Biological Weed Control utilizing Grass Carp (*Ctenopharyngodon idella*) in Egyptian Waterways

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Abstract: In 1990, Ministry of Water Resources and Irrigation (MWRI), banned the use of chemical control methods (herbicides) to save the environment from pollutants, since then, grass carp has been used as an alternative approach for chemical method of aquatic weed control in Egypt. The objective of this research is evaluate the results of applying grass carp in the reach between High Dam and Aswan Reservoir as well as in a number of canals and drains. Also, to verify the application efficiency of reducing maintenance costs by using biological control comparing to mechanical control. The biological weed control evaluation by grass carp in Egypt of the canals and drains showed that the effectiveness of the biological weed control was higher in canals than in drains. The application success in the canals reach to 51 % with high efficiency, 40 % with medium efficiency, and 9 % with weak success efficiency, while, in the drains reach to 18 % with high efficiency, 46 % with medium efficiency, and 36% with weak success efficiency. Also, the applying biological weed control rather than mechanical weed control for Suez canal, West Al-Nubaria drain and the reach between High Dam and Aswan Reservoir reduces the costs of maintenance by about 64%, 46% and 43% respectively. As well as, the efficiency of weed control by grass carp in waterways increases when applied the correct criteria for the application of biological weed control and vice versa. In addition to, the necessary management techniques are mainly based on yearly restocking with grass carp and cooperation between waterways authorities and the professional fishermen.
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1. Introduction

Grass carp (*Ctenopharyngodon idella* Val.) is an herbivorous fish that have been introduced to Egypt since 1976 biological agent for investigating the potential application of biological weed control for its waterways. During the period 1976 -1990, grass carp was used on a trial scale at the Channel Maintenance Research Institute (CMRI) laboratories, and was applied for Egyptian channel. Ministry of Water Resources and Irrigation (MWRI), banned the use of chemical control methods (herbicides) since 1990 to save the environment from pollutants **(Bakry and Abdel-Meguid, 2001).** The biological aquatic control using grass carp (Ctenopharyngodonidella Val.), was the alternative to the chemical method **(Abdel-Meguid and Bakry, 2000 and Bakry et al., 2004).** Expansion to apply biological weed control by grass carp in Egypt to cover many canals and drains reached 75 canals managed by 24 irrigation administrations, and 14 drains managed by 14 drainage administrations as well as the reach between High Dam and Aswan Reservoir. **Abou El Ella and El Samman (2016)** mentioned that the infested percentage was evaluated before and after application for the twenty-one public irrigation directorates, the decrease in infestation in some directorate is considered weak. But it maintained the stability of aquatic weeds. Also, the estimation number of grass carp, which was stocked into the canals, was suitable to control weeds in most canals. Results have shown that, for instance, applying biological weed control, rather than mechanical weed control, reduces the costs of maintenance by about 70% **(Hosny et al., 2008)**. To increase the effectiveness of grass carp for weed control, it is necessary to stock fingerlings water ways with continuous water flow and good water quality.

In this search was verified the role of biological submerged weed control in reducing maintenance costs. **Glen (1995)** reported that cost-benefit analysis can provide much useful information for those involved in such decision making. It can also provide a framework for the scientist to look objectively in a wider context than that of scientific merit.

The objective of this research is to evaluate the results of applying biological weed control method by grass carp in Egypt at the reach between High Dam and Aswan Reservoir as well as a number of canals and drains. These verifies the application efficiency of controlling weed infestation and reducing maintenance costs by comparing to mechanical control as well as varyings the success factors and weakness of using the biological weed control by grass carp.

2. Materials and Methods

Evaluation the biological weed control utilizing grass carp in Egyptian waterways in this research was determined through two main components, the first is evaluation of the biological control of submerged weed infestation using grass carp in the different waterways, and the second is the role of biological control in reducing of maintenance costs. To verify this, using of experiments and studies to evaluate the biological control carried out by (CMRI) and (MWRI) during the period from 1987 to 2016 were evaluated.

Data of experiments and studies collected were analyzed to verify the application efficiency of controlling weed infestation on the canals during period 1987 - 2013, and drains during period 1999 - 2006 as well as the reach between High Dam and Aswan Reservoir during period 1998 – 2016. In addition, for strategic importance of Suez canal and West Al-Nubaria drain as well as the reach between High Dam and Aswan Reservoir were selected to determine the application efficiency of controlling weed infestation and reducing maintenance costs.

