WORSENING WATER QUALITY CONDITIONS AT INNER PUNO BAY, LAKE TITICACA, PERU, AND THEIR EFFECT ON *LEMNA* SPP. BIOMASS

MARIA ASUNCION RAMOS CRUZ, EDMUNDO MORENO TERRAZAS AND TOM NORTHCOTE

[1]M.A. Ramos Cruz & [2]Dr E.G. Moreno Terrazas, Universidad Nacional del Altiplano, Facultad de Ciencias Biologicas, Puno, Peru
Email: [1]mariacruza@hotmail.com; [2]gmorenot@yahoo.com

Dr T.G. Northcote, 10193 Morrison Close, Summerland, B.C., Canada V0H 1Z7. Email: tnorthcote@vip.net

Introduction

Although there have been a number of studies on aquatic conditions and the flora and fauna of Lake Titicaca over many decades (Gilson 1939, 1964; Uéno 1967; Richerson et al. 1975), most of this work has been centred on the offshore regions of the main lake. More recently studies have begun to focus on near-shore waters, especially of Inner Puno Bay (Luna 1981; Northcote et al. 1989 (Spanish version 1991)). Here there has been a deterioration in water quality conditions, especially near areas close to a levee built very recently for tourist viewing, called ‘Bahia de los Incas’ (Figs. 1, 2, 3). Water quality there has been degrading and abundant growth of *Lemna* spp. has been developing (Cruz 2005). To some extent this *Lemna* growth can take up nutrients (Quispe 1999) and heavy metals (Choque 2000), but these would be released, in part, with annual die-down.

Lemna spp., commonly called floating duck-weed or ‘lenteja de agua’ in Puno, occurs perennially in most parts of the inner Puno Bay shore-line (Northcote 1992). Surprisingly, studies on the macrophytes of Lake Titicaca have given little attention to *Lemna* (Collot 1980; Cornejo & Aramayo 1989; Raynal-Roques 1992; Iltis & Mourguiart 1992). In this article, we compare water quality changes over recent decades in shore-line regions of Inner Puno Bay and their possible effects on the distribution, abundance and biomass of *Lemna* spp.

Recent and present water quality conditions

Sampling surveys and locations

In the 1980s a detailed study (Northcote et al. 1989) was made on water quality conditions in Inner Puno Bay at a series of stations widely dispersed within that region and also at its exit into outer Puno Bay near

Ojerani for comparison (Fig. 1). At that time wastewater from UNA (Universidad Nacional del Altiplano) (1) and from several parts of the city and nearby settlements of Puno (2 – 5) entered Inner Puno Bay. Gradually during the 1990s most of these sources were piped to a sewage treatment lagoon located beside Isla Espinar (Fig. 1) which functions poorly in part because it is far too small for the rapidly increasing population of Puno, now over 120 000.

In 2002, a dyke was covered with gravel and sand to create a walkway extending from the north side of Puno's shipping dock towards UNA, for tourists to see Inner Puno Bay and some parts of outer Puno Bay. Three gates provide access for water to enter through the dyke from Inner Puno Bay, and the operation of four spray pumps (Figs. 2, 4) attempt to aerate the water. The present study was undertaken in 2005 and focuses on the area of Inner Puno Bay to the west of this walkway – an area of approximately 20 ha. For the purposes of the study, the area was divided into two sections, a western section comprising 27 % of the total area and an eastern section comprising the remainder (Fig. 2). There were two physical-chemical sampling regions in each section (W1, 2; E1, 2).

Water quality conditions, 1970–2005

Data for physical and chemical conditions in Inner Puno Bay, close to the present study area, are available for 1970 to 2005 (Table 1) and show some changes in water quality during this period.

Surface temperatures recorded in January to March were slightly lower in 2005 (near 16 °C to 17 °C) than in 1982 (17 °C to 18 °C; Morales et al. 1989), although without further data it is not clear whether this is significant.

