Evolution of shrimp production and pond bottom in a semi-intensive system

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Shrimp farming started u in New Caledonia in 1970 and is based on the culture of the blue shrimp *Litopenaeus stylirostris*. Production stands at 1,800 tons per year. New Caledonia shrimp farmers have selected and refined two grow-out techniques: semi-intensive and intensive systems. The semi-intensive system represented 56 percent of the farmed surface and 47 percent of total production in the 1999/2000 harvest season.

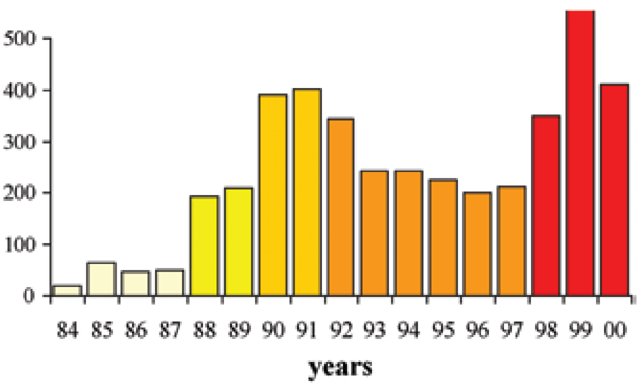

Fig. 1. Annual production of the semi-intensive shrimp farm La Sodacal.

Pond Construction

Shrimp farms are built in the intertidal zone between mangroves and agricultural land, with ponds integrated as much as possible to the natural landscape. Respectful of the environment, the farmers do not induce mangrove destruction. The salt marsh soils are usually a mixture of clay and silt with a pH between 7 and 8. Soil quality varies within the marshes with an increase in the amount of clay, organic matter and pH from the highest elevation (agricultural land side) toward the lowest elevation (mangrove side).

Semi-intensive Grow-out Management

Semi-intensive typical pond size ranges from 7 to10 hectares. Plowing of the first 5 cm of pond bottom is commonly practiced during the dry-out period, which covers usually more than 30 days. Ponds are filled with pumped water screened at 700 μm, and drained by gravity. Postlarvae, which are produced from fully domesticated broodstocks in controlled hatchery cycles, are stocked at densities between 15 and 25 per m^2. Partial harvests start after five months of growout (18 g average weight) with the final harvest ending about three months later (40 g average weight). Mean survival is 50 percent and food conversion ratio (FCR) is around 2.0. Mean yield is 3.5 tons/ha/year.

Two growout techniques used to be practiced in New Caledonia: direct stocking of postlarvae (PL20) and stocking of pre-grown shrimps (1 g). The latter method included transferring the PL20 to a small pond, and then the pre-grown shrimp were moved to the growout pond. Currently, that method has been dropped by the majority of the farms and is seldom practiced by the few others.

Drop in Productivity and the Hypothesis of Toxicity of Sediment

Drops in production and epizootics without obvious causes have been recorded on some farms in the last few years. Degradation of the pond bottoms with time was thought by shrimp farm managers and several authors to play a key role in the decrease in survival and production. As was pointed out by Boyd (1995), a prolonged use of aquaculture ponds can lead to a degradation of the soil characteristics, which could be linked to feed input. The degradation of the sediment not only occurs during a grow-out cycle but also over successive cycles (Hussenot and Martin 1995). The hypothesis of sediment toxicity, from the buildup of reduced organic wastes releasing harmful compounds after several growout cycles, has been put forward to explain some production drops. For instance, the annual production of a 130 ha farm named La Sodacal went from 402 tons in 1992 to 243 tons in 1993 and down to 200 tons in 1996 and 1997 (Figure 1).

The La Sodacal" Farm

The farm was built between 1983 and 1987 (Figures 2 and 3). It was initially a showcase of shrimp farming biotechnical know-how at the industrial level. At the time, the innovative and pioneering appeal of the project overshadowed economic considerations. It was original in the Pacific region considering the new rearing techniques employed, such as the production of postlarvae from captive broodstock using controlled reproduction. The following steps outline the development of the farm:

Construction, 1983 – 1987. Construction of the first module took place in 1983 (35.5 ha) and a second in 1987 (99.5 ha).

Ultimately, eight ponds from 8.1 to 10.7 ha were built. The farm's pumping capacity was 9,000 m^3/hr. Low production during those years (Figure 1) is explained by the fact that the period was essentially devoted to experimenting with the techniques and several species *(P. indicus*, *L. stylirostris*, *P. monodon*) and the development of management strategies.

