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Effect of stocking strategy on distribution and recapture rate of common carp in a large and shallow temperate lake: implications for recreational put-and-take fisheries management

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Short title: Common carp stocking strategies for angling

Summary

It is hypothesized that stocking procedure influences survival, growth and distribution of introduced fishes; however, there is still limited information on the effect of various stocking strategies on recaptures in natural freshwaters. The present study aimed to investigate how the rate and distribution of anglers' common carp (*Cyprinus carpio*) catches vary with the stocking season (i.e. spring, summer and autumn), lake area, method (i.e. shore and offshore releases) and fish size (i.e. ≤500 g and >500 g) in large and shallow Lake Balaton, Hungary. In 2010, 4500 two-summer old, individually tagged common carp were stocked to test 36 releasing set-ups (i.e. three seasons × three lake areas × two methods × two size groups). Anglers reported date, location and fish size (standard length and weight) on 787 recaptures within two years after the release. Recapture rate was highest in summer and lowest in autumn stockings, but it was not affected by the stocking area, method and fish size. Recaptures dispersed most in space in stockings carried out in autumn and the centre of the lake, but movement of fish was not influenced by stocking method and fish size. To conclude, in summer, stocking quotas should be evenly distributed along the entire shore line, while early spring stockings may be optimized for transport cost and concentrated by each lake basin. Late autumn stockings should be avoided, and the capacity of effective wintering ponds developed. This study also provides a good framework for testing fisheries management alternatives in other intensively fished habitats.

Keywords: angling, *Cyprinus carpio*, fisheries management, game fishes, mark and recapture, stocking strategy.

Introduction

Recreational fishery (i.e. angling) is displacing commercial fishery from freshwater habitats in developed countries, especially in Central and Western Europe and North America (Hickley, 2009). Intensive angling requires specific fisheries management. In general, anglers are selective and fish for a few valuable species, putting unbalanced pressure on fish assemblages (Vostradovský, 1991; Arlinghaus and Mehner, 2003; Hickley, 2009). Consequently, maintaining high angling activity in freshwaters generally requires stocking of the most important game fishes, especially in areas where captured fish are not returned to the water and natural recruitment is unsatisfactory.

In some European and Asian countries, common carp, *Cyprinus carpio* L., is a much preferred commercial and game fish (e.g. Czech Republic: Vostradovský, 1991; Germany: Arlinghaus and Mehner, 2003; United Kingdom: Linfield, 1980; Poland: Wolos et al., 1998). Unfortunately, due to human-induced habitat alterations, wetland draining, floodplain isolation by dykes, overfishing and intensive stocking of domesticated strains, most native wild common carp populations have become endangered (e.g. River Danube subpopulation listed as critically endangered in the IUCN Red List; Kottelat, 1996). Therefore, to maintain common carp populations and establish conditions of intensive fisheries utilization, extended stocking programmes have been implemented mainly in Central Europe.

In fisheries oriented stocking programmes, most important indicators of efficiency are the recapture rate, distribution of recaptures in space and time, and size of fish at recapture in relation to resources invested (i.e. number of fish stocked and cost of the project; Patterson and Sullivan, 2013). Generally, in the temperate region, fish stocked in spring have better survival rate than those stocked before the winter (Kennedy et al., 1982; Vostradovský, 1991), and post-stocking survival and recapture rates positively correlate with size of fish at release (Kennedy et al., 1982; Michaletz et al., 2008). Further, place of stocking can also influence survival and recapture rates (Balfry et al., 2011; Vostradovský, 1991; Michaletz et al., 2008), and movement and distribution of the released fish may vary between size-groups and sexes (Young et al., 1999; Stuart and Jones, 2006). However, although common carp is one of the most important game fishes and is stocked in large amounts in freshwater systems, there is still limited information on the effect of different stocking strategies on recaptures in natural waters (Vostradovský, 1991). In addition, to the best of our knowledge, no study has yet investigated the relationship between stocking strategy and recapture rate and distribution of common carp in large water bodies (>100 km^2).

Common carp is native to Hungary including Lake Balaton, but it has lost the majority of its natural spawning and nursery areas due to flood and wetland regulations in the last 100-150 years. Thence, in order to maintain good angling conditions for the 40 000 anglers visiting Lake Balaton each year, 250 to 350 tons of two and three-summer old (1+-2+ age groups) common carp are stocked annually. Up to the present, stockings were implemented primarily on the basis of anglers' catch statistics and available stocking resources (i.e. the capacity of rearing ponds and the income from angling licences). By now, annual stockings have reached their maximum and it has also become evident that traditional catch statistics have little relevance and cannot be used effectively for fisheries management planning. Consequently, strong motivation has arisen from anglers and fisheries managers to examine how the recapture rate and its distribution in space and time could be improved under the given stocking rate and angling activity pattern.