There has been a marked decrease, however, in transparency, with midday Secchi disc readings reaching zero in 2005 (Ticona 2005), compared to a minimum of 1.0 m in the early 1980s. The low readings in 2005 are because the western part of the study area was often almost totally covered with *Lemna* brought in from the eastern part by a floating boom, to provide better water visibility for tourists walking on the dyke (Figs. 2, 4).

No conductivity data are available near the present study area in the 1980s or earlier. The present values, average summer surface readings of 1089 µS/cm in the eastern part of the study area and 1108 µS/cm in the western part (Cruz 2005), are slightly above the 1000 µS/cm quality standard for potable water given by Carranza (2001).

There was no conclusive evidence of change in pH values, although recent summer values (average pH 7.5 in the eastern parts of the study area

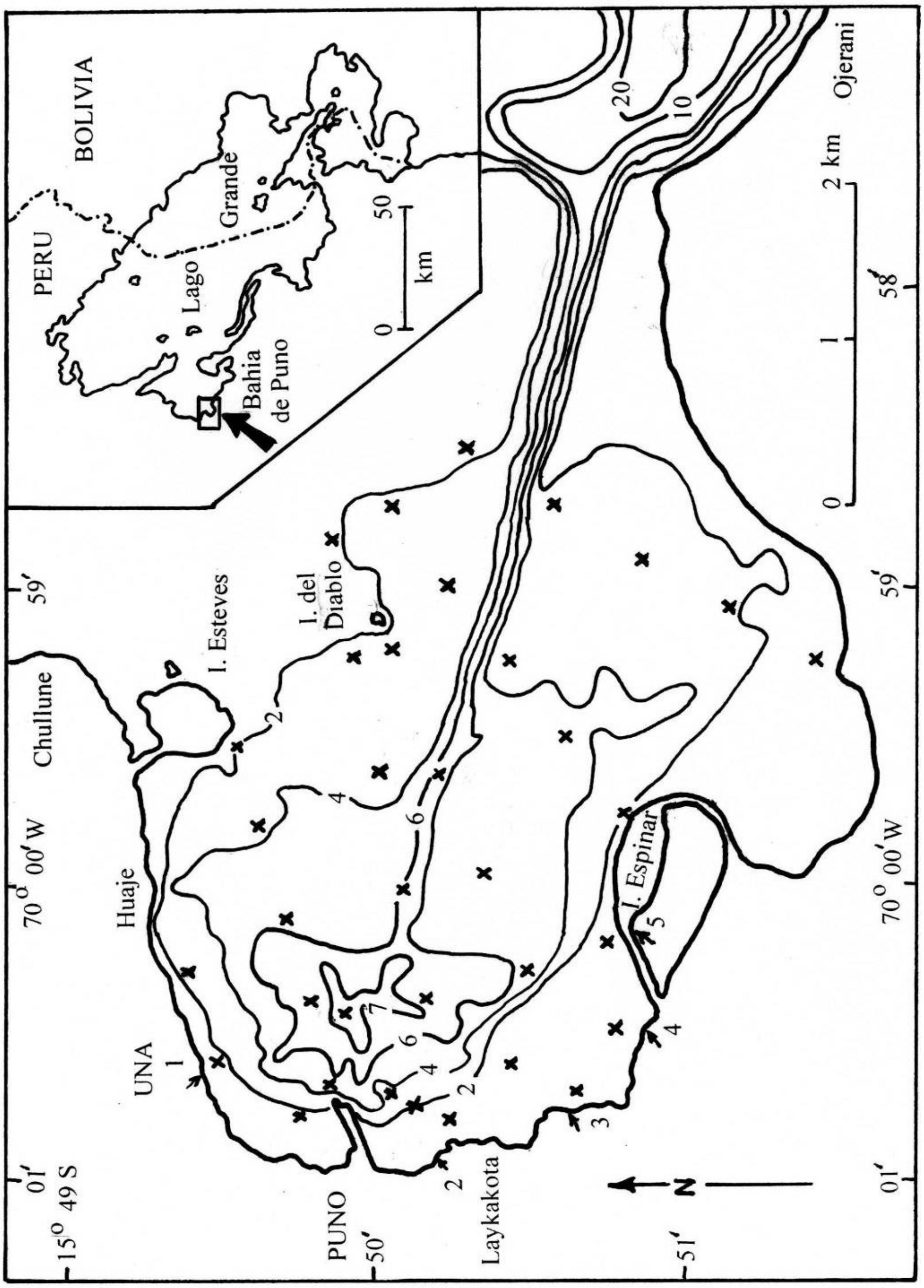

FIG.1. *Upper right inset:* Lake Titicaca in Peru and Bolivia, at nearly 4000 m elevation, showing Lago Grande and Puno Bay. Arrow shows Inner Puno Bay *(main figure)* which was the site of an intensive study of water quality conditions in the 1980s (Northcote et al. 1989) and now a detailed study in 2005 (Cruz 2005). Depth contours shown in metres (2 m –7 m). Numbers around shoreline indicate sewage outfalls in the 1980s. Note the large shipping dock on western shore of Inner Puno Bay.

