days. Fishing goes on all year, so a vessel can make around 10 mares a year. Most vessels are owned by foreign, European, companies. Reported landings in the Casamance varied between 800 and 1.200 tonnes between 2000 and 2006 (IDEE Casamance 2007). Total artisanal pink shrimp landings (including the Casamance region) represent on average 60% of total pink shrimp landings in Senegal which varied between 2.500 and 3.600 tonnes between 2004 and 2006. Consequently, around 40%, or 1.100-1.600 tonnes are fished in the trawl fishery described below (DPCA, Diarra Dioup unpubl.). No estimates of CPUE in the Casamance fisheries have been documented so far. However CPUE at sea, i.e. in the trawl fishery, decreased by over 90% between 1970 and 2005 (UNEP 2002, Samb et al 2007). Decreasing CPUE has also been documented recently for the five most commercially important species by the Senegalese oceanic research centre CRODT, which all can be found in the shrimp bycatch (Samb et al 2007) Seasonal variation occur with two peak catches, the largest one after the rain season (September-Oktober), implying to cohorts and recruitment periods (Matthews et al 2006)

Method / Approach

System boundary

The studied system starts with production of supply materials for the respective fisheries, e.g. fuel and gear material. Fishing is presumed to be undertaken by félé-félé and mujas nets[1] (50% each with regard to *total* landings) due to the low importance of xuus nets in total shrimp landings. In the case of the artisanal fishery, the shrimps are landed in the villages along the rivershore, where they are bought and transported by traders to the processing plants in Ziguinchor by a pick-up, cleaned and deep frozen before transport via warehouse to the port in Dakar. The study ends at the point of import, i.e. no further transport, storage, preparation or waste treatment is included, mainly due to the lack of data and the fact that the chains to be compared are identical from the point of export. The transport to Europe was included (even though it is the same in the two chains) as the role of long-distance food transports is often debated. In the case of the trawl fishery, processing, including packaging, is done at sea. The products are landed and taken for storage in Dakar where they are stored for, on average, 1-2 months. From there, the same type of transport on container freighters takes the product to the European market. The main market for shrimp product from trawl fisheries are Greece, Portugal and France.

[1] Xuus nets are not considered in the assessment because of the low importance for total shrimp landings

Functional unit

The functional unit in the present study is ***one kilogram of frozen, whole, pink shrimps*** packed in a plastic bag inside a cardboard box, delivered to the port of Vigo, Spain. The shrimps originate either in the Dakar-based trawl fishery or in the Casamance artisanal fishery, assumed to be done by equal use of mujas and félé-félé nets with regard to total landings.

Allocations

Allocations were necessary in two cases in this study. In the fishing phase, several species are landed together and the allocation between them has been done on an economic basis. Especially in the trawl fishery, the amount of landed by-catch terms of weight is considerable (88%), while the economic importance of it is much less important (54%). Therefore, it is assumed that the shrimps are the driving force of this fishery rather than the fish that is also landed. In the processing plant, shrimp products are produced from large shrimps.

Data inventory

Data inventory of the foreground system in the Casamance was undertaken by local experts (IDEE Casamance and CRODT) in collaboration with the Swedish-Danish LCA team (SIK and Aalborg University) from November to December 2007. Relevant authorities and organisations were visited and existing documentation regarding the stock and the fishery gathered. Data for the Casamance fishery was collected by visiting fishing villages, interviewing fishermen and inspecting their catches upon landing.

Traders buying shrimps and taking them to the processing plants were also interviewed. Two processing plants in Ziguinchor were visited and technical staff answered questions with regard to production, logistics and the use of e.g. energy, refrigerants, packaging material, freshwater etc. Data for the background system, e.g. production of packaging materials, fuels and transports was taken from database Ecoinvent v.2.0[2]. Electricity production in the Casamance was modelled based on information from the local producer.

In Dakar, the data inventory was undertaken in collaboration with a shrimp biology expert from Centre de Rechereches Oceanographiques Dakar-Thiaroye (CRODT) from December 2007 to January 2008. With regard to the fishery, data from the two largest trawling companies was used. These two companies operate 15 and 4 shrimp trawlers, respectively and so 19 out of the total number of vessels of 30 were covered. Representatives of the companies provided data on landings, fuel use, use of refrigerants and logistics after landing. Information on the composition of different energy sources in average Senegalese electricity production (used in the present study for electricity use in the Dakar region) was found on the website of the International Energy Agency.

