VII.1e. Influence of the lake on littoral agriculture

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On approaching the shores of Lake Titicaca a marked change in agricultural practices is evident to any visitor. As one approaches the lake, the population density rises (often to more than 100 inhabitants per km^2 in contrast to 30 further away). Crops grow well and mature 2 to 3 months earlier than on the rest of the Altiplano. Herds of cattle graze in the shallow waters of the lake or on the shore where their diet consists mostly of aquatic plants. This very obvious influence of Lake Titicaca on agricultural activity drove the fathers of the first agricultural tax in Bolivia to divide the altiplano into two zones: one that benefited from the lake's influence, and one that did not. It is easy to prove the existence of two different types of agriculture, but its causes and the zoning have been little studied. We will try therefore in this chapter try to identify the major factors related to the lake which modify the agriculture, and to evaluate their importance, their range of influence and their consequent effects on agriculture.

The study area consists of the Bolivian shore of Huinaimarca. The results that we present are neither exhaustive nor completely generalised, but they will allow, we hope, a better understanding of how agriculture functions on the shores of Lake Titicaca.

The influence of Lake Titicaca on certain important agroecological factors

We have mainly considered the influence of the lake on climate and soil; determining factors for agriculture as well as for the production of macrophyte fodder.

Climate

The major limiting factors for agriculture on the altiplano are incontestably drought and frost (Morlon, 1987; Vacher et al. 1987). The ability to grow maize and other crops for almost ten months a year on the shores of the

C. Dejoux and A. Iltis (eds.), Lake Titicaca, 511–522.

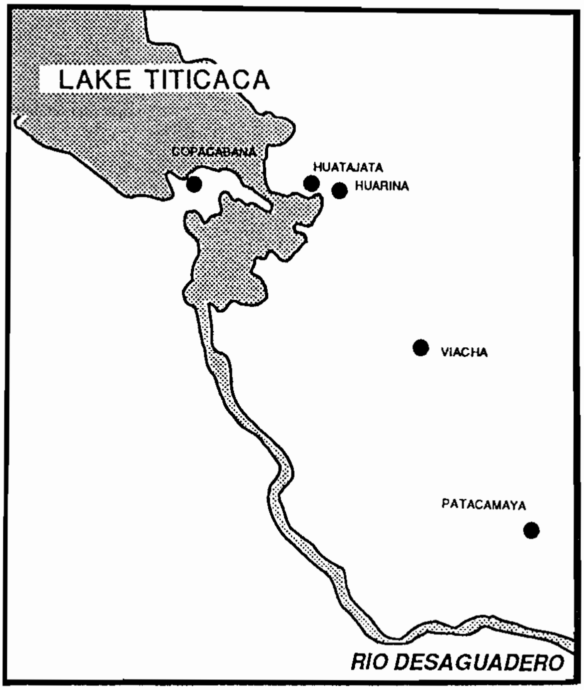

Fig. 1. Map showing localites of meterological stations. Scale 1/1 500 000.

lake testify to the superior climatic conditions in this zone compared to elsewhere on the altiplano. We will now try to analyse the influence of the lake on risks of drought and frost, using meteorological information from the National Service of Meteorology and Hydrology with data obtained at stations at various distances from the lake.

Risks of drought

Four stations were chosen: Copacabana, Huatajata, Huarina and Viacha (Fig. 1). The stations of Copacabana and Huatajata are located on the lake shore, Huarina approximately one kilometre from the lake and Viacha 60 km from the lake. This last station is representative of the agroclimatic zone of the north Altiplano (Vacher and Imaña 1989). We will compare the amount of precipitation at each station, and then, with the help of a simple hydrological balance model, evaluate the risks of drought.

Mean annual precipitation and its distribution over the year for each station are given in Fig. 2 and Table 1; these show that:

– The lake has a very marked influence on the total annual precipitation

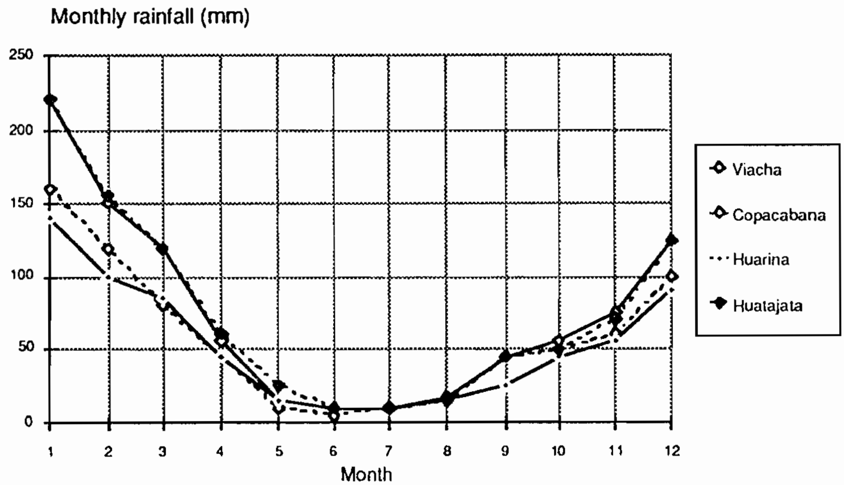

Fig. 2. Seasonal distribution of average monthly rainfall at four stations on the Bolivian Altiplano.

