Tropical Medicine and International Health

VOLUME 5 NO 8 PP 545–552 AUGUST 2000

Evaluation of environmental methods to control snails in an irrigation system in Central Morocco

H. Laamrani[1,3], K. Khallaayoune[1], E. Boelee[2], M. M. Laghroubi[1], H. Madsen[3] and B. Gryseels[4]

1 *Département de Parasitologie, Institut Agronomique et Vétérinaire Hassan II, Rabat, Morocco*
2 *Faculty of Medicine, Department of Parasitology, University of Leiden, Leiden, The Netherlands*
3 *Danish Bilharziasis Laboratory, Charlottenlund, Denmark*
4 *Prince Leopold Institute for Tropical Medicine, Antwerp, Belgium*

Summary The Moroccan Ministry of Public Health has launched a programme to eliminate schistosomiasis. One of the components in this process is the control of *Bulinus truncatus*, the intermediate host snail of *Schistosoma haematobium*. We evaluated three environmentally safe measures to control *B. truncatus* in siphon boxes, the main breeding sites for these snails in the Tessaout Amont irrigation system. The first method involved covering the siphon boxes to exclude light and reduce algal growth, the second consisted of increasing the frequency of emptying and cleaning the siphon boxes, and the third method increased water velocity to hinder the establishment of the intermediate hosts. The results showed that covering had a pronounced effect on snail and egg mass density, was accepted by the local community and prevented water contact. Cleaning the siphons three times during the irrigation season led to a reduction in snail density although it was not statistically significant and recolonization was rapid. Increasing water velocity by reducing the dimensions of siphon boxes delayed recolonization, but such a control measure can be applied only in specific situations where it does not pose hydraulic problems. The three interventions were selectively effective against *B. truncatus,* whereas other snails such as *Physa acuta* and *Lymnaea peregra* were hardly affected. Covering, the most promising control measure, could be useful in the Moroccan schistosomiasis eradication programme. However, further investigations are needed to assess its impact on water quality.

keywords schistosomiasis, environment, irrigation, snail control, *Bulinus truncatus*, siphon boxes, Morocco

correspondence Dr Henry Madsen, Danish Bilharziasis Laboratory, Jægersborg Allé 1D, 2920, Charlottenlund, Denmark. E-mail: hm@bilharziasis.dk

Introduction

In Morocco, urinary schistosomiasis was first mentioned in 1914. A national control programme was set up in 1982 and launched the following year in all affected provinces. The programme was successful and schistosomiasis is no longer a public health problem, although in 1997 it was still endemic in 17 of the 20 provinces where it prevailed in the early 1980s (Ministry of Health 1998). In 1993, the prevalence was reduced to a point that warranted the launching of a national schistosomiasis elimination programme in 1994 (Ministry of Health 1995). Nevertheless, prevalence has stabilized and the risk of outbreaks is still present. Case detection and treatment are the main strategy to control disease transmission, while snail control is considered an important secondary strategy by the Ministry of Health (Ministry of Health 1995). The last national meeting for the evaluation of the control progress recommended environmental control of the snail intermediate hosts as an integrated part of schistosomiasis elimination. The basic assumption of the programme is that physical control of snails will be cheaper than chemicals (Ministry of Health 1998). Moreover, recent studies in the Tessaout Amont irrigation scheme have shown that environmental methods can lead to encouraging although less effective results than a chemical molluscicide (Khallaayoune *et al*. 1998a).

Schistosomiasis in Morocco is primarily associated with irrigated agriculture. Realistic environmental control measures obviously depend on the design of the irrigation system. The options available for environmental control in irrigation canals and reservoirs are increased water velocity (Jones 1993), fluctuation of water level (Jobin 1970; Ofoezie & Asaolu 1997), periodic drying of canals (Pike 1987), removal of aquatic

macrophytes and algae (Oomen *et al*. 1990) and creating artificial shade (Khallaayoune *et al*. 1998a). In establishing new schemes, the design should prevent colonization of the system by snail intermediate hosts, e.g. by using concrete-lined rather than earth-lined canals to allow the rapid flow of water, or, if possible, sprinkler irrigation. Our objective in Tessaout Amont irrigation scheme in central Morocco was to evaluate the effectiveness of three measures to control *Bulinus truncatus* in tertiary siphon boxes. These canal structures are the main snail breeding sites (Khallaayoune *et al*. 1998a) where transmission of schistosomiasis takes place (Khallaayoune & Laamrani 1992).

Materials and methods

Study area

The Tessaout Amont irrigation system lies in the eastern part of the Haouz plain, between the eroded hills of Jebilet and the High Atlas mountains. The plain has a semi-arid to arid climate characterized by low and irregular rainfall from year to year as well as during the year. Annual precipitation in Attaouia, at the centre of the system, varies from 250 to 400 mm, with the main rainy season from October to May. In summer there is drought with the hot Saharan Sirocco wind. The mean annual temperature is 20 °C, relative humidity 54%, and evaporation 2300 mm.