The evaluation elements of the biological control efficiency

The procedure followed for evaluation elements were identified to verify the biological control efficiencies (High - Medium - Weak), as follow:

- Evaluating the percentages of submerged weed infestation before and after applying biological control using Echo Sound Devices or by site investigation and observations.
- Investigate of the mechanical control prior stocking grass carp fingerlings or not.
- Investigate of fish numbers that actually stocked in the waterways and adequacy according to the CMRI criteria and calculate the percentage of fish numbers actually stocked compared to required numbers for stocking.
- Fish sampling from the waterways for their weight and examine the food content inside the fish during the evaluation period.
- Observe overfishing for the waterways during the period of application.

Verification of the role of biological control in reducing of maintenance costs have been conducted by comparing between biological and mechanical control costs through the data collected from Suez canal and West Al-Nubaria drain, as well as, the reach between High Aswan Dam and Aswan Reservoir.

Study area

For the strategic importance the study areas included, the reach between High Dam and Aswan Reservoir during the period from 2000 to 2016, forty three canals were related to apply the biological weed control (which managed by24 irrigation administrations) during the period from 1987 to 2013, eleven drains were selected to apply biological weed control (managed by14 drainage administrations) during the period from 1999 to 2006.

Suez Canal

Suez Canal is the main source of drinking water for Suez Governorate in addition to agriculture and other purposes. There are many drinking water stations on this canal; the canal feeds the water stations with water. The length of the Suez Canal is about 89 kilometres and the average width is ranging from 20 m to 25 m as shown in Figure (1). Before applying biological weed control by grass carp, this canal was suffering from submerged aquatic weed infestation that negatively affected drinking water stations by blocking water intakes in front of drinking water stations, increase the flow resistance, reduce water velocity and prevent water to reach the canal end. Suez canal is one of the first waterways were applied the biological weed control in Egypt since 1987.

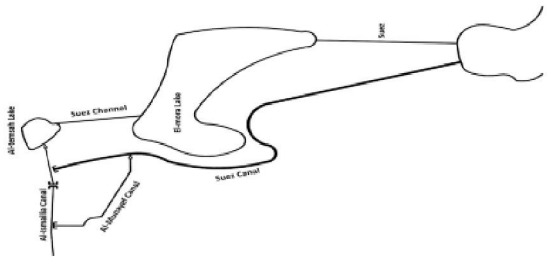

Figure 1: Map showing the Suez Canal site.

West Al-Nubaria drain

In year 1999, the first experiment was conducted to verify the application efficiency of biological weed control in Egyptian drains (brackish water) in West Al-Nubaria drain. The length of the West Al-Nubaria drain is about 68.400 kilometers with width is ranging from 12m to 25 m. Biological weed control experiment were applied to West Al-Nubaria drain for 8 months.

The experiments were divided into two reaches as shown in Figure (2).

- The biological weed control experiment using Grass carp was carries out in the first reach of length3 km from 65.400 km to 68.400 km. Fishing nets were put to prevent the fish from escaping in the experimental reach; submerged aquatic weed were removed mechanically before stocking grass carp fingerlings by one week. 36000 fingerlings weighted 13 grams each stocked it.
- The mechanical weed control applied in another reach with total length 3 km from 62.400 km to 65.400 km, the mechanical submerged weed control was carried out four times during a period 8 months.

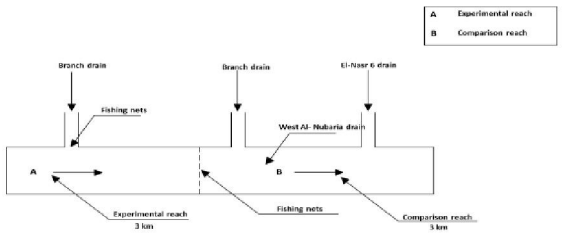

Figure 2: Schematic of reaches on the West Al-Nubaria drain.