(200 mm more for the lake stations) and on its year to year and monthly regularity.

- This influence is very restricted since Huarina, located 1 km from the lake, has the same annual precipitation as Viacha.
- The difference between the stations on the lake and the others occurs essentially during the December–February rainy season; this does not however explain the two months' difference in sowing date between the two areas.

By using a hydrological balance model, taking into account soil behaviour (Lhomme and Eldin 1983, Atteia *et al.* 1988), hydrological deficits for potatoes have been calculated for each ten-day period at each of the four stations (Fig. 3). To make the analysis of the influence of climate easier we have considered only one soil type and one germination date (early December). Evapotranspiration (ETP) was estimated from a Penman type formula, adapted for the altiplano (Vacher *et al.*, 1989). The reduction in the partial hydrological deficit for lake stations for each ten-day period is very great,

Table 1. Comparison of total annual rainfall at some stations on the Altiplano

Sites	Annual mean (mm)	Coef. var.	Prob. 75 %	Prob.25 %
Copacabana	893	0.20	762	1025
Huatajata	862	0.16	751	937
Huarina	616	0.26	501	683
Viacha	679	0.24	526	788

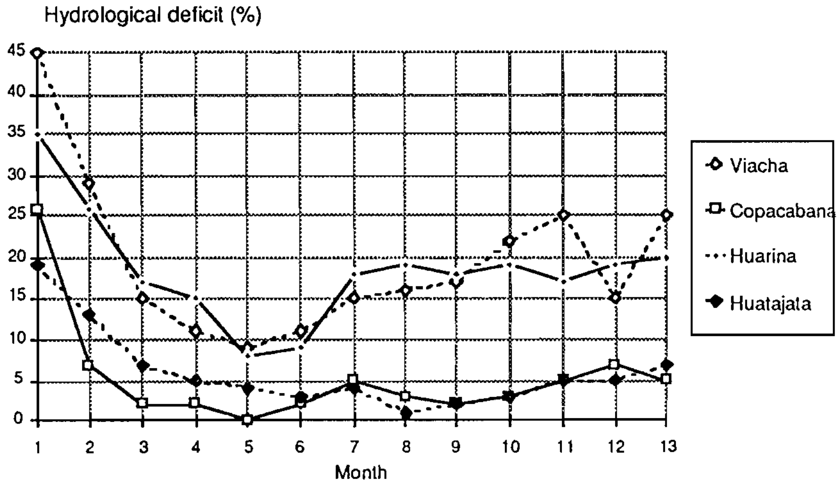

Fig. 3. Average hydrological deficits at four stations on the Bolivian Altiplano.

particularly in mid-February and early April, during tuber growth, a determining period for final production.

Risk of frost

Total losses of crops due to frost are regularly mentioned in reports ever since Colonial times and are also recalled by peasants. A frost risk study for potato cultivation has shown that the average frost-free period ranges from 100 days on the central altiplano to 140 days on the northern altiplano, thus highlighting the limiting nature of this factor for agriculture (Le Tacon, 1989; Vacher and Imaña, 1989). The probabilities of occurrence of frosts affecting potatoes at Copacabana, Huarina, Viacha and Patacamaya (representative of the central altiplano) are shown in Fig. 4. The probability is very high for Viacha, Huarina and Patacamaya, but is almost non-existent at Copacabana; the average frost-free is 320 days at this station as against 150 days for the other stations, so agriculture is possible almost the whole year round on the shores of the lake. However, this influence is limited to the narrow area of high precipitation. In the future, analysis of satellite images in the infrared band should allow us to localise precisely the influence of the lake on minimum temperatures (for frost risks on the lake shores in Peru, see Morlon 1978, 1979 and 1987).