The irrigation system

The irrigation system serves an area of 53 000 ha, of which 33 000 ha are equipped with modern concrete irrigation canals. This modern part is managed entirely according to the water requirements of the crop adapted to water availability. Another 20 000 ha are provided with water from the modern system through traditional canals, following traditional water rights. Traditional canals are being replaced by cement-lined ones. The system consists of a large dam with a storage lake and a diversion structure. Downstream after a sand trap, a large distribution structure conveys water to an extensive network of canals. The principal, primary, secondary and tertiary canals are cement-lined.

Primary canals (58.5 km length) are embedded with a trapezoidal cross-section. Secondary (170 km) and tertiary (720 km) canals are semicircular conduits of different sizes, often elevated above ground level. Quaternary canals are earth-lined field canals. An extensive network of drainage canals exists, complementary to the irrigation network. The elevated canals necessitate siphons to give access to fields and villages. Generally siphons are constructed to lead water under the road or track. A typical siphon consists of two rectangular boxes, usually 0.8 m × 0.8 m (or 1.1 m) × 2 m deep, connected by an underground pipe (Figure 1). Being below canal level, these boxes contain water almost permanently. In the absence of wells or natural water courses, siphon boxes are an important source of water for the local population (Watts *et al*. 1998).

Study sites

Eighteen siphon boxes located near six villages were selected. Only tertiary siphon boxes were chosen for covering and cleaning, while both tertiary and secondary canal siphon boxes were selected for being reduced in size to increase water current velocity. Criteria for site selection were based on snail density. This had to be important enough to monitor the seasonal dynamics, availability *vs.* lack of alternative water source

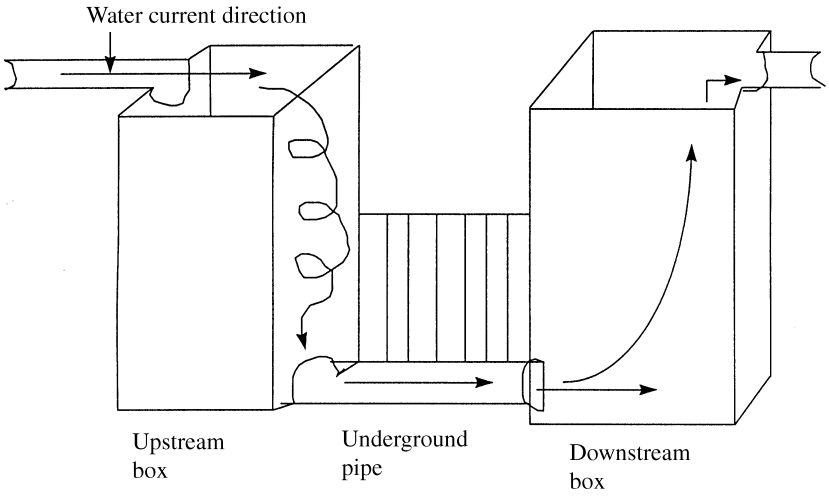

Figure 1 Schematic drawing of a siphon

for the villagers and occurrence of cases of schistosomiasis in recent surveys. Based on these criteria, study siphons were selected near Baaja (covering), Oulad Mesbah (cleaning) and Sidi Meslem/Smoun (control) villages. Criteria for selection of siphons for reduction of dimensions were based on the snail intermediate host and hydraulic considerations. It was important that the reduction of siphon dimensions should not cause overflow at the upstream part of the canal. Sites selected for this modification were located at Oulad Naceur.

Manipulation in the tertiary siphon boxes

During the pre-intervention period, snail populations were monitored from July 1995 to May/June 1996. Thereafter, modifications/manipulations were implemented and their effects on snail and egg mass density evaluated monthly for one year post-intervention.

Close to Baaja village all siphon boxes (57) were covered and three siphon boxes were followed to assess the effect of covers on snail populations and prevention of water contact. Before implementing this intervention, we obtained detailed information from a separate social science survey (Watts *et al*. 1998) on the use of water from the surrounding siphon boxes. The siphons used by the population were covered with movable steel lids that allowed access to water for domestic use. The siphons not in use were covered with fixed lids.

Close to Oulad Mesbah village, we wanted to evaluate the effect of more frequent emptying and cleaning of siphon boxes on snail populations. Normally, the siphons are cleaned once a year at most unless the underground pipe is clogged. The frequency suggested was three times a year. The boxes were cleaned after the beginning, midway and towards the end of the irrigation season that starts in May/June and ends in September/October during a season with regular rainfall. In 1996, the irrigation season was extended until December because of the low precipitation. Therefore, all siphons in the tertiary canal were cleaned in July, September and December 1996 in collaboration with the Association of Water Users for Irrigation and the local irrigation board. In the original design, three siphon boxes were selected and followed. We had to drop one due to repeated perturbations such as washing tools used in olive oil extraction or canes used to mix up pesticides in this siphon box, which caused extermination of the snail fauna. Five siphon boxes were selected as untreated control sites in Smoun and Sidi Meslem villages.