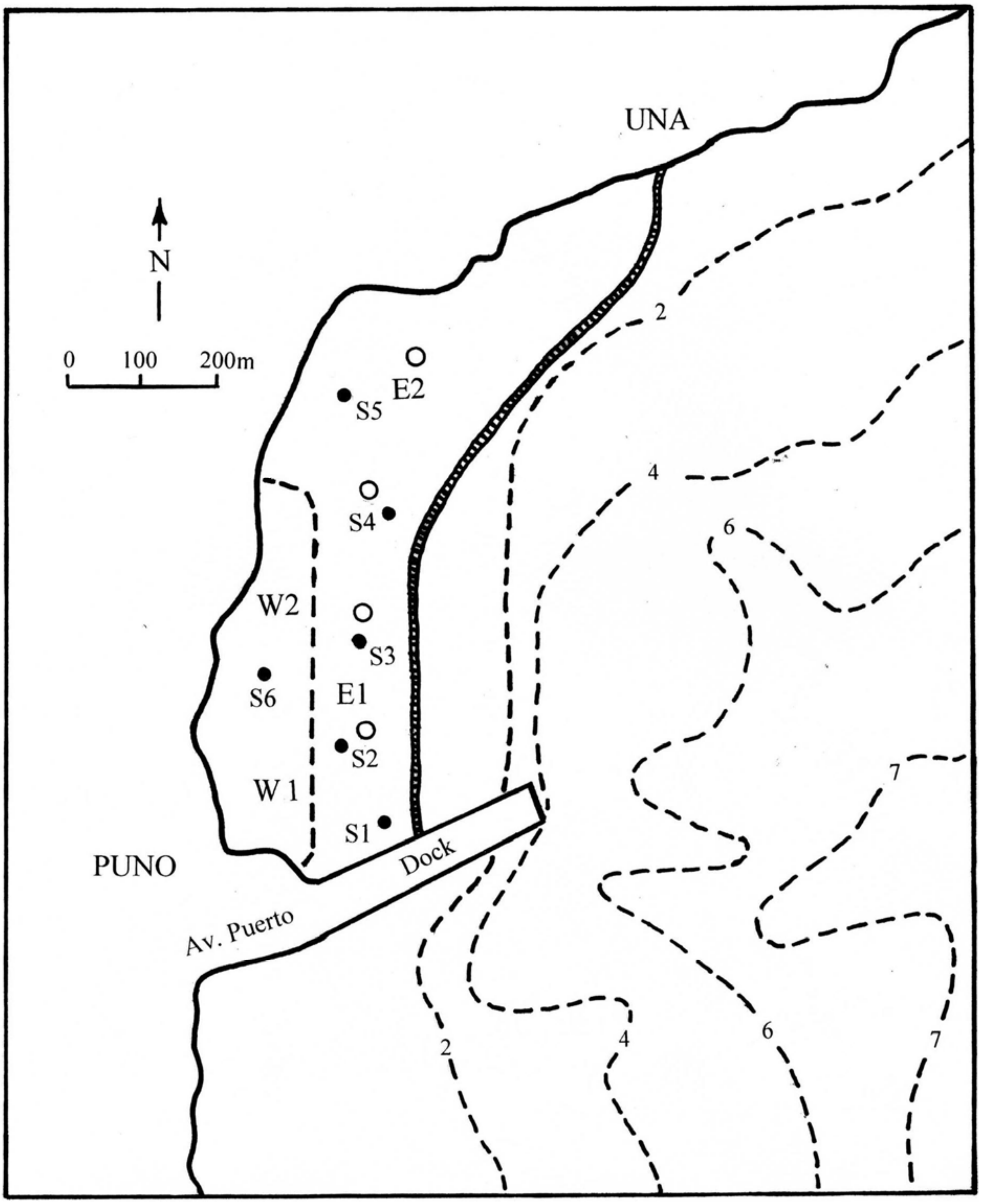

FIG. 2. A sketch map enlarged from the Puno side of Inner Puno Bay showing the study area of Cruz (2005) north of the dock. Nearby depth contours (dashed lines) in metres. The study area has eastern and western sections with five sampling sites in the former and one in the latter (S1–5 and S6). Open circles show large aeration pumps. Hatched double line shows tourist walkway from the dock to UNA (Universidad Nacional del Altiplano).

and pH 7.3 in the western parts) were slightly lower than values recorded in February 1970 (Luna 1981) and summer 1983 (Miranda et al. 1989).

A deterioration in dissolved oxygen concentrations is apparent. In the summer of 1982 near-surface concentrations occasionally fell briefly to levels as low as 2.8 mg/L but usually were in the 5 mg/L – 8 mg/L range (Miranda et al. 1989). In 2005, however, they averaged 0.6 mg/L in eastern parts of the study area and 0.5 mg/L in western parts (Cruz 2005). Although no data are available on oxidation-reduction potential (redox potential) in the 1980s or earlier, values in 2005 (mean -47.6 mV in eastern parts and -45.8 mV in western parts of the study area; Cruz 2005) are indicative of frequent anoxic water conditions.

Levels of total dissolved solids increased only slightly during the period, from 920 mg/L – 1099 mg/L in 1970 (Luna 1981), to a mean of 1068 mg/L in eastern parts of the study area in 2005 and 1108 mg/L in western parts (Cruz 2005).