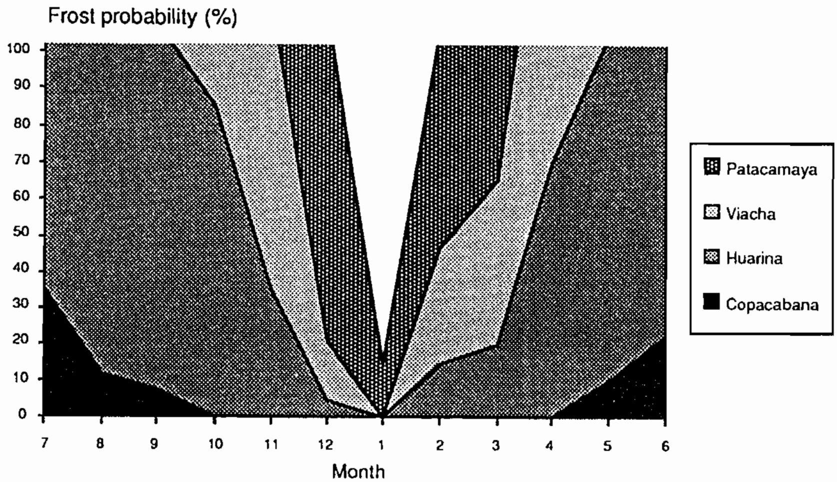

Fig. 4. Frost risks for potato cultivation at four stations on the Bolivian Altiplano.

Soils

The wide fluctuations in the level of Lake Titicaca (Wirrman, 1987; Mourguiart, 1987) have led to the formation of deep soils. Along the shore of the lake another important factor for the irrigation of crops is the shallowness of the water table (Liberman, 1987). The influence of the lake on the physical, trophic and hydrological features of the soils can be determined from the analysis of the limited information in the literature and the results of experiments carried out during the Program for the Study of the Agroclimate of the Bolivian Altiplano.

The physical, trophic and hydrological features of the soil formed from lacustrine deposit (Belen, located 2.0 km from the lake shore), a typical soil from the northern altiplano (Viacha) and the soil of the central altiplano (Patacamaya) are shown in Table 2. The results refer to the top 30 cm of soil underneath pasture land and demonstrate the higher agricultural value of the alluvial soils. The texture is finer, the organic, total nitrogen and potassium contents are twice as high and assimilable phosphorus is five times higher. The presence of a compact clay horizon at Viacha and of a stone

Table 2. Soil characteristics at scientific stations at varying distance from Lake Titicaca

Sites	Clay (%)	Silt (%)	Sand (%)	pH	O M	N tot. (%)	P. ass. (ppm)	K. bot. (meq)
Belén	31	40	29	7.4	3.4	0.16	32	0.53
Viacha	20	29	51	7.2	1.9	0.09	5.3	0.25
Patacamaya	15	26	59	7	1.4	0.06	8.3	0.14

horizon at Patacamaya at a depth of 35 cm limits root penetration and rising capillary action reducing water availability in the cultivated area (Vacher *et al.*, 1988). In the areas closest to the lake shores (under the 50 m contour), the soil is always wet since the water table lies at a depth of only 30 to 50 cm (Cochrane, 1973; Liberman, 1987). The presence of abundant soil water allows for fast plant growth and germination, even during drought. Occasionally, the water table reaches the surface over extensive areas; agriculture in such areas is carried out by the almost abandoned ditch and hummock system which is in the process of rehabilitation in Peru where it is known as "Waru waru" and in Bolivia where it is called "Suka Kollos" (Erickson, 1987; Garaycochea, 1987; Morlon, 1978, 1979, 1987).

Production of macrophyte forage

The main macrophytes used for cattle feeding are "totora" (*Schoenoplectus tatora*) "chanco" (*Myriophyllum elatinoides*) and "hancha" (*Elodea potamogeton*). Totora is the most widely used forage plant; it is a cyperaceous plant that generally reaches a height of 4 m, two thirds of this being under water. It is usually cut two to three times a year within limited plots that the peasants maintain and resow. The average dry biomass production at Huiñaimarca has been estimated at 132 000 tonnes and the annual production at about 5.5 tonnes per hectare (Collot *et al.*, 1983). However, a great increase in the lake level in 1986 produced a major decline in totora production due to asphyxia and competition with *Chara*; this had serious consequences for cattle feeding in the lake area. Forage macrophytes from the lake represent a very important food supply for cattle, with a high production per hectare allowing the existence of cattle herds with very little pasture, even by farmers with very little land.

Some general features of agriculture on the shores of Lake Titicaca

We have already described how the present lake reduces the risks of drought, almost removes the risk of frost and provides better agricultural soils and forage production. What are the consequences on agriculture?

Plate 7. Typical land activity along the Lake Titicaca shoreline. Above: Sheep and pigs grazing in felds after harvesting. Cows are mainly feeded with totora or other macrophytes. Agriculture is little mecanized and wood ploughs tracted by oxen are still used. Center: traditional terraces are used everywhere along the shores in shear areas. Agricultural practices respect rotation cycles with potatoes, corn, beans or quinua. Down: corn (wheat, oats, maize) grow very close to the extention limit of water, mainly in the large lowland areas arround the bays. (Photos Claude Dejoux.)