The reach between High Dam and Aswan Reservoir

The length of the reach between High Dam and Aswan Reservoir is about 6 Kilometers and the average width is ranging from 0.5 km to 2.5 km, the total water area of the reach is about 9690450 m2. In this reach, the MWRI manages the water level in order to release sufficient amount of water to generate the hydroelectric power and to satisfy domestic, agricultural and industrial needs. In 1998, before biological weed control by grass carp, the fluctuation of water level in the reach caused fragmentation of submerged weed stems, followed by re-establishment and rapid re-growth of the fragment **(Abdel-Meguid et al., 2002)**. Drifting of submerged aquatic vegetation caused a major problem that interfered with the programs of water resource utilization and management in the reach. The drifted aquatic weeds accumulated in front of the operated pumps of the hydroelectric system in Electric Power Station (1) and (2) in Aswan and caused serious problems by clogging intake pumps. In addition to, the reach was suffering from submerged aquatic weed infestation that negatively affected the movement of tourist boats leading from and to the Temple of Phila located inside the reach. Based on the previous experiences and studies **(Abdel-Meguid and Bakry, 2000; Bakryet. al., 2004; Abou El Ella et. al., 2009 and Abou El Ella and El Samman 2013)** CMRI launched annual program for biological submerged weed control by grass carp fingerlings from year 1999 to year 2016 in the reach between High Dam and Aswan Reservoir. Biological weed control was evaluated in the reach in this period through divided into 3 sectors as shown in Figure (1), sector 1 (Right sector) with an area 3380330 m^2, sector 2 (Middle sector) with an area 781100 m^2 and sector 3 (Left sector) with an area 5519050 m^2 to calculate the percentage of aquatic submerged weed infestation **(Bakry et.al., 2004)**. The percentage of the submerged weeds infestation in the studied reach were detected by using calculated manner in seventeen sites in these three sectors as shown in Figure (3).

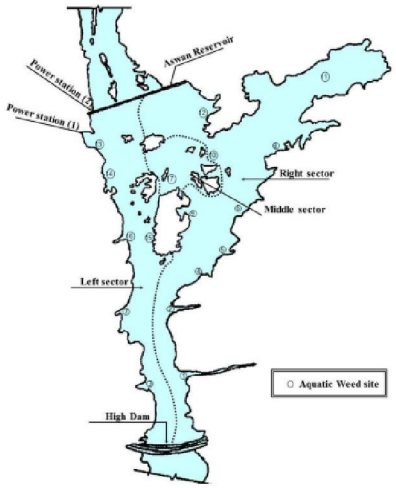

Figure 3: Schematic map showing aquatic weed sites in the reach between High Dam and Aswan Reservoir.

3. Results and Discussion

Using the grass carp in canals and the reach between High Dam and Aswan Reservoir, and in brackish water (open drains) aims to decrease the growth problem of submerged weeds. In addition to, keeping the infestation percentages of weed at an acceptable low level with a minimum cost, in the same time save water that consumed by the plants.

3.1 Controlling submerged weed infestation in the canals and drains

From the obtained results of the evaluation of biological control to verify the application efficiency for forty-three canals and eleven drains. The application efficiency of biological weed control was divided into three indicators (High - Medium - Weak) as shown in Table (1).

Tables (2) and (3) shows numbers and percentages of stocked fingerlings, infestation percentages of submerged weeds before and after biological weed control, the decrease rate of infestation, and the application efficiency.

From the obtained results of the canals and drains as shown in Tables (2) and (3), the success percentages of biological weed control were calculated in the canals and drains in Egypt, it was concluded:

- The application success of biological submerged weed control in the canals reach to 51 % with high efficiency, 40 % with medium efficiency, and 9 % with weak success efficiency, while, the application success of biological submerged weed control in the drains reach to 18 % with high efficiency, 46 % with medium efficiency, and 36% with weak success efficiency.
- The biological weed control evaluation by grass carp in Egypt of the canals and drains showed

that the effectiveness of the biological weed control was higher in canals than in drains, due to, the water velocity was higher in canals than in drains leading to high dissolved oxygen. While, in drains, the poor water quality and human activities along the drains which lead to low dissolved oxygen and some fish mortality. This interpretation agree with both **(Wells et.al., 2003 and Hofstra et.al., 2014)** they mentioned the biological weed control by grass carp in the drains could be used to remove weed, but that such control could be compromised by poor water quality. Successful weed control in the drains due to water flows velocity, water flows velocity appears to reduce the impacts of high temperatures and low dissolved oxygen, which lead to fish mortality.

Table 1: Indicators of the application efficiency using Grass carp as a biological weed control in canals and drains in Egypt.