A difficult start, or how to grow shrimp? 1988 - 1989. In 1988 and 1989, La Sodacal produced 200 tons of shrimp from 130 ha, a productivity of 1.5 tons/ha/year. Survivals were low with an average of 30 percent. Several associated factors were identified: feed quality (several feeds and formulations still on trial, supply problems, poor growth), postlarval supply problems inducing a prolonged dry-out period (pond use rate of 74 percent) and the presence of competitors, especially bird predation.

The good years, 1990 – 1991. In 1990/1991, production had improved and was considered very good for the period, with 400 tons of shrimp produced per year, a productivity of 3.0 tons/ha/year. Survival was greater than 50 percent for a growout period longer than 230 days. During those two years, the use of a new feed led to a decrease in FCR. Because of electrolysis problems on the pumps set in 1987, the deficient pumping station was replaced by a new one in early 1991. A study carried out after harvest in 1991 showed a high level of sediment accumulation in preferential zones with low redox potentials (< -200 mV at 10 cm depth) indicating high organic matter reduction (Martin and Guelorget 1995).

The collapse, 1992 – 1997. This period was characterized by a 10 to 20 percent decrease in shrimp survival regardless of growout technique. The annual production in 1992 was reduced to 344 tons. Crops from 10 direct stockings with a mean initial density of 24 shrimp/m^2 resulted in a poor survival rate of 35 percent after 242 days. In 1993, annual production was as low as 243 tons, a productivity of 1.9 tons/ha/year. Poor growth rate and survival were observed. Quality of postlarvae produced by the La Sodacal hatchery was suspected, checked, but eventually was not judged to have been involved. It was then decided between the farm and IFREMER that two ponds would be managed by IFREMER to test the mismanagement hypothesis. Still, poor growth rates and a few conspicuous mortalities were recorded. In 1994, a technical audit did not show any significant mismanagement of the farm in the previous years and, for the first time, a link between the collapse in production and the quality of pond bottom was suspected (Griessinger, IFREMER, perssonal communication). In fact, dry-outs could not be performed in all ponds; some areas remained wet and impossible to plow (Della Patrona, biologist of the farm in 1994, personal communication.).

In 1994, annual production remained as low as 244 tons. Whatever the season, the survival ranged between 24 percent and 44 percent with an average of 30 percent. The technique of stocking pre-grown shrimp was dropped after the occurrence of high mortality within 36 hours after transfer. Moreover, at the start of the cold season, high mortalities were assumed from cast net sampling data even if they were not directly observed. The high mortalities were associated with disease outbreaks**,** observed on some growout farms in New Caledonia. The origin of the epizootic was a septicemic vibriosis, called "syndrome

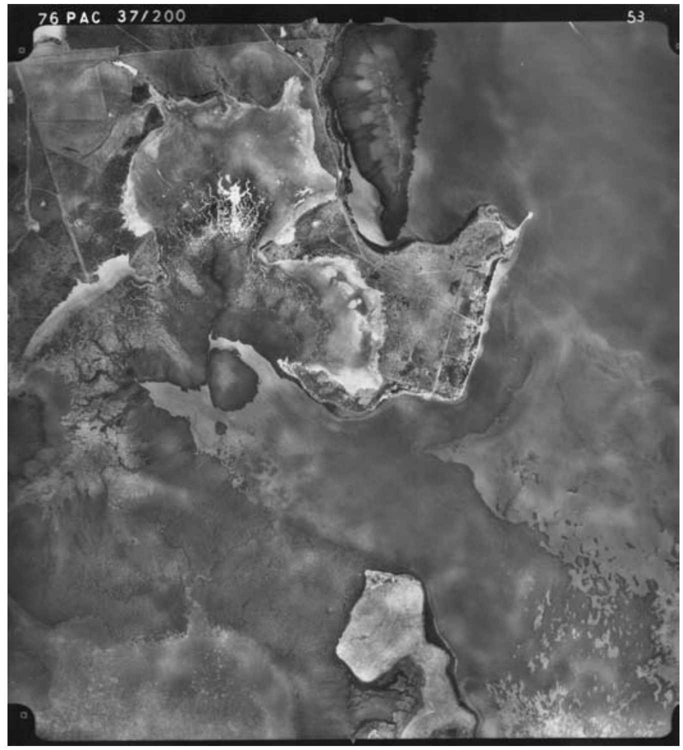

Fig. 2. Aerial view of the site before building the farm. (Source: DI3T)

Fig. 3. Aerial view of th farm in 1996. (Source: La Sodacal)

93" and was characterized by short outbreaks essentially at both ends of the cold season (Goarant et al. 1996).