Accordingly, the main objectives of the present study were to investigate how the rate and distribution of common carp catches by anglers vary with the stocking season (i.e. spring, summer and autumn), lake area (i.e. Keszthely, Szemes and Siófok), method (i.e. shore and offshore releases) and size of fish at release (i.e. ≤500 g and >500 g) in Lake Balaton. It was hypothesised that: (i) recapture rate will be higher in spring and summer than autumn stockings when winter mortality is expected before the next angling season (from the end of March to the end of October in common carp), will be positively affected by fish size at release, and will be similar across stocking areas and methods; (ii) mean time between the release and recapture will be shorter in spring and summer than autumn stockings (which is trivial because carp fishing is ineffective in winter), for shore than offshore releases when fish should move to preferred inshore habitats to be exposed to fishing, will be negatively affected by size of fish at release, and will be similar across stocking areas; (iii) fish will travel longer distances and (iv) recaptures will cover larger areas in autumn, central (Szemes) basin and offshore stockings than in other stocking set-ups, and the distribution of fish will be positively affected by size of fish at release.

Materials and methods

Study area

Lake Balaton is the largest shallow lake (surface area: 593 km^2; mean depth: 3.2 m) in Central Europe, located at 46^o 42' - 47^o 04' N, 17^o 15' - 18^o 10' E and 104.8 m above sea level. The lake is meso-eutrophic with mean annual chlorophyll-*a* concentrations of 3.6-18.7 mg m^{-3} (Istvánovics et al., 2007). At present, only 47% of the lake shore is in a natural or semi-natural state and these sections are covered by reed grass *Phragmites australis*. Submerged macrophytes occur sparsely in the littoral zone. A majority of the lake area (>85%) is largely homogeneous open water providing mainly zooplankton and benthic chironomids as food for fishes. This area is inhabited by a species-poor fish assemblages dominated by bleak, *Alburnus alburnus* (L.), common bream, *Abramis brama* (L.), razor fish, *Pelecus cultratus* (L.) and introduced hybrid Asian carp, *Hypophthalmichthys molitrix* (Valenciennes) × *H. nobilis* (Richardson). The littoral zone is more heterogeneous and inhabited by a diverse fish assemblage including the common carp (Specziár et al., 2013). Angling for common carp is allowed throughout the year and individuals above 300 mm standard length (*SL*) may be kept by anglers up to maximum of three individuals per day.

Tagging and release of fish

In 2010, 4500 two-summer old (1+-2+ age-groups, depending on the season of stocking), fully scaled, less domesticated (c.f. Klefoth et al., 2013) common carp were tagged with Floy® FD-68BC T-Bar Anchor Tags (2 × 38 mm; www.floytag.com) of orange colour and marked with unique tag numbers as well as the name and address of the Balaton Limnological Institute. All experimental fish were hatched and reared in the fish farm of the Balaton Fish Management Non-Profit Ltd. and belonged to the same strain. Tagging was performed in the fish farm, near the pond from which experimental fish were obtained by seine netting. Only fish in good condition and with no visible signs of disease or injury were used. Fish were anesthetized in groups in a 0.1 g l^{-1} solution of clove oil prior to tagging. Each fish was measured for *SL* and body mass (*M*) to the nearest 1 mm and 1 g, respectively. Tagging was made with the maximum accuracy in order to achieve the best possible tag retention. All tags were inserted by the same long-experienced person (B. Turcsányi, with 15 years of tagging experience) between the pterygiophores of the dorsal fin with a Floy® tagging gun (www.floytag.com). As such, the T-bar leaned against two neighbouring pterygiophores and from the other side the tag body hung out of the fish. In each individual, the inserted tag was pulled slightly to ensure that it was fixed properly, and thereby minimize initial tag loss (Booth and Weyl, 2008). Tagged fish were transported from the fish farm to the stocking site or the nearest harbour (for offshore stocking) by tanker truck in oxygenated water, at a biomass density of <160 kg m^{-3} (each experimental group of 250 individuals was transported in a separate tank filled with 1 m^3 culture pond water).

Tagged fish were released seasonally (i.e. in spring, summer and late autumn), at three lake areas (Keszthely, Szemes and Siófok) and both from the shore and offshore, at standard locations (Table 1, Fig. 1). Accordingly, common carp were released in groups of 250 tagged individuals representing 18 stocking trials (Table 1). Upon arrival to the lake, fish were acclimated to ambient water temperature. At shore sites, fish were released to the water directly from the tanker truck by a flexible tube. For offshore stocking, tagged fish were taken by a boat equipped with tanks suitable for safely carrying fish, and then fish were released to the water 2 km offshore by buckets. Before being released, fish in each tank were checked again for viability, and the bottom of the tank was searched for lost tags. No post-handling tag loss and injury were observed among the tagged fish.