Application efficiency	Evaluation results
High	• The infestation percentages of submerged weed before biological weed control ranged between 8 – 20 %, 15 – 20 % while, the infestation percentages after biological weed control ranged between 2 – 7 %, 5 – 7 % in the canals and drains, respectively. • Decreasing the rate of weed infestation percentage by using Grass carp ranged between 65 – 80 %, 65 – 67 % in the canals and drains, respectively. • The infestation percentages before biological weed control increased when the mechanical control was performed prior stocking grass carp fingerlings in period ranged between one month to two months, while, the infestation before biological weed control decreased when the mechanical control was performed prior stocking grass carp fingerlings in period ranged between one week to two week. • The percentage of numbers actually stocked from grass carp fingerlings was100 % from the recommended stocked for both canals and drains. • Fish sampling showed the intestines are full of weeds and the average weights of fingerlings were stocking at the end of the evaluation period ranged between 350 - 500 gram, 300 - 400 gram in the canals and drains, respectively. • Paucity of the fishermen in the canals and drains during the period of application (Non-overfishing of grass carp).
Medium	• The infestation percentages of submerged weed before biological weed control ranged between 20 – 35 %, 20 – 36 % while, the infestation percentages after biological weed control ranged between 7 – 15 %, 8 – 15 % in the canals and drains, respectively. • Decreasing the rate of weed infestation percentage by using Grass carp ranged between 50 – 65 %, 50 – 61 % in the canals and drains, respectively. • The infestation percentages before biological weed control increased when the mechanical control was performed prior stocking grass carp fingerlings in period ranged between two months to three months, while, the infestation before biological weed control decreased when the mechanical control was performed prior stocking grass carp fingerlings in period ranged between two week to one month. • Percentage of numbers actually stocked from grass carp fingerlings ranged between 53 – 83 %, 46 – 79 % from numbers required for stocked in canals and drains, respectively. • Fish sampling showed the intestines are full of weeds and the average weights of fingerlings were stocking at the end of the evaluation period ranged between 300 - 400 gram, 250 - 300 gram in the canals and drains, respectively. • A few fishermen were observed in the canals and drains engaged in fishing during the period of application.
Weak	• The infestation percentages of submerged weed before biological weed control ranged between 30 – 50 %, 40 – 53 % while, the infestation percentages after biological weed control ranged between 18 – 30 %, 30 – 40 % in the canals and drains, respectively. • Decreasing the rate of weed infestation percentage by using Grass carp ranged between 25 – 43 %, 22 – 25 % in the canals and drains, respectively. • The infestation percentages increased prior biological weed control because no mechanical control on submerged weed before stocking fingerlings. • Percentage of numbers actually stocked from grass carp fingerlings ranged between 36 – 48 %, 25 – 44 % from numbers required for stocked in canals and drains, respectively. • Fish sampling showed the intestines are full of weeds and the average weights of fingerlings were stocking at the end of the evaluation period ranged between 250 - 350 gram, 200 - 250 gram in the canals and drains, respectively. • A fishermen were observed in the canals and drains engaged in fishing during the period of application.

Table 2: Numbersand percentages of stocked fingerlings, infestation percentages of weeds before and after biological weed control and the application efficiency in the canals during the period from 1987 to 2013.

Administration name	Canal name	Numbers required for stocking (10-15gm) (10^3)	Numbers actually stocking (10-15gm) (10^3)	Percentage of stocking %	Mean of infestation percentages of total water surface % (b)	Mean of infestation percentages of total water surface % (a)	Decrease rate of infestation %	Application efficiency
Aswan	Wadi Al-Naqra	2400	2400	100	15	5	67	High
	Al-Tawisa	1950	1950	100	18	5	72	High
East Qena	Al-Kalabia	4000	2100	53	35	15	57	Medium
West Qena	Asifun	900 (40-50 gm)	750 (40-50 gm)	83	30	14	53	Medium
Sohag	Naga Hammadi East	2000	2000	100	20	6	70	High
Asyut	Naga Hammadi West	1650	1085	66	25	10	60	Medium
Menia	Sri Pasha	1900	1170	62	35	16	54	Medium
Bani Sweif	Al-Giza	228 (40-50 gm)	185 (40-50 gm)	81	25	10	60	Medium
Fayoum	Bahr Wahbi	390	390	100	15	3	80	High
Giza	Mansourieh	625	225	36	40	30	25	weak
	Dahshour	200	120	60	25	10	60	Medium
Ismailia	Suez	1800	1800	100	15	4	73	High
	Port Said	1200	1200	100	15	5	67	High
	Al-Munayef	500	500	100	15	5	67	High
Al-Salhiya	Al-Ismailia	1650	1650	100	12	4	67	High
	Al-Malak	160	120	75	30	12	60	Medium
	Al-Salhiya	900	900	100	12	3	75	High
East Al-sharqia	Bahr Moise	700	700	100	12	4	67	High
	Bahr Abou El Akhdar	700	700	100	15	5	67	High
	Bahr Faqus	650	650	100	8	2	75	High
West Al-sharqia	Bahr Moise	800	800	100	15	3	80	High
East Dakahlia	Bahr Tanah	500	300	60	20	10	60	Medium
South Dakahlia	Al-Huhia	850	700	82	20	7	65	Medium
Al-Kilyubia	Al-Basusia	400	400	100	15	4	73	High
	AL-Sharqawi	400	300	75	20	10	50	Medium
Monoufia	Al-Bajuria	1500	1500	100	15	3	80	High
	Al-Neanaeia	280	280	100	20	7	65	High
	Al-Sirsawia	150	150	100	15	4	73	High
Al-Gharbia	Al-Qasid	650	650	100	15	5	67	High
	Bahr Shebin	650	450	69	20	10	50	Medium
	Al-Ssahil	250	120	48	50	30	40	weak
West Kafr El Sheikh	Bahr Nushirat	120	120	100	15	5	67	High
	Al-Munayifa	300	250	83	33	15	55	Medium
	Al-Bahr Al-Saeidiu	350	250	71	20	8	60	Medium
Zafataa	Bahr Shebin	1100	750	68	30	12	60	Medium
Damietta	Bahr AL-Sharqawi	525	250	48	35	20	43	weak
Al-Nubaria	Al-Nubaria	2400 (40-50 gm)	2000 (40-50 gm)	83	35	15	57	Medium
Al-buhayra	Mahmoudiyah	2900	2900	100	15	5	67	High
	Al-Kanubih	100	70	70	20	10	50	Medium
	Sahil Marqas	200	90	45	30	18	40	weak
West Al-buhayra	Al-khandaq Eastern	1160	1160	100	15	5	67	High
	Sahil Marqas	560	560	100	12	3	75	High
	Dalil Al-Aintilaq	70	50	71	35	15	57	Medium