Total hardness increased from close to 200 mg/L in 1970 (Luna 1981) to up to double that in the early 1980s (Miranda et al. 1989), but decreased back to 1970 levels in 2005 (Cruz 2005). However, summer levels of total

Table 1. A comparison of near-surface water quality conditions in Inner Puno Bay, Lake Titicaca, Peru, during the last 35 years (1970–2005). Data relate to sampling stations close to the present study area. See Luna (1981), Northcote et al. (1989), Morales et al. (1989), Miranda et al. (1989), Cruz (2005) for methods and other relevant information.

Parameter	Summer 1970 (Luna 1981)	Mainly summer 1981–1989 (Luna 1981, Morales et al. 1989, Miranda et al. 1989)	Summer 2005 (Cruz 2005)
Temperature (°C)	–	17 – 18	16 – 17
Transparency (Secchi, m)	-	1.0 – 2.0	0 – 1.4
Conductivity (µS/cm)	–	–	1089 – 1108
pH	7.5 – 7.9	7.6 – 8.6	7.3 – 7.5
Oxidation-reduction potential (mV)	–	–	-47.6 to -45.8
Dissolved oxygen (mg/L)	–	2.8 – 8.0	0.5 – 0.6
Total dissolved solids (mg/L)	920 – 1099	–	1068 – 1108
Total hardness Ca CO_3 (mg/L)	183 – 203	300 – 400	193 – 204
Total alkalinity (mg/L)	159 – 205	83 – 100	285 – 286
Chloride (mg/L)	268 – 332	–	167 – 180
Sulphate (mg/L)	55 – 58	183 – 203	715 – 905
Total phosphorus (µg/L)	–	1.0 – 15.2	5 – 7
Soluble reactive phosphorus (µg/L)	–	0.5 – 13.8	(not available)
Dissolved nitrate – N (µg/L)	–	7.0 – 90	(not available)