In 1995, another audit (Anonymous 1995) pointed out serious technical and staff mismanagement. Amid the technical problems, the pumping capacity was reduced by half between 1994 and 1996. As a consequence of the bad results, this period ended in the bankruptcy of the farm.

The come-back, 1998-today. New management teams took over and carried out important work in 1997 and 1998. Pumping capacity was increased from 4,000 m^3/hr to 15,000 m^3/hr. Work

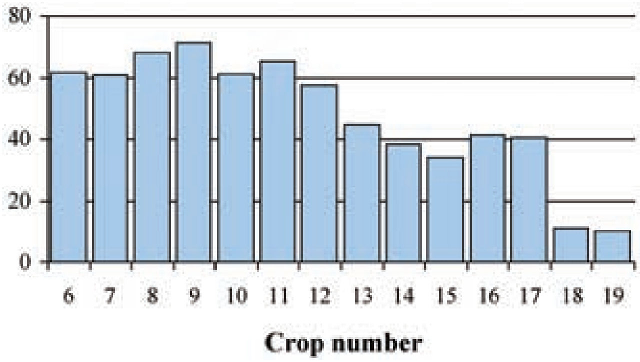

Fig. 4. Evolution of final survival of the W pond between the 6th and 19th crop.

Fig. 5. Aerial view of the pond W after sediment redistribution. (Source: La Sodacal)

on ponds was also carried out and bottom cleaning using a snow plow was engaged. Dikes were refurbished. A new growout management procedure was implemented based on food monitoring in order to obtain the best growth rate. Production increased from 200 tons in 1997 to 565 tons in 1999.

In 1990-1991, good crops led to increased accumulation of wastes on the pond bottoms. The accumulation was suspected to be the cause of production problems in 1992-1993 and in 1994-1996. However, during the second period other factors were also involved, including low pumping capacity, the appearance of a disease and mismanagement. To test the hypothesis of pond bottom degradation as the main cause of production drops in 1992-1993, an analysis of the processes occurring in a typical pond, called pond W, was carried out.

Pond W

This pond, one of the oldest in New Caledonia, covers 8.1 ha and is part of the first module built in 1983. It was filled up for the first time in September 1984. Five crops were produced over the first three years to select the most adapted species and to define growout techniques. Industrial production started only with the 6th crop in 1987.

Figure 4 shows the evolution of final survival between the 6th and 19th crops. Between the 11th and 17th crops, a decrease in survival from more than 60 percent to less than 40 percent occurred, with an average of 50 percent over the 13 crops concerned, regardless of growout strategy. A dramatic decrease occurred with respect to the 18th and 19th crops where survival as low as 10 percent were recorded.

Temporal evolution of the pond bottom. Data were available for the analysis of the evolution of the pond bottom. They included:

- An aerial view, a topographic description and soil characteristics of the site prior to the aquaculture activity.
- Data on pond bottom management.
- Results from a study on the sediment quality carried out in 1996 (silting level, pH, redox potential, organic mater, water content, ammonia in pore water). An aerial photo was taken on that occasion.
- An aerial view taken in 1998 during a dry-out period (Figure 5).

Situation in 1983. The soil was a mix of clay and silt. Topographic study, data from soil analysis and picture analysis were used to draw a map of the bottom of the pond in the future. Soil quality was typical of Caledonian salt marshes. The soil analysis coupled with the topographic measures revealed a spatial heterogeneity, characterized by a shisteous zone at the upper level of the pond in the future, on the water inlet side, and an increase of the clay proportion with the natural slope on the water outlet side. Organic matter in the initial soil was relatively high with an average of eight percent.

Situation in 1996. A map of the soils drawn from data on sediment coupled with the aerial picture shows clear evolution since 1983. Sediment distribution on the pond bottom was heterogeneous with areas of accumulation and erosion. This reorganization of the soils was enhanced by the combined effects of wind, tilling during dry-outs and shrimp bioturbation (Lemonnier and Brizard 2001). The sediment distribution led to a high spatial variation in soil quality (ammonia, pH, organic matter, redox potential). However, this level of sediment accumulation was similar to the usual amount encountered on other farms in New Caledonia (Lemonnier and Brizard 2001).