(b) Before application biological control. (a) After application biological control.

Table 3: Numbers and percentages of stocked fingerlings, infestation percentages of weeds before and after biological weed control and the application efficiency in the drains during the period from 1999 to 2006

Administration name	Drain name	Numbers required for stocking (10-15gm) (10^3)	Numbers actually stocked (10-15gm) (10^3)	Percentage of stocking %	Mean of infestation percentages of total water surface % (b)	Mean of infestation percentages of total water surface % (a)	Decrease rate of infestation %	The application efficiency
KomOmbo	Al-Atamir	110	70	64	25	10	60	Medium
South Qena	HijazaAl-Raisi	350	95	27	53	40	25	weak
North Qena	HamadAl-Raisi	550	150	27	45	35	22	weak
Sohag	Sohag Al-Raisi	885	700	79	30	15	50	Medium
Asyut	Abu Tig Al-Raisi	400	100	25	40	30	25	weak
Fayoum	Al-Gharaq Al-Raisi	300	300	100	20	7	65	High
West Monoufia	Denshawe	350	250	71	20	8	60	Medium
West Kafr El Sheikh	Nasharat Al-Asfal	162	162	100	15	5	67	High
Damietta	Namara (2)	435	330	76	30	14	53	Medium
Al-Nubaria	West Al-Nubaria	1700	750	44	40	30	25	weak
North Al-buhayra	Al-Nubaria	400	300	75	36	14	61	Medium

(b) Before application biological control. (a) After application biological control.

3.2 Controlling submerged weed infestationin Suez Canal

The biological weed control were applied during 1987 – 1996the relationship between application efficiency and percentage of stocking required grass carp fingerlings, as shown in Table (4) and Figure (4), it was concluded that:

Table 4: Numbers and percentages of stocked grass carp fingerlings, infestation percentages of submerged weeds and the application efficiency in Suez Canal as a result biological control during 1987 - 1996

Year	Numbers required for stocked (10-15gm) (10^3)	Numbers actually stocked (10-15gm) (10^3)	Percentage of stocking %	Mean of infestation percentages of total water surface % (b)	Mean of infestation percentages of total water surface % (a)	Decrease rate of infestation %	Application efficiency
1987	1800	1800	100	30	12	60	High
1988	1800	1800	100	25	8	68	High
1989	1800	1800	100	15	5	67	High
1990	1800	720	40	25	20	20	Weak
1991	1800	684	38	30	25	17	Weak
1992	1800	1800	100	25	10	60	High
1993	1800	1800	100	20	8	60	High
1994	1800	1800	100	15	5	67	High
1995	1800	1800	100	12	4	67	High
1996	1800	1800	100	10	3	70	High

(b) Before application biological control. (a) After application biological control.