Increasing water velocity

Jones (1993) had determined that the annual mean vertical water velocity in siphon boxes with *B. truncatus* in this area did not exceed 0.04 m/s. Above this threshold, water velocity would wash out snails and prevent recolonization of the siphon boxes. Dimensions of three siphons (four boxes on a secondary canal and two boxes on a tertiary siphon) approaching this limiting velocity were reduced. Two tertiary siphon boxes with water velocity under 0.04 m/s were used as control sites. To increase velocity by 50%, concrete walls were built inside three of the four sides of the siphon boxes, reducing their interior surface area by 1/3. Before any construction work took place, the hydraulic performance of the smaller siphon boxes was checked by temporarily placing plywood boards in the interior. Trials with these boards showed that in every case the siphon boxes were considerably larger than necessary to convey the discharges required. A reduction by 30–40% did not pose any hydraulic problem.

Snail sampling methods

Densities of snails and egg masses were recorded monthly from July 1995 to June 1997 using a drag-scoop. The scoop was made of a frame 10 cm × 20 cm supporting a wire mesh (0.8 mm) mounted on a 2-m-long handle. It was used to scrape perpendicularly along the walls of the siphon box from the bottom to the surface once on each of the four sides, thus scraping an area of 4 × 20 cm × depth in cm. The number of snails and the number of egg masses was counted in the four scrapings and recorded. Snails were identified to species level and their shell height measured to the nearest millimetre using callipers. *B. truncatus* were screened for schistosome infection by exposing them individually to artificial light for 4 h, mostly between 12.00 and 16.00 h. Egg masses were also identified to species level. Within 24 h snails and egg masses were returned to the same sites where they were collected.

Chlorophyll *a* concentration in covered and uncovered siphons

In summer 1997, the chlorophyll *a* concentration in samples of water from the three covered and three uncovered siphon boxes was determined following the method described by Pearson *et al*. (1987).

Data analysis

For each siphon box, snail or egg mass counts for different seasons were logarithmically transformed (base 10) after the addition of one, and compared between treatments during specified periods by two-way analysis of variance (Zar 1984). Pairwise comparisons between treatments were done by Scheffé *post hoc* test. Student's *t*-test was used to compare water components between covered and uncovered siphon boxes.

Results

Pre-intervention period (July 1995-May/June 1996)

As shown in Figure 2, *B. truncatus* was collected throughout almost all of the pre-intervention period in the two intervention and control sites. Its density was high in July 1995 in the siphon boxes selected for cleaning and covering and lower in the control boxes. During the period November 1995–May 1996, the cleaning group of siphon boxes tended to have lower snail counts than the groups selected for coverage and control, but differences were not statistically significant, as shown in Table 1. In the two types of intervention sites, density of *B. truncatus* decreased from July 1995 to November 1995 and remained low until March/April 1996, when it started to increase. Density in the control group remained almost stable until April 1996. Few egg masses were collected during the coldest months (Figure 3). Peaks in egg mass density were recorded in late spring and early summer and no significant difference was noticed between intervention and control sites (Table 1). Figure 4 shows that the number of young snails

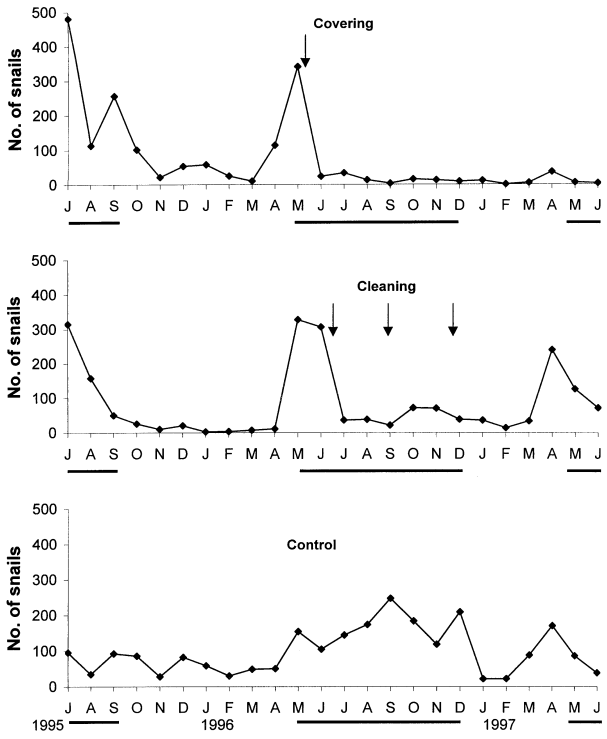

Figure 2 Seasonal changes in the number of *Bulinus truncatus* (no. collected in four drag scoops per siphon box) in intervention and control sites from July 1995 to June 1997 (the bar below the *X*-axis indicates the timing of the irrigation season).