Data gathered of 30 landings in two fishing villages (around Ziguinchor and Bangangha, around 20 km upstream from Ziguinchor), constitute the basis for the artisanal biological part of the present analysis. Fishermen were either instructed beforehand to bring the entire catch ashore and sort it into landing and discard there or they were asked to estimate the weight and species discarded. Length distribution of landed shrimps was measured (carapace length) and landed by-catch was identified to species or genus and weighed, as were the landed shrimps.Local authorities' provided data for discard assessments onboard trawlers based on surveillance agreements with Mauretania and also records of total landings by species in terms of mass and economic value. The companies themselves provided length distribution data and boat inspections provided data for the seafloor disturbance calculation. Calculation setup was based on effective opening width with utter board length added, average speed, and average trawling time allocated economically to the yield per trip.

[2] A Swiss life cycle data database.

Method for Impact Assessment

The impact assessment method chosen here is CML 2001 (Guinée 2002) and the categories studied are Global Warming Potential, Acidification Potential, Eutrophication Potential, Photochemical Ozone Creation Potential, Ozone Depletion Potential, Human toxicity, Terrestrial toxicity, Marine Aquatic Toxicity and Terrestrial Ecotoxicity and Energy as these categories were considered to be the most relevant ones for the chains studied. The category Global Warming Potential was updated with the new characterisation factors according to IPCC 2007. For energy the method Cumulative Energy Demand Pré (2007), in SimaPro, developed by Pré Consultants was used. The LCA was carried out in LCA software SimaPro v.7 (2007). In addition to the characterised LCA results, some biological aspects such as under sized individuals, bycatch, discard and seafloor impact are also displayed as biological impact parameters, by quantifying them and relating to the functional unit. Bycatch here is defined as all catch except target catch (*P.notialis*). Discard is defined as "the proportion of catch that is returned to the sea, in most case dead, dying or badly damaged" (Kelleher 2005), i.e a fraction of the bycatch which in not used.

Results

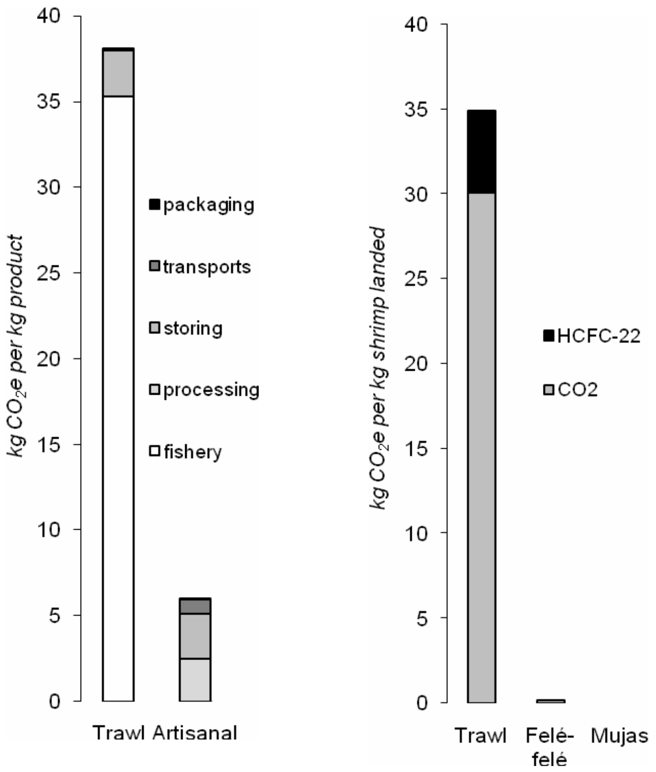

Figure 1: Global Warming Potential caused by a) a kilogram of shrimp product delivered to Vigo and fished either in artisanal fisheries or in the trawl b) only the fishing phase contribution is divided into refrigerants leakage and combustion CO_2 . Note that artisanal HCFC leakage of HCFCs instead are included in processing phase.