Sediment quality at the water/sediment interface (first centimeter). Values of organic matter, pH and ammonia concentration observed at the sediment/water interface did not reach toxic levels, nor even stressful levels for the animals. There was no evidence that the sediment had any detrimental effect on the productivity of the pond. Levels of ammonia nitrogen in pore water were very low at 0.22 mg/l on average, which is not considered stressful for shrimp (Allan et al. 1990). Redox potential was high, indicating a good oxygen supply to the pond bottom and/or a very low oxygen requirement. Interestingly, values greater than +150 mV at the water/sediment interface over such an important area of the pond are unusual. pH tended to be basic with values between 7 and 8, which, in shrimp farming, is considered to be a good range for the bacterial process of mineralization. Levels of organic matter in zones of accumulation greater than 6 cm amounted to about nine percent, which was similar to the value recorded in 1983 in the original soil.

A map of sediment distribution reflected the hydraulic circulation pattern within the pond. Between 1983 and 1996, the pond current pattern at the bottom changed progressively as mineral and organic particles settled where the water current sowed. As a consequence, there was no or very weak water currents in more than 50 percent of the pond bottom area.

Sediment accumulation was observed on the upper side of the pond due to the dominant wind, coupled with the effect of the water inlet's position and the topography of the pond bottom. The aerial picture shows a clear spot on the upper side of the pond that corresponds to a mound where the soil was originally higher. Two channels corresponding to the two water inlets had been gradually formed around it.

Situation in 1998 (Figure 5 and 6). The new manager decided to partially remove the sediment that had accumulated with a snow plow (Figure 6) in order to get rid of sediment assumed to be toxic for the shrimp. At the same time, the pumping capacity of the farm was increased. Spectacular improvement in production was obtained following these modifications: yield was 6.2 tons/ha/year compared to the previous 1.0 ton/ha/year and a final survival of 66 percent as opposed to 10 percent.

Water Circulation Management: One of the Tools for Sustainable Production?

The history of La Sodacal is a good example of the positive or negative effects of water circulation on sediment characteristics and shrimp production. A progressive build up of sediment from pond walls and bottom erosion was observed The result was preferential distribution of fine sediment in the pond. As a consequence, a new water circulation pattern was established within the pond. A direct feedback effect was the appearance of dead zones where sediment and wastes accumulated and incoming water was channeled between them.

Fig. 6. Soil work with a snowplow.

The gradual increase of production between 1988 and 1991 emphasized the heterogeneity of the pond bottom topography and quality as plowing increased the pond bottom erosion, higher densities led to greater bioturbation and more organic wastes. In 1991 and later, insufficient dry-outs (the soil remained wet in some parts of the pond) between crops did not permit the quality of the soil to be maintained.

As a consequence of the new water circulation pattern, waste within the pond could not be recycled properly because of the progressive decrease waste-carrying capacity. In 1992, degradation of the pond bottom could have been the reason for the decrease of farm production.

Between 1992 and 1996, poor crops with low survival rates caused less waste to be released, allowing an improvement of pond bottom quality. Therefore, in 1996, we found good soil quality based on its chemical profile. However, the waste carrying-capacity of the pond remained low because water circulation was still uneven in the pond.

In 1998, the partial removal of accumulated sediment had an effect on water circulation by changing the pond topography into one close to the original. As a result, water circulation was improved over the whole pond surface.

It seems likely that the initial cause of the dramatic decrease observed in production was the negative preferential water circulation pattern that progressively took place in the pond. This disrupted water circulation led to the degradation of the pond bottom linked to an uneven waste distribution and poor waste recycling. When good water circulation was restored, production was back on the right track.

Thus, water management appears very important in order to maintain good sediment quality. This includes checking currents within the pond and eventually changing them to avoid any dead areas. Keeping a close eye on water management and water currents within a pond could be one of the key tools for a sustainable semi-intensive shrimp culture system.

(Continued on page 71)

theoretical market for its products, is a very, very good reason for caution - no matter how persuasive the promoters might be.

Author's Note

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New Literature

M. B. Timmons, J. M. Ebeling, F. W. Wheaton, S. T. Summerfelt, and B. J. Vinci. 2001. Recirculating aquaculture systems. Cayuga Aquaculture Ventures, Ithaca, New York USA. 650 p.

This book contains 16 paper chapters and a 17th in the form of a CD-ROM containing software programs. The hard copy chapters include an introduction to recirculating culture technology and those on water quality; fluid mechanics and pumps, mass balances, loading rates and fish growth; culture units; solids capture; biofiltration; gas transfer; system monitoring and control; waste management and disposal; system management and operations; ozonation and UV-irradiation; fish health management; environmental control; economics and management; and fish nutrition and feeds. Contact Cayuga Aqua Ventures, 126 Sunset Drive, Ithaca, New York 14850 USA for ordering information.