(< 3 mm in shell height) was relatively high in summer 1995 and spring 1996. Juvenile snails were rare or even absent in some samples from November 1995 to March 1996. Thereafter, their number started to increase.

Post-intervention period (May/June 1996– June 1997)

Following the interventions of covering siphons in late May (after the sampling) and cleaning in early July 1996 (before the July 1996 sampling), marked reductions in the density of *B. truncatus* were observed for these two interventions, while density in the control siphon boxes continued to increase during this period (Figure 2). Cleaning kept the density of *B. truncatus* relatively low from July to November 1996, although the difference to the control group was not statistically significant (Table 1), but the population built up as usual the following spring (March 1997) and density and pattern were similar to that in the control. Density of *B. truncatus* remained very low in the covered siphon boxes for the rest of the post-intervention period, and was significantly different from the control during this period (Table 1). Only a minor build-up was observed in March/April 1997.

Regarding reproduction of *B. truncatus*, covering resulted in a rapid and lasting reduction in egg mass production (Figure 3). Egg mass counts decreased markedly from May to June in all three treatments and picked up again in July and August 1996 in the control group, while few egg masses were observed in the cleaned boxes during these months (Figure 3). The second cleaning did not prevent a peak in egg mass count from September to December and such a peak was not seen in the control boxes (Figure 3). However, the number of juvenile snails was generally lower in the cleaned boxes than in the control boxes during the irrigation season in 1996 (Figure 4). From March to June 1997, significantly more eggs were found in the siphon boxes that were cleaned than in the control boxes (Table 1) and the number of juvenile snails also tended to be greater in cleaned boxes than in control boxes. Covering kept the number of young snails low until the end of the post-intervention period except for a slight increase noticed in April 1997. A few juvenile snails were found in the covered boxes during the irrigation season in 1996, but since no egg masses were observed during this period, these are likely to have drifted in from upstream canal structures.

In covered and cleaned siphon boxes, interventions did not lead to a reduction in numbers of *Physa acuta*, *Lymnaea peregra, Melanopsis praemorsa and Ancylus fluviatilis* comparable to that observed for *B. truncatus* (no data presented). There was no significant difference in density of *P. acuta* and *L. peregra* between treated and control siphons. During the entire period of this investigation no schistosome-infected snails were found. However, *B. truncatus* shedding cercariae of *Paramphistomum microbothrium* were collected. Results also

Table 1 Mean number of *Bulinus truncatus* snails and egg masses for different seasons and different treatments† (i.e. Log_{10}(count + 1) ± Standard error). Sample sizes (No. of siphon boxes times no. of samplings) are given. *P*-values are from two-way analysis of variance (treatment and month for the selected periods)

	Covering		Cleaning		Control		*P*-value
Snails							
July–October 1995	12	2.13 ± 0.15	8	1.78 ± 0.28	22	1.53 ± 0.16	*n*.s.
November 1995–May 1996	21	1.48 ± 0.13	14	0.99 ± 0.18	35	1.41 ± 0.11	*n*.s.
July–October 1996	12	1.02 ± 0.12*	8	1.35 ± 0.23	20	1.90 ± 0.18	< 0.01
November 1996–February 1997	12	0.76 ± 0.14*	8	1.49 ± 0.13	20	1.51 ± 0.17	< 0.01
March–June 1997	12	0.87 ± 0.13*	8	1.68 ± 0.29	20	1.66 ± 0.13	< 0.01
Egg masses							
July–October 1995	12	0.43 ± 0.12	8	0.46 ± 0.19	22	0.37 ± 0.08	*n*.s.
November 1995–May 1996	21	0.49 ± 0.14	14	0.65 ± 0.20	35	0.46 ± 0.10	*n*.s.
July–October 1996	12	0.05 ± 0.03*	8	0.64 ± 0.27	20	0.78 ± 0.13	< 0.01
November 1996–February 1997	12	0.15 ± 0.06*	8	0.73 ± 0.22	19	0.47 ± 0.10	< 0.05
March–June 1997	12	0.10 ± 0.10*	8	1.19 ± 0.21*	20	0.54 ± 0.14	< 0.001

* Indicates significant difference from the control group of siphon boxes using Scheffé *post hoc* test

† Boxes were covered in May 1996 (after the month's sampling) and cleaning started in July 1996 (before the month's sampling)