As is evident from Figure 1, the difference in Global Warming Potential (GWP) between artisanal and industrial fisheries is enormous due to the use of 9.8 l of diesel fuel and 2.7 g of refrigerant R22 in the trawl fishery as opposed to 0.05 l of fuel and no use of refrigerants in the fishing phase in the artisanal fisheries. It must be kept in mind, though that processing is included in the trawl fishery, which explains part of the difference. Over 35 kg of CO_2e are emitted per kg of shrimps landed in the trawl fishery, 0.2 kg in the félé-félé fishery and no global warming emissions at all in the mujas fishery. When the life-cycle after landing is added, the artisanal product causes emissions of 7.8 kg CO_2e per kg of product and the industrially fished product 38 kg CO_2e per kg. The major contributions to global warming emissions from the artisanal product are caused by energy- and refrigerant-related emissions in processing and storage.

The difference with regard to eutrophication is considerably larger and this category is dominated by emissions of nitrous oxides from combustion of fossil fuels in both chains. In the acidification category, the impact of the industrially fished product is three times higher than the artisanal one. The diesel fuel used in the trawl fishery has a sulphur content (0.4%) only 10 percent of the heavy fuel oil used for electricity production in the Casamance (4%), otherwise the difference would be even greater. The combustion and production of these fuels explain the main part of the acidification caused throughout the chains. Shipment also plays a role. Artisanal fisheries score 50- 60% lower in all toxicity categories with the exception of terrestrial toxicity which is higher for the artisanal product. This is due to the emission of mercury to soil from the batteries used. Many of the toxic emissions also originate from the production of fossil fuels. For the trawlers, the aquatic emissions of copper ions from the anti-fouling paint, accounts for a considerable part of the aquatic toxicity results.

The formation of ozone is largely correlated to the use of gasoline and to the production of fossil fuels: gasoline, diesel as well as heavy fuel oil. Gasoline in the chains studied only occurs in the félé-félé fishery stemming from the use of outboard engines. The diesel is used on the trawler and for transports and heavy fuel oil is used for electricity production. This is the category where transports score highest (almost 20% of the artisanal products emissions).

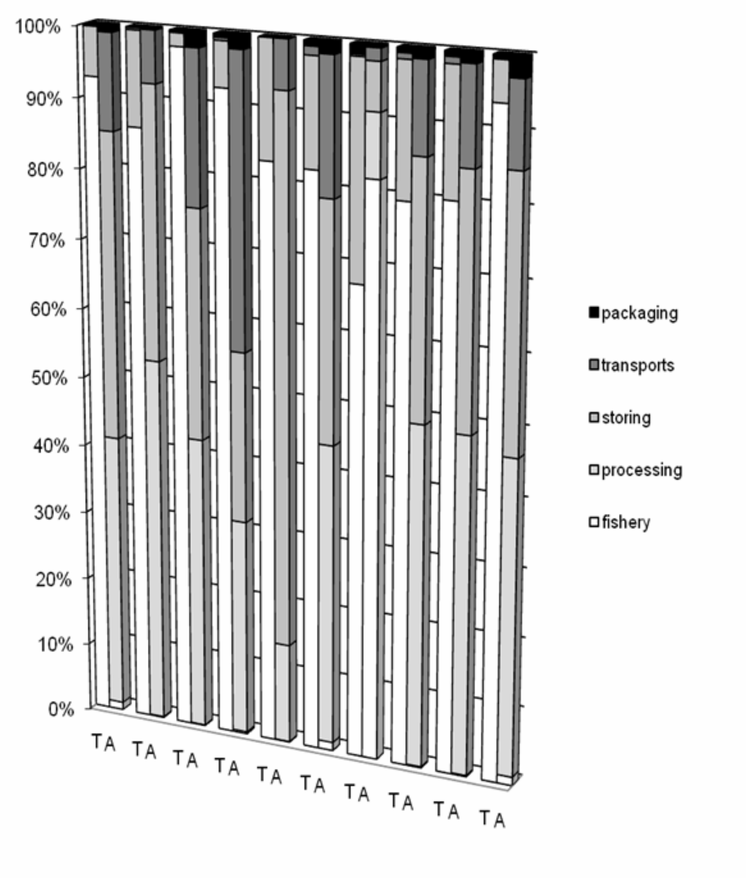

Figure 2: *Relative impact category contribution by product phase in trawl chain (T) and artisanal chain (A). From left: 1) GWP 2) AP 3) EP 4) POCP 5) ODP 6) Human Tox. 7) Terrestrial tox. 8) Tox m.aq. 9) Tox m.sed*

A refrigerant with a high ozone depletion potential, R22, is used both onboard the trawlers and in the processing plant on land. At the processing plant, two refrigerants are used, one for ice-making (R22), of which only the very low amount used for shrimps is allocated to the products and one for freezing and maintenance (R404a) which is entirely allocated to the shrimps. R22 has a high ODP and GWP, while R404a has zero ODP, but an even higher GWP compared with R22. Therefore R22 dominates this category while R404a is important in the category GWP.