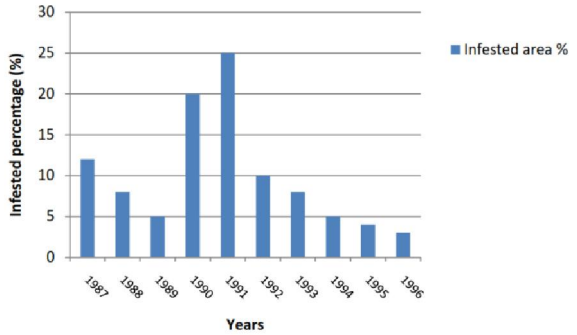

Figure 4: Infestation percentage of submerged weeds (%) in Suez canal during 1987 – 1996

- The results of biological weed control in Suez Canal hada successful results during 1987 until 1989. The infestation percentages of aquatic weed along the Suez Canal during that period decreased from 12 % in year 1987 to 5 % in year 1989 due to the percentage of stocked grass carp fingerlings reached about100 %, and following the correct steps to apply biological control according to evaluation elements.
- Then, the infestation percentages increased to 20 % and 25 % in years 1990 and 1991 due to the percentage of stocking grass carp fingerlings was not enough to control submerged weeds and reached about 40 %, 38 % from the required stocked numbers of grass carp fingerlings during 1990 and 1991.

Moreover, the infestation percentages of aquatic weed reached about 25 %,30 % during 1990 and 1991 due to these was not mechanical control prior stocking grass carp fingerlings in accordance with the criteria required.

- Then, the infestation percentages decrease from 10 % in year 1992 to 3 % in year 1996 due to the percentage of stocking grass carp fingerlings reached about 100 % from therequired numbers for stocking during years 1992 - 1996.

Consequently, the application of biological weed control using grass carp in the canal had a success results.

3.3 Controlling submerged weed infestation in West Al-Nubariadrain

Investigations and observations were conducted on the two reaches in West Al-Nubaria drain during the experiment period, the results were as follows:

- Infestation percentages of submerged aquatic weed for the total water surface before starting the experiment in two reaches were reached to 10 %. After 8 months (the experiment period) infestation reached to 1.5 % (biological), 5 % (mechanical).
- The application efficiency of biological weed control was 85 %, while, the application efficiency of mechanical weed control was 50 %.
- At the end of the experiment, grass carp fingerlings weight was about 300 grams (initial average weight was 13 grams) and 1470 kg of fish were caught.

The results of the experiment showed that, the application efficiency of biological weed control was higher than mechanical weed control.

3.4 Controlling submerged weed infestationin reach between High Dam and Aswan Reservoir

The results in Table (5) and Figure (5) show a relationship between application efficiency and percentage of stocking required grass carp fingerlings, it was concluded that:

Table 5: Numbers and percentages of stocked grass carp fingerlings and infestation percentages of submerged weeds in the reach between High Dam and Aswan Reservoir during 1998 - 2016

Year	Numbers required for stocked (10^3)	Numbers actually stocked (10^3)	Percentage of stocking (%)	Percentage of weed infestation (%)
1998	Start of evaluation			0.520
1999	1000	1000	100	0.200
2000	1600	1600	100	0.088
2001	1500	1500	100	0.085
2002	2000	2000	100	0.050
2003	1000	1000	100	0.035
2004	1000	1000	100	0.057
2005	1500	1500	100	0.070
2006	1000	1000	100	0.066
2007	1000	900	90	0.070
2008	1250	1000	80	Not evaluated
2009	1250	1000	80	Not evaluated
2010	1500	1000	67	0.360
2011	1300	1300	100	0.260
2012	1300	155	12	Not evaluated
2013	1500	1000	67	1.22
2014	2000	1000	50	1.07
2015	1000	1000	100	Not evaluated
2016	1250	1250	100	0.46

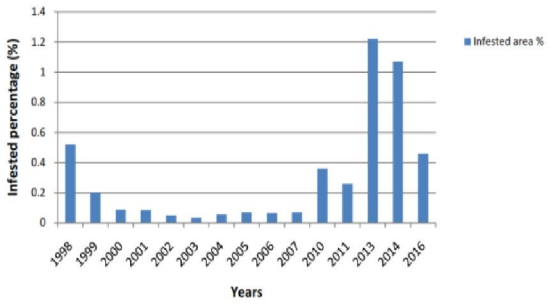

Figure 5: Infestation percentage of submerged weeds (%) in the reach between High Dam and Aswan Reservoir during 1998–2016

- The percentage of the aquatic weed infestations along the whole reach sharply decreased from 0.52 % in year 1998 to 0.07 % in year 2007 when the percentage of stocking grass carp fingerlings reached about 100 %.
- In years 2010, 2013 and 2014, the percentage of weed infestation increased to 0.36 %, 1.22 % and 1.07 %, respectively, due to the percentage of stocking grass carp fingerlings was not enough to control submerged weeds and reached about 12 %, 67 % and 50 %, respectively.
- Then, the percentage of weed infestation decrease to 0.46 % in year 2016 due to return to

enough of stocked grass carp fingerlings to control submerged weeds reached about100 % in years 2015, 2016 **(CMRI, 2016)**.