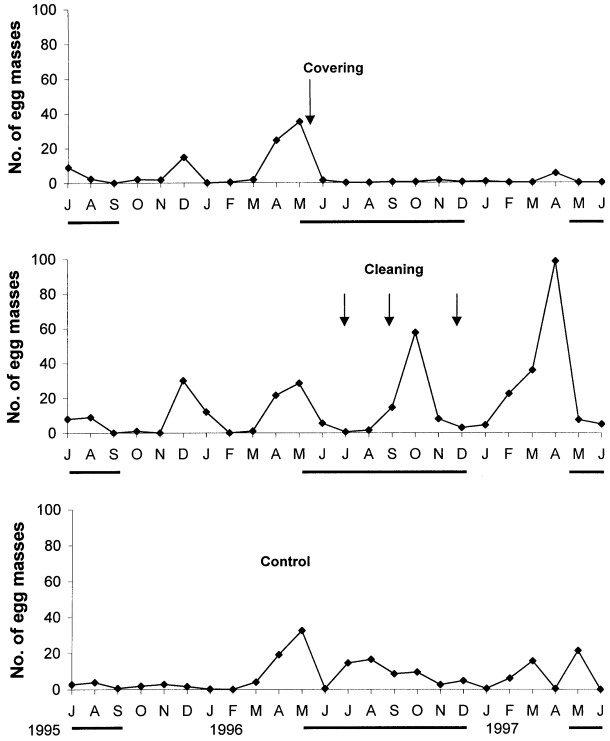

Figure 3 Seasonal changes in the number of egg masses of *Bulinus truncatus* (no. collected in four drag scoops per siphon box) in intervention and control siphon boxes from July 1995 to June 1997 (the bar below the *X*-axis indicates the timing of the irrigation season).

showed a significant difference in chlorophyll *a* content between uncovered and covered siphon boxes, 585 μg/l and 193 μg/l, respectively ($t = 4.54$, $P < 0.05$).

Increasing water velocity

Results obtained are presented in Figure 5. The dimensions of the siphon boxes were reduced after construction work and this led to the elimination of *B. truncatus* and its egg masses. Increased water velocity kept snail density low, though recolonization was fast at the secondary siphon I. Snails and egg masses were collected less than one month after the intervention at this site. In September 1996, the upstream siphon box at the secondary siphon II showed the highest snail density ever recorded after the intervention. At the tertiary siphon boxes, snail density started to increase only after the third month post-intervention.

Discussion

The outcome of this investigation could be evaluated with regard to two major points. The first and most important is that environmentally safe methods to control snails were put into effect and one of them led to results comparable to those which could be obtained using chemicals. Moreover, the ecological methods exert an effect only on *B. truncatus* and not on non-target snails such as *P. acuta* and *L. peregra*. The second point is that information on water use was a key element in the success of environmental control measures against the intermediate hosts. In a previous study in Tessaout Amont, fixed covers of

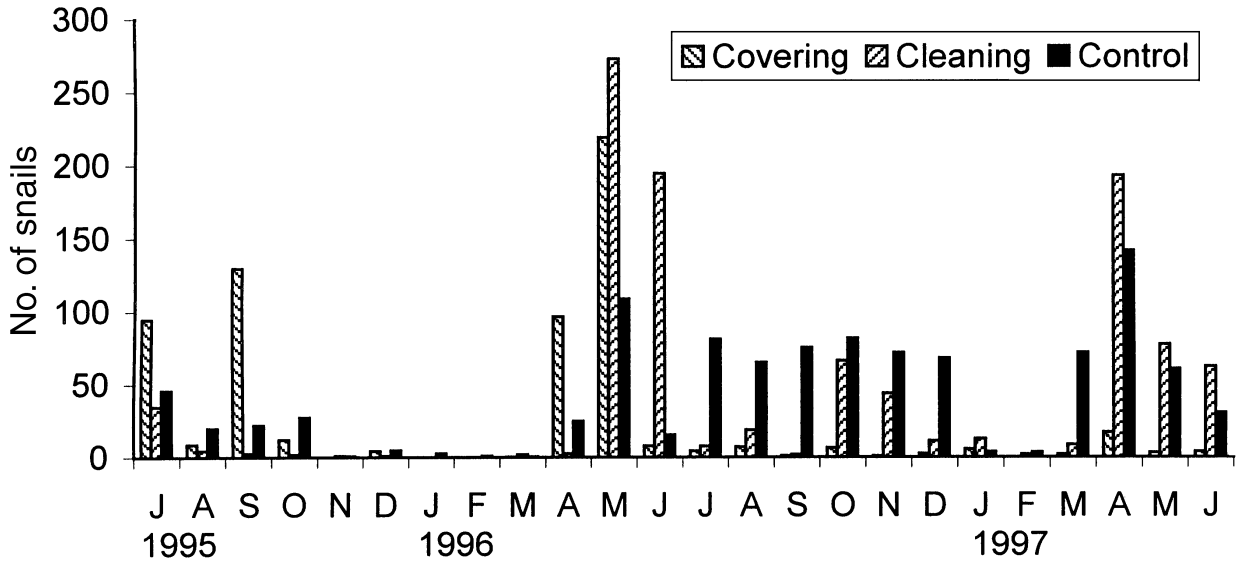

Figure 4 Seasonal changes in the number of young (shell height < 3.0 mm) *Bulinus truncatus* (no. collected in four drag scoops per siphon box) in the control and intervention siphon boxes from July 1995 to June 1997.

siphon boxes had been destroyed by villagers after eight months (Khallaayoune *et al*. 1998b).We considered the pattern of water use in the design of alternative covers.