alkalinity have increased markedly, from mostly being below 200 mg/L in 1970 and the 1980s, to 285 mg/L and 286 mg/L in eastern and western parts of the study area in 2005 (Cruz 2005).

Summer concentrations of chloride have decreased appreciably between 1970 and 2005. In contrast, concentrations of sulphate have more than trebled in both parts of the study area.

Total phosphorus concentrations averaged 4.6 µg/L in 1983 (Miranda et al. 1989); in 2005, the mean concentrations were 5 µg/l and 7 µg/L in eastern and western parts of the study area respectively (Cruz 2005). Concentrations of soluble reactive phosphorus (SRP) occasionally rose above 10 µg/L in the 1981 – 1983 period, but usually were less than 4 µg/L (Miranda et al. 1989). Similarly, there were only a few sampling dates in the 1981 to 1983 period when nitrate N concentrations rose above 70 µg/L, and usually were less than 20 µg/L (Miranda et al. 1989). Unfortunately, no data for SRP or nitrate N are available for the 2005 survey.

Lemna spp.

Distribution and abundance

There may be two species of *Lemna* in Lake Titicaca, *Lemna gibba* L. and *Lemna* cf. *aequinoctialis* (Raynal-Roques 1992), usually called there ‘lenteja de agua’ (Collot 1980) and commonly included with other macrophytes that float on the lake surface, sometimes in very high abundance. In general *Lemna* occurs over a wide temperature range (8 °C to 45 °C) in lakes and ponds (Quispe 1999).

Lemna reaches very high abundance in the western part of the Puno study area, and now also around much of the other shoreline parts of Inner Puno Bay, especially those south-east of Isla Espinar. At times during the day masses of *Lemna* drift offshore with the wind to outer reaches of Inner Puno Bay well beyond Isla Esteves and Isla del Diablo (Figs. 2, 3, 4), and then shoreward again at night. *Lemna* distribution and abundance varies from year to year, covering an area ranging from 179 ha to 393 ha in Inner Puno Bay (Quispe 1999).

Biomass

One of the first general studies on *Lemna* biomass in Inner Puno Bay was that of Palacios & Laguna (1991) who showed that in the area near Laykakota there were 2.68 kg/m^2, near Chullune 2.37 kg/m^2, near Isla Espinar 2.34 kg/m^2, and near Huaje 2.34 kg/m^2 (see Fig. 1 for locations). Choque (2000) reported that over the whole of Puno Bay *Lemna* biomass was 3.5 kg/m^2.

Table 2. *Lemna* spp. biomass (kg/m^2) in the six sites of the detailed study area of Inner Puno Bay, Lake Titicaca (see Fig. 2), from Cruz (2005). For statistical analysis 0.001 was added to all biomass numbers.

Date (2005)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
12 April	0.251	1.542	0.174	0.005	0.188	0.575
15 April	0.010	0.112	0.075	0.078	0.085	0.800
18 April	0.625	0.193	0.046	0.075	0	1.500
21 April	0.525	0.350	0	0	0.010	1.150
24 April	0.287	0.070	0	0	0.150	1.750
April mean	0.340	0.453	0.059	0.032	0.087	1.155

The first detailed study of *Lemna* biomass was in April 2005 (Cruz 2005) in the near-shore area behind the dyke providing the tourist walkway from the Puno shipping dock to UNA (see Figs. 1, 2). Data were collected at five sites in the eastern part of the study area (S 1-5, Fig. 2) and one (S 6) near the centre of the smaller western part. *Lemna* biomass, averaged over the five April 2005 sampling dates, was greater than 1 kg/m^2 in the western part of the study area (Site 6; Table 2), in comparison with all other five sites in the eastern part where the mean biomass was less than 0.5 kg/m^2. Statistical analysis (ANOVA) showed this difference to be highly significant ($p = 0.0002$). In part, this difference was a result of the daily use of a floating boom (Fig. 4) to move much of the *Lemna* from the eastern part of the study area into the western part.