Environmental Impact category	Félé-félé fishery	Mujas fishery	Trawl fishery	Data quality/ Uncertainty
Global warming	+ cooling agents, oil-based electricity	+ cooling agents, oil-based electricity	- fuel use in fishing, cooling agents, less oil-based electricity	good data on use of energy and cooling agents in processing and in trawl fishing, rather large uncertainty of fuel use in félé-félé fishery
Eutrophication	+ oil-based electricity	+ oil-based electricity	- NOx from fuel use in fishing	good data on energy use in processing and fishing
Acidification	+ high sulphur fuel oil for electricity	+ high sulphur fuel oil for electricity	- less oil-based electricity, but high fuel use in fishing	good data on energy use in processing and fishing
Aquatic toxicity	+ no anti-fouling	+ no anti-fouling	- anti-fouling	high variation in fuel use data and estimations on emissions and content of copper
Terrestrial toxicity	- mercury batteries	- mercury batteries	+ no mercury batteries	good data on battery use, estimations on mercury content and emissions

Table 1 *Summary of results of comparisons between the three fisheries in the different environmental impact categories included (+ means overall better environmental performance, - means overall less good environmental performance), main factors influencing this result (both positive and negative) in text in each box and an estimate of data quality/variation/uncertainty.*

Biological Impact Categories

A full stock assessment based impact could not calculated because of data deficiency, however size distribution, and relative yield size shows that both fisheries contributes with comparable outtake of resources counted in biomass, whilst the artisanal fishery catches mostly small pre mature individuals and the industrial mostly larger mature individuals. As an LCA biological parameter this can be described as less than 0.1 kg under sized shrimps per F.U. in the industrial case, compared with 1.4kg for Félé-félé and 0,4 kg for Mujas.

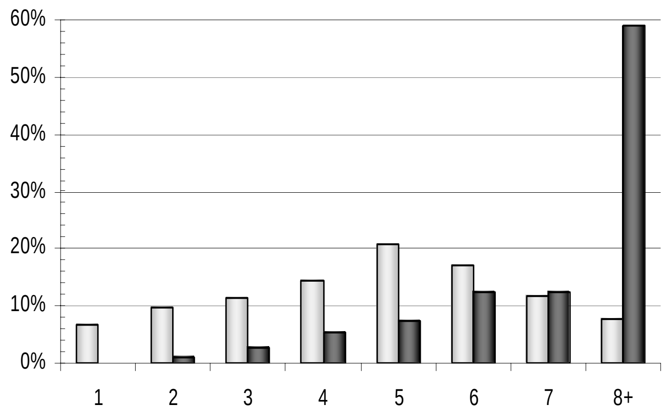

Fig 3 *Size distribution from 2005-2006 by a major company representing 60% of all industrial catches, compared with one out of three artisanal (black) distributor factories active in Casamance in Nov 2005. 1 is largest, 8+ is smallest legal and smaller.*

Biological Impact Category	Artisanal		Industrial
	Félé-félé fishery	*Mujas fishery*	*Trawl Sengal*
Discard kg/kg FU	0.15	0.8	2.7
Bycatch kg/kg FU	0.25	1.2	7.3
Under sized kg/kg FU	1,4	0.4	0.09
Seafloor m^2/ kg FU	0	0	10100

Table 2: *Summary of results between the three fisheries in the different biological impact categories - measured in relation to the functional unit.*

By catches rates (88%) implies over 7 kg of non target catch per F.U. is caught in the industrial case, of which almost 3 kg (30%) are discarded back to the sea. Mujas, the worst artisanal gear catches around over 1.2 kg bycatch (54%) of which 0.8 kg (35%) are discarded. The FéleFéle rates are lower and thus corresponding mass per FU is 0.25kg bycatch (25%) and 0.15 kg (15%) discard for every kg shrimps caught. Both artisanal fishing methods are approximated to null in their effective seafloor disturbance. Offshore trawlers however needs to sweep roughly one hectare for every kilogram of target catch.