Results reiterate that *B. truncatus* is present in the tertiary siphon boxes throughout most of the year. Snail and egg mass dynamics showed peaks in density during spring and summer. High temperatures and stagnant water conditions have been identified as factors favouring proliferation of *B. truncatus* in siphon boxes (Khallaayoune & Laamrani 1992; Khallaayoune *et al*. 1998a).

In Oulad Mesbah, villagers were involved in emptying and cleaning all siphon boxes located at the tertiary canal. Apparently the method had some effect on snail density and reproduction, but these effects were not clear-cut and of limited duration.When siphons were emptied, snails were removed but egg masses stuck to the inner walls of boxes. Although egg masses of planorbid snails do not tolerate desiccation as shown for *Biomphalaria glabrata* (Chernin & Adler 1967), the siphon boxes probably do not dry out completely during cleaning despite the high temperatures prevailing in the area during summer. A study on the microdistribution of *B. truncatus* and its egg masses within the siphon boxes showed egg masses at depths ranging from less than 0.2–1.6 m (Laamrani *et al*. 1998). Location at the deepest parts of the siphon box (which remain humid and sheltered) is likely to protect them against desiccation. Recolonization of siphons may be due to the fact that some snails could be present in the underground pipe where a small amount of water remains even when the boxes are emptied. It could also be due to snail drift from upstream structures. *B. truncatus* has a high reproductive rate as was shown by Dazo *et al*. (1966) in Egypt and therefore may rapidly recolonize modified siphon boxes.

Cleaning was less effective than brushing the siphon box sides repeatedly during each irrigation period throughout the irrigation season (Khallaayoune *et al*. 1998b). Consequently, repeated emptying and cleaning the siphons could be recommended only in situations with focal transmission in order to prevent the peak of snail density.

In covered siphon boxes, the effect of darkness on *B. truncatus* density and egg mass density was pronounced and lasted until the end of the post-intervention monitoring. A similar result had been reported for a population of *Biomphalaria pfeifferi* that was eliminated from a canal within 6 weeks after artificial shade was introduced, and recovered to the same density as in other zones within 8 weeks after removal of the artificial cover (Loreau & Baluku 1991). *B. truncatus* kept in continuous darkness under laboratory conditions showed a reduction in egg laying (El-Emam & Madsen 1982). The fact that other snail species were not affected by covers is in line with a previous observation that showed that *Potamopyrgus antipodrum* (Hydrobiidae) was not affected by artificial shading in a stream in New Zealand (Towns 1981).

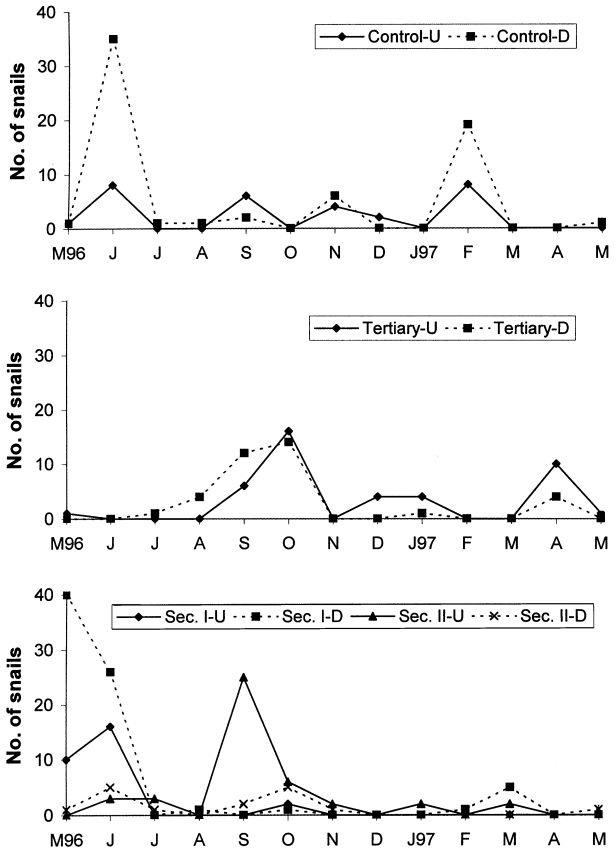

Figure 5 Changes in number of *B. truncatus* in control and modified siphon boxes (no. collected in four drag scoops per siphon box) from May 1996 to May 1997. Re-dimensioning of the siphon boxes was done in early May 1996. U and D signify upstream and downstream siphon box, respectively; Sec. I and Sec. II are secondary siphon I and II.