From the evaluation for the application of biological control in the reach, it was noticed that the generation efficiency of Aswan Hydropower stations 1, 2 was improved.

3.5 Reducing maintenance costs using biological submerged weed control

To identify the role of biological weed control in reducing maintenance costs a comparing between the biological and mechanical control costs for Suez Canal, West Al-Nubaria drain and the reach between High Dam and Aswan Reservoir were conducted.

Suez Canal

Through the collected data from Ismailia irrigation administration for comparing between biological weed control costs at Suez canal and mechanical weed control costs in the similar area of another canal, as shown in Table (6).

Table 6: Comparing between biological weed control costs of Suez canal and mechanical weed control costs in the similar area of another canal

Total area (m^2)	Biological control costs of Suez canal				Mechanical control costs of another canal
	Number of stocked grass carp fingerlings (10^3)	The price of stocked fingerlings (10^3 LE)	Price of mechanical control/ one time (10^3 LE)	Total price of biological control (10^3 LE)	Total price of mechanical control six times (10^3 LE)
1800000	1800	306	267	573	1602

Price/1000 grass carp fingerlings = 170 LE.

From the results of Table (6) show that the number of stocked grass carp fingerlings reached to 1800 thousand fingerlings for the biological weed control at Suez canal.

The costs of biological control in Suez canal was 573 thousand LE, divided into the costs mechanical removal of submerged weed for one time only before biological weed control was 267 thousand LE, in addition to, the costs of stocked grass carp fingerlings in Suez canal was 306 thousand LE.

The costs of mechanical control was carried out six times to removal of submerged weed was about 18 thousand LE/km/year in the same infested area for another canal similar of Suez canal, therefore, the total cost of mechanical control for length 89 km (similar water area of Suez canal) was 1602 thousand LE.

By comparing between biological weed control costs in Suez canal and mechanical weed control costs in the similar area of another canal shows that, the application efficiency by Grass carp reducing maintenance costs comparing to mechanical control by about 64 %this results agree with **(Hosnyet al., 2008)**, and the mechanical control costs about 2.80 fold that of biological control costs for the same infested area. The annual cost from biological control was 1029thousand LE/year lower than the costs of mechanical control.

West Al-Nubaria drain

Comparative experiments were conducted between biological and mechanical control of submerged weed in West Al-Nubaria drain for 8 months as shown in Figure (3). Table (7) show the comparing between biological and mechanical control costs of the experiment reach and the comparison reach in West Al-Nubaria drain.

From the results of Table (7) show that the total costs of biological control (in the experiment reach) was 11.370 thousand LE/ 8months, divided into the costs of mechanical removal of submerged weed for one time only before biological weed control was 5.250 thousand LE, in addition to, the costs of stocked grass carp fingerlings was 6.120 thousand LE. The total cost of mechanical control in the comparison reach four times to remove the submerged weed was 21000 LE during 8 months.

Table 7: Comparing between biological and mechanical control costs of the experiment reach and the comparison reach in West Al-Nubaria drain.

Total area (m^2)	Biological control costs of the experiment reach				Mechanical control costs of the comparison reach
	Number of stocked grass carp fingerlings (10^3)	The price of stocked fingerlings (10^3 LE)	Price of mechanical control/ one time (10^3 LE)	Total price ofbiological control (10^3 LE)	Total price of mechanical control four times (10^3 LE)
36000	36	6.120	5250	11370	21.000

Price/1000 grass carp fingerlings = 170 LE.

Comparing between biological and mechanical control costs of the experiment reach and the comparison reach in West Al-Nubaria drainshows that, the application efficiency by Grass carp reducing maintenance costs comparing to mechanical control by about 46%, and the mechanical control costs 1.84 fold that of biological control costs for the same infested area. The annual costs from biological control was saved9630 LE for infested area of 3 Km. Therefore, when the applications of biological weed control overall the length of West Al-Nubaria drain (68.400 km) will save219564 LE/year.