One of the main features of this favoured agricultural area is the greatly increased density of cultivation. The total area per farmer ranges from 0.6 to 3 hectares (Brasier de Thuy, 1989; Liberman, 1987; Urioste, 1977), made up of 12 to 20 plots. This is true for both the Bolivian and Peruvian areas (Montoya *et al.*, 1987). In contrast the cultivated area per farmer varies from 15 to 60 hectares for the rest of the altiplano. This reduction in land holding is a determining factor for cultivation and cattle rearing systems; peasants usually only possess 2 to 3 plots of less than 1000 m^2 area on the shores of Lake Titicaca.

Good edaphic and agroclimatic conditions promote early sowing, the absence of fallow land and higher productivity. The main crops are, as on the rest of the altiplano, potatoes, barley, beans and "quinoa" (a type of buckwheat). The sowing periods are at the end of July for beans and mid-September for potatoes, which provides crops at the beginning of January when selling prices are still high. The most common rotation is potatoes followed by beans, cereals or quinoa, followed by a forage crop, usually barley. There is no fallow stage, whereas on the rest of the altiplano land is usually left fallow for more than 6 years. Cultivation of beans and onions has been increasing for some years now, but according to peasants disease and decreased soil fertility have appeared.

The retention of soil fertility is currently a major agricultural problem on the lake shores. The reduced size of pastures and of aquatic macrophyte plots per farmer, added to the large decrease in totora production since 1986, limits the numbers of livestock. Each family now only owns 2 to 4 cattle (usually cows) and 3 to 8 sheep, which do not provide enough manure or animal traction. The intensity of agricultural exploitation is not accompanied with adequate restitution of organic and mineral nutrients. Chemical fertilizers are scarce and incomes are often too low to purchase sufficient quantities. The lack of draught animals results in farmers renting tractors at a very high cost.

The existence of mimimal climatic risks and good edaphic conditions is reflected in an intensification of agricultural systems on the lake shores, which is aggravated by the division of land holdings into small plots. Peasants benefit from the higher and more consistent agricultural production compared to any other part of the altiplano, although their agriculture is more vulnerable and fragile. In fact, each farmer only has a reduced area of cultivated land and there is no land for cattle grazing nor totora enough to feed a sufficiently large herd to provide good ploughing and restitution of nutrients to the arable land, or to provide a reserve capital during lean years. The recent flood on the lake shore was particularly catastrophic for peasants who saw their most productive land disappear and cattle production drop.

This disaster only emphasises the tendency for multiple activity, and although it would appear paradoxical, farmers in the area where the agricultural conditions are extremely suitable have more diversified activities (education, fishing, handicrafts, etc.) than in other areas.

Conclusions

It is evident that Lake Titicaca has a clear beneficial influence on the agroclimate and local edaphic conditions and also provides a considerable production of "aquatic" forage of about 8 tonnes of dry material per hectare. The influence of the water body and its heat content considerably decreases the risk of droughts and practically eliminates the risk of overnight frost.

Taking into account the further physical and trophic advantages of the soils derived from lacustrine deposits, agricultural conditions are highly favourable along the shores of the lake, but high agricultural productivity is limited to a narrow band. The existence of good edaphic conditions leads however to a great reduction in the size of agricultural holdings and the division into multiple plots. The area useable for cattle rearing is very reduced and the cultivation of arable plots is very intensive. Thesc conditions produce fragile soils, and do not allow for adequate restitution of nutrients and organic matter. In addition, the limited numbers of cattle reduce the possibilities of using natural manure and compels the farmers to resort to a certain level of mechanization, that further reduces their income. All these led to multiple activity, a tendency reinforced by the recent flooding of Lake Titicaca.

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C. DEJOUX and A. ILTIS / Editors

Lake Titicaca

A Synthesis of Limnological Knowledge

Kluwer Academic Publishers

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KLUWER ACADEMIC PUBLISHERS

DORDRECHT / BOSTON / LONDON

Library of Congress Cataloging-in-Publication Data

Lake Titicaca : a synthesis of limnological knowledge / edited by C. Dejoux and A. Iltis.
p. cm. -- (Monographiae biologicae ; v. 68)
Includes indexes.
ISBN 0-7923-1663-0 (HB : alk. paper)
1. Limnology--Titicaca Lake (Peru and Bolivia) 2. Aquatic resources--Titicaca Lake (Peru and Bolivia) I. Dejoux, Claude. II. Iltis, A. III. Series.
QP1.P37 vol. 68
[QH128]
574 s--dc20
[574.5'26322'098412] 92-7958

ISBN 0-7923-1663-0

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Kluwer Academic Publishers incorporates
the publishing programmes of
D. Reidel, Martinus Nijhoff, Dr W. Junk and MTP Press.

Sold and distributed in the U.S.A. and Canada
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers Group,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

Printed on acid-free paper

Printed in the Netherlands