The decline in density of *B. truncatus* could be due to the low algal growth that was observed on the sides of siphon boxes, and it is likely that reduced density of *B. truncatus* is partly due to food limitation. The low chlorophyll *a* content recorded in the covered siphon boxes provides an additional argument on the possible role of food resource. The limiting role of food in small reservoirs was reported for *B. globosus* at the Kenya coast (O'Keeffe 1985). Nevertheless, further investigations are required to monitor the seasonal changes in snail food preferences and availability in modified and control siphon boxes. The low concentration of chlorophyll *a* noticed in covered siphon boxes indicates that covers induced a change in photosynthetic intensity. Therefore, reduction of snail density is probably due to indirect effects of covering on other habitat factors, especially food resources. The role of the snails' endogeneous factors was not investigated. Stagnant water with less photosynthetic activity would contain less dissolved oxygen and would probably be favourable to the proliferation of anaerobic microorganisms. Consequently, more investigations are needed to clarify the effects of covering on water quality considering the fact that it is used in some part of the irrigation scheme for drinking. A side benefit of this control measure pointed out by the social science survey (unpublished) consisted of a substantial reduction in the density of mosquitoes as mentioned by the villagers. However, this aspect requires further investigation.

In Oulad Naceur, reduction of dimensions delayed recolonization in only one of the two secondary siphons. Densities of *B. truncatus* remained relatively low throughout the post-intervention period. However, re-establishment of *B. truncatus*, *L. peregra* and *P. acuta* was evident sooner or later in the two other intervention siphons. This result points out that siphons are more complex habitats than canals, where the effect of water velocity was proved to be effective in snail removal (Jones 1993).

At the site where the inimical effect of increased water velocity was most pronounced, the thickness of the substratum layer (i.e. the sediment attached to the vertical sides of the boxes) was kept low by the current throughout the post-intervention period (no data presented). This could be due to the fact that it will take time for a silt layer to increase on the renovated surface of siphon boxes, or to the high water velocity that hampers silt deposits and therefore food availability. This would corroborate Appleton's (1978) finding that an adverse effect of water velocity on snails could be caused by detritus (and probably other food items) being washed out by the water current. Apparently water velocity is slow in some parts of the siphon box, which creates protected areas for snails (Laamrani *et al.* 1998). Similarly, small-scale variation in velocity creates suitable refuges for snail breeding as reported for *B. truncatus* and *Biomphalaria alexandrina* in a large canal in Egypt (Mousa & El Hassan 1972).

In conclusion, environmental measures can be effective in reducing the density of *B. truncatus*, but investigations of water use are essential for their success. The best results were obtained by covering siphon boxes. The method is well accepted by villagers as elicited by a post-intervention survey. Installation of covers is a one-time final investment of around 52 US$ per siphon box (104 per siphon), which would have a long-lasting effect, while molluscicide is a recurrent activity that requires repeated investments in chemicals, transport and labour power.

Of the three environmental methods to control snail intermediate hosts that we evaluated, covering siphon boxes may be useful to the national programme of schistosomiasis eradication. The cost would be justified in view of the side benefits and the extended impact on the control of paramphistomiasis and fascioliasis, which prevail in the region (Khallaayoune &

El Hari 1991; Laamrani *et al*. 1997). More investigations are needed on how such modifications affect snail populations, to test whether water quality is adversely affected and to explore possibilities of more local involvement in the planning and implementation of environmental methods for schistosomiasis transmission control.

Acknowledgements

This study was supported by the European Commission (Grant no. Avi. CT 93.0004). H. Laamrani had a PhD grant from The Netherlands Foundation for the advancement of Tropical Research (WOTRO, Grant no.WB 93–260)/Prince Leopold Institute for Tropical Medicine, Antwerp, Belgium. Thesis write-up at the Danish Bilharziasis Laboratory was supported by Danish International Development Assistance (DANIDA). Thanks are due to the Avicenne team, the staff of Attaouia Health Centre and 'Subdivision d'Irrigation et de Drainage' and to the farmers at Oulad Mesbah and Baaja villages for their collaboration.

References

Appleton CC (1978) Review of literature on abiotic factors influencing the distribution and life cycles of bilharziasis intermediate host snails. *Malacological Review* **11**, 1–25.

Chernin E & Adler VL (1967) Effects of desiccation on eggs of *Australorbis glabratus*. *Annals of Tropical Medicine and Parasitology* **61**, 11–14.

Dazo BC, Hairston NG & Dawood IK (1966) The ecology of *Bulinus truncatus* and *Biomphalaria alexandrina* and its implications for the control of bilharziasis in the Egypt 49 Project area. *Bulletin of the World Health Organization* **35**, 339–356.