A bromatological analysis for contents of water, protein, ash, fat and fibre was performed on *Lemna* collected from Sites 1, 2, 4, 5 and 6 (too little was available for Site 3). There were no statistical differences (arc sin square root transformation of percentages) among sites tested for the above constituents. Mean percentages for these respectively were 91.2 %, 24.9 %, 13.6 %, 4.2 % and 19.4 %. These data are similar to those reported by Quispe (1999), and a special project on Lake Titicaca (Anonymous 1996).

Concluding remarks

Several different indicators of water quality conditions in Inner Puno Bay suggest that there has been a gradual deterioration over the last few decades. In the first place, water transparency is now often well below 2 m in summer and at times drops down to 0 m because of heavy coverage of floating *Lemna* mats. Secondly, dissolved oxygen concentrations now frequently drop below 1 mg/L in summer and at times down to levels of 0.6 mg/L – 0.5 mg/L or below, approaching anoxic conditions in comparison with the normally much higher concentrations in the offshore waters of Puno Bay. Probably this near-shore decrease results from

FIG. 3. *Upper left*: Inner Puno Bay shoreline showing part of the tourist walkway in early stages of construction (2002) from Puno dock to UNA on mid-right. Note the nearly complete coverage of the water surface with *Lemna*. *Upper right*: completed tourist walkway (2005) showing a boat harvesting *Lemna* for cattle fodder. *Lower left*: Inner Puno Bay (2003) looking north towards UNA; Huaje just outside picture on far right (see Fig. 1). Note the extensive *Lemna* coverage. *Lower right*: Inner Puno Bay near dock (2003). *Lemna* mat approximately 5 cm thick.

contact with high sewage inputs from Puno. In addition there has been a considerable increase in both total alkalinity and sulphate concentrations, possibly a result of increased inputs from domestic and industrial surface wastewater inputs, as well as other sources into the near-shore waters of Inner Puno Bay. *Lemna* distribution around Inner Puno Bay has broadened greatly, its floating mats have thickened, and its biomass per unit area has increased.

In the rainy season (December – February) the inadequate and poorly functioning sewage lagoon for the rapidly expanding population of Puno overflows, spreading high nutrient wastes out into the surrounding near-shore lake waters. Nevertheless there are now many more tourists coming to see the remarkable high elevation Lake Titicaca, and their first impressions are concentrated around the shoreline of Inner Puno Bay! As well as the aesthetic considerations, however, there are implications for human health, wildlife and economic activity. Present generations of young people heavily use the littoral zone for recreational purposes, as will future ones, exposing them to a high risk of infection. There are also important plants and animals living only a few kilometres away from the ever increasing and widening source of contamination, one example being the trout culture activity near Chuquito. Clearly this serious problem around Inner Puno Bay demands prompt attention and effective remediation.

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FIG. 4 *(Facing page)*. Inner Puno Bay, 2005. *Upper*: view across Inner Puno Bay towards northern end of the Western study area (see Fig. 2), with part of the floating boom (bottom of photograph) used to move *Lemna* from the Eastern study area. *Middle*: floating boom containing *Lemna* with one of the aeration spray pumps operating in the Eastern study area. *Lower left*: entrance of sewage discharge to Inner Puno Bay (near Laykakota, Fig. 1) with potato crops on left and right; *Lemna* and *Totora* beyond and Isla Esteves on left. *Lower right*: sewage canal leading to shoreline area in lower left.

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