Discussion

For all impact categories studied, the shrimps from the trawled fishery have a higher environmental burden, except for terrestrial toxicity, where artisanal fisheries have higher results because of the use of mercury-containing batteries. The main impact for the trawled shrimps is at the fishing stage, which also include processing and packaging. The use of fuel and refrigerants in the trawl fishery is very high and although there may be ways to decrease the fuel use onboard (Hassel et al. 2001), the type and amount of refrigerants used may be an easier improvement to achieve in the short-term.

Artisanal shrimps scored very low in term of resources used for fishing and the processing phase dominated the same categories as the trawling: energy, GWP and ODP. The source of energy used (and of course the amount) is very important for this result and an important improvement option would be to change from using average Casamance electricity to renewable energy sources. The use of refrigerants at the processing plant and storage was important from a global warming and ozone depletion perspective and a switch to less harmful refrigerants and/or decreased leakage represents important improvement option regarding in this respect. Looking at a future scenario, where the processing plant and ice production plants in the Casamance use solar energy for electricity production and an environmentally harmless refrigerant (NH_3), the global warming emissions of the artisanal product would decrease drastically to less than 4 kg of CO_2e/kg (half of today's emissions) and these would mainly be related to the storage in M'bour and transports. Whether or not this scenario is realistic is not judged here, but the example shows the potential of designing the chain on land of artisanal seafood products in an environmentally efficient way. Moreover, the use of mercury-free batteries and the collection of used batteries should be encouraged. Providing fishermen with environmentally friendly batteries could be an option.

On the biological side, stock assessment and relating fishing effort to its outcome is the basis of sustainable fishing practices. The use of a selectivity device, such as a species-selective grid, could be very favourable both in the trawl fishery and in the mujas fishery, decreasing the amount of discard and fish by-catch. That would decouple the fish fishery from the shrimp fishery and make it possible to optimise each of them. An increase in mesh size in both artisanal fisheries could also decrease the catches of undersized fish, something already suggested by the fishermen. The netting used today is of a “mosquito net type”. Also, in artisanal fisheries, a spatial regulation could improve the catch composition of the félé-félé fishery. If it were conducted further upstream, a smaller proportion of small shrimps would be caught as the shrimps migrate upstream in the areas where félé-félé nets are set.

Conclusion

There are major differences between the artisanal fishery and the trawl fishery in all environmental impact categories included. Trawling uses much more fuel and refrigerants and leads to much higher amounts of landed fish by-catch, discard and seabed impact than do the artisanal methods. Since processing is done onboard the trawlers it is not completely fair to compare the fishing phase alone. The difference decreases when processing on land is added to artisanal fishing but still the trawl fishery leads to five times higher global warming emissions than artisanal fishing including processing. Transports and packaging only contribute a minor part to the overall result in both chains. The most important biological improvement options for the trawl fishery in addition to performing stock assessment and relating the fishing effort to its results, consist in implementation of more selective gears that separate the shrimp and fish catches from each other. Exchanging the refrigerants used onboard from so called synthetic (e.g. HCFCs and HFCs) to natural ones (e.g. NH_3 and CO_2) would result in considerable improvements in the categories ozone depletion potential and global warming potential.

Consumer pressure requires traceability and therefore traceability and labelling of the products as to origin in artisanal or industrial fisheries, perhaps even to distinguish between félé-félé and mujas fishery would be desirable to make active consumer choices possible. Intercontinental trade of seafood is sometimes debated as inefficient from a global warming emission perspective. The present study shows that frozen seafood products produced in developing countries in highly energy-efficient fisheries, like the studied artisanal fisheries, could well be environmentally competitive even on markets that are located far away from the fishery. Prerequisites are that the chain on land is designed in a resource-efficient way and that biological sustainability can be ensured

Acknowledgements

We would like to thank IDEE Casamance and CRODT and their staff who were involved in the study for all their help with the data collection. Likewise, numerous anonymous sources have been most helpful providing us with data including fishermen, government officials, fishing vessel owners, staff at the processing plant and many more. We would also like to thank the Swedish Board of Fisheries and the Fisheries and Aquaculture Department at FAO for taking the initiative to this project and the Swedish International Development Co-operation Agency (Sida) for funding the work.

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