El-Emam MA & Madsen H (1982) The effect of temperature, darkness, starvation and various food types on growth, survival and reproduction of *Helisoma duryi*, *Biomphalaria alexandrina* and *Bulinus truncatus* (Gastropoda: Planorbidae). *Hydrobiologia* **88**, 265–275.

Jobin WR (1970) Control of *Biomphalaria glabrata* in a small reservoir by fluctuation of the water level. *American Journal of Tropical Medicine and Hygiene* **19**, 1049–1054.

Jones HRR (1993) Water velocity as a control of aquatic snails in concrete canal systems for irrigation. PhD Thesis, Loughborough University of Technology, United Kingdom.

Khallaayoune K & El Hari M (1991) La fasciolose dans le Haouz. *Annales de Recherches Vétérinaires* **22**, 219–226.

Khallaayoune K & Laamrani H (1992) Seasonal patterns in the transmission of *Schistosoma haematobium* in Attaouia, Morocco. *Journal of Helminthology* **66**, 89–95.

Khallaayoune K, Laamrani H & Madsen H (1998a) Distribution of *Bulinus truncatus*, the intermediate host of *Schistosoma haematobium* in an irrigation system in Morocco. *Journal of Freshwater Ecology* **13**, 129–133.

Khallaayoune K, Madsen H & Laamrani H (1998b) Evaluation of three methods to control *Bulinus truncatus*, the intermediate host of *Schistosoma haematobium* in an irrigation scheme, Tessaout Amont, Morocco. *Acta Tropica* **69**, 51–63.

Laamrani H, Khallaayoune K, Madsen H & Gryseels B (1997) The role of *Bulinus truncatus* in the transmission of *Schistosoma haematobium* and *Paramphistomum microbothrium* in Tessaout-Amont irrigation scheme, Morocco. *Bulletin of the Scandinavian Society for Parasitology* **7**, 14–15.

Laamrani H, Laghroubi MM, Khallaayoune K, Madsen H & Gryseels B (1998) Micro-distribution of *Bulinus truncatus* in tertiary siphon boxes in Tessaout Amont irrigation system, Morocco. Preliminary results. *Proceedings of* 'Workshop on Medical Malacology in Africa', Harare, Zimbabwe, September 22–26, 1997. Danish Bilharziasis Laboratory, Denmark, pp. 185–191.

Loreau M & Baluku B (1991) Shade as a means of ecological control of *Biomphalaria pfeifferi*. *Annals of Tropical Medicine and Parasitology* **85**, 443–446.

Ministry of Health (1995) Etat d'avancement des programmes de lutte contre les maladies parasitaires. Année 1994. In: *Service des Maladies Parasitaires. Direction de l'Epidémiologie et de lutte contre les maladies*. Ministère de la Santé, Rabat, pp. 29–42.

Ministry of Health (1998) Etat d'avancement des programmes de lutte contre les maladies parasitaires. Années 1996–97. In: *Service des Maladies Parasitaires. Direction de l'Epidémiologie et des programmes sanitaires*. Ministère de la Santé, Rabat, pp. 25–44.

Mousa AH & El Hassan AAA (1972) The effect of water movements on the snail intermediate hosts of schistosomiasis in Egypt. *Journal of the Egyptian Medical Association* **55**, 255–260.

O'Keeffe JH (1985) Population biology of the freshwater snail *Bulinus globosus* on the Kenya coast. II. Feeding and density effects on population parameters. *Journal of Applied Ecology* **22**, 85–90.

Ofoezie IE & Asaolu SO (1997) Water level regulation and control of schistosomiasis transmission: a case study in Oyan reservoir, Ogun state, Nigeria. *Bulletin of the World Health Organization* **75**, 435–441.

Oomen JMV, De Wolf J & Jobin WR (1990). *Health and Irrigation*, **Vol. 1**. International Institute for Land Reclamation and Improvement, Publication 45, Wageningen, pp. 151–154.

Pearson HW, Mara DD & Bartone C (1987) Guidelines for the minimum evaluation of full scale stabilization pond systems. *Water Research* **21**, 1067–1075.

Pike EG (1987). *Engineering Against Schistosomiasis/Bilharzia. Guidelines Towards Control of the Disease*. MacMillan, New York, pp. 25–41.

Towns DR (1981) Effects of artificial shading on periphyton and invertebrates in a New Zealand stream. *New Zealand Journal of Marine and Freshwater Research* **15**, 185–192.

Watts S, Khallaayoune K, Bensefia R, Laamrani H & Gryseels B (1998) The study of human behavior and schistosomiasis transmission in an irrigated area of Morocco. *Social Science and Medicine* **46**, 755–765.

Zar JH (1984). *Biostatistical Analysis*. Prentice Hall, Englewood Cliffs, pp 206–35.