The reach between High Dam and Aswan Reservoir

During the period from year 1999 to year 2016, the biological control of submerged weed were successfully applied annually by stocked grass carp fingerlings. Mechanical control of submerged weeds were carried out once in year 2015 due to stocking incorrect numbers from grass carp fingerlings in the reach during years 2012, 2013 and 2014.

To identify the role of biological submerged weed control at the reach between High Dam and Aswan Reservoir in reducing maintenance costs by comparing the average cost of biological control during 1999 - 2016 and mechanical control in 2015. Biological control costs in the reach between High Dam and Aswan Reservoir were collectedfrom year 1999 to year 2016, as shown in Table (8).

From the results in Table (8) clear that the average annual cost of biological control in the reach between High Dam and Aswan Reservoir during 1999 -2016 was 199 thousand LE/ year. Mechanical control costs in 2015 reached to 350 thousand LE for the same infested area.

By comparing the average cost of biological control during 1999 - 2016 and mechanical control in 2015 in the reach between High Dam and Aswan Reservoir, the following is shown:

- The application efficiency by Grass carp reducing maintenance costs comparing to mechanical control by about 43 %, and the mechanical control costs reached 1.8 folds that of biological control costs for the same infested area.

Annual costs from biological control were savedwas 151 thousand LE/year, and wassaved2.400 million LE/16 year.

Table 8: Biological control costs in the reach between High Dam and Aswan Reservoir from year 2000 to year 2016.

Year	Number of stocked grass carp fingerlings (10^3)	Price/1000 grass carp fingerlings (LE)	Biological control costs (10^3 LE)
1999	1500	170	255
2000	1600	170	272
2001	1500	170	255
2002	2000	170	340
2003	1000	170	170
2004	1000	170	170
2005	1500	170	255
2006	1000	170	170
2007	900	170	153
2008	1000	170	170
2009	1000	170	170
2010	1000	170	170
2011	1300	170	221
2012	155	170	26
2013	1000	170	170
2014	1000	170	170
2015	1000	200	200
2016	1250	200	250
Average	--	--	199

Success factors and weakness of using the biological weed control by grass carp

From the results of the biological weed control evaluation using grass carp in canals and drains, as well as the reach between High Dam and Aswan Reservoir, conclude that. When applying biological weed control by grass carp, need to take into consideration the important steps for the successful application of biological weed control and weakness factors that reduce the efficiency of biological weed control in Egypt.

The important steps for the successful application of biological weed control in Egypt.

- Determinate areas, percentage of aquatic weeds, and its types in the waterways before the biological weed control application.
- Determinate the appropriate dates to stock the grass carp fingerlings for application of biological weed control (usually during February and March according to Egyptian conditions).
- Removing the weeds by mechanical control in the infested area before a week to two weeks from stocked the fingerlings, and must remove the weeds away from the sides of the waterway to prevent them falling again in the waterway.
- Prohibition of fishing in the waterways applied to them biological control for specific period (often from 9 to 10 months of stocking).
- Calculation of the fish numbers that stocked in waterway based on the total water surface area and not on the infestedarea only.
- The rates stocking of carp fish fingerlings 120 kg/ha, and the average weight for use in weed control from 10 g to 15 g.

Weaknesses factors and reducethe efficiency of biological weed control.

- Stocking incorrect numbers from grass carp fingerlings in the waterways.
- Non-compliance with the specific time periodsfor mechanical control of weeds in waterways before applying biological weed control.
- Using fingerlings weight lower than the appropriate weight forthe biological weed control.
- Fish trucks of fingerlings transport are not equipped, and non-observance of distance between fish farms and stocking places in the waterways causing to fingerlings stress and the death of some fish.
- Non-prohibition of fishing in the waterways applied for them biological control.

Conclusions and Recommendations

From the results of the research can be inferred the following:

- Evaluation the biological weed control utilizing grass carp in Egyptian waterways showed success this agree with **(Opuszynski and Shireman 1995)**, the efficiency of biological weed control increased when applying the correct criteria for the application of biological weed control and vice versa.
- Comparing with the mechanical control costs, it was found that biological weed control reduced the maintenance costs by about 64%, 46% and 43% for Suez canal, West Al-Nubaria drain and the reach between High Dam and Aswan Reservoir, respectively.
- It is recommend restocking the grass carp yearly to replace those caught by fishermen and eaten by predatory fishes, as well as the cooperation between waterways authorities and professional fishermen.

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