Recapture of fish and data processing

Tagged fish were recaptured and reported by the anglers. The experiment, its goal and a guide of how the tagged fish should be processed and reported were advertised in written and electronic media and an instruction was also enclosed to each angling licence. However, no information was provided to the anglers about the study design, including date and size at which fish were released. Anglers were instructed to report (either by mail, email or phone) tagged fish irrespective of size, but after measurement undersized fish (i.e. <300 mm *SL*) were to be released back into the lake. Anglers were asked to provide information about the date and location (i.e. nearest settlement and street, estimated distance from the closest unambiguous geographical point or GPS coordinate) of the catch and the size (either *SL* or *M*, preferably both) of the fish at capture. Anglers were distinctly instructed to indicate also if they were not able to provide precise data and were rewarded identically. Ambiguous data were handled as missing information. In order to certify the recapture, anglers were asked to cut the tag and send it (by mail or personally) to the Institute. Consequently, multiple recaptures could not be monitored. It has been shown that an adequate reward significantly increases reporting rate (Denson et al., 2002). Therefore, anglers reporting tagged fish received a bonus (3000 HUF≈10 EUR, which is about one half of the average daily net wage in Hungary) to be added to their next licence.

MapSource version 6.16.3. software (Garmin Ltd.; www.garmin.com) and the NaviGuide Hungary version 6.51 map layer (Navi-Gate Ltd.; www.garmin.hu) were used to process distribution data of recaptured fish. Distance (i.e. shortest route in the water) between the release and recapture locations was assessed for each fish. The distribution of fish by release strategy was characterised with the length of shore line (i.e. potential angling area), measured separately for the northern and southern shore lines, covered by the first 50, 75 and 90% of recaptures according to their distance from the release point.

Statistical analysis

The present study relies on assumptions that reporting rate (i.e. number of reports sent per number of actually captured tagged fish) was similar for all size-groups, capture season and area and that tag retention rate did not vary between releasing strategies. Note that, under the applied experimental setup, testing the study hypotheses does not require any information on the absolute value of the tag retention and reporting rates and on the level and distribution (either in time and space) of the fishing effort (for more details see discussion).

Reported recapture rate (thereafter ‘recapture rate’) and the distribution of recaptures in time and space were tested by using analysis of variance (ANOVA) to the second degree of factor interactions except hypothesis (iv) where only main effects could be analysed. For statistical analysis, fish were grouped into two size-groups (≤500 g and >500 g) based on their *M* at release and supported by the preliminary experiments (Specziár, 2010). Accordingly, 36 releasing set-ups were differentiated on the basis of four explanatory factors: season (i.e.

spring, summer and late autumn), area (i.e. Keszthely, Szemes and Siófok basins), method (i.e. shore and offshore) and fish size (i.e. ≤500 g and >500 g *M*) of release. To test study hypotheses, separate ANOVAs were performed evaluating effects of the four explanatory factors (i) on the recapture rate, (ii) number of days fish spent in lake, (iii) distance between the release and recapture sites, and (iv) shore line length covered by the first 50, 75 and 90% of recaptures, based on their distance from the release site. Percent recapture data were arcsin square-root transformed, whereas the other response variables were $\log_{10}(x+1)$ transformed prior to analysis. In case of significant factor effect ($P<0.05$), ANOVA was completed with Tukey HDS post hoc test. In order to ensure comparability across releasing strategies, only data of fish recaptured within two years (730 days) after release were considered in the above analyses.

Results

Reported recapture rate

Altogether 787 recaptures (17.5% of the fish released) were reported within 730 days after release (Table 1). Recapture rate varied between stocking seasons, but not between lake areas, methods and fish size-groups and all combinations of second degree factor interaction were also unimportant (Table 2). Recapture rates were unequivocally highest in summer (25.9%±6.6%; mean±SD; Tukey HDS post hoc test, $P<0.05$), followed by spring (17.0%±3.8%) and least in late autumn stockings (10.4%±3.3%).

Time in lake

Recaptures started with four months delay in the late autumn, but immediately in spring (two days after release) and summer stockings (on the day of the release) (Fig. 2). Catches showed a marked seasonality; very few common carp were caught at <8 ^{o}C water temperature (i.e.

from November to March) and most recaptures were reported from June to September at 16-25 ^{o}C (Fig. 2). Depletion of recaptures was rapid; 88.6%±5.9% of the 730 days recaptures occurred within the first year after release of fish (i.e. within 365 days after release) and only 11.4%±5.9% in the second (Student's t-test, t_{70}=55.9, P<0.001).

The number of days from release to recapture was evidently influenced by the stocking season (Table 2) and common carp released in late autumn spent much longer periods (271±119 days) in lake than those released in spring (152±106 days) and especially in summer (123±146 days; Tukey HDS, P<0.05).

Distribution of fish

The majority of recaptures were reported from the littoral zone and only 19 common carp were caught >300 m offshore and 15 in southern inflows. Individual fish showed remarkable differences in their movements; some specimens travelled >60 km within 60-150 days, but others were recaptured <3 km distance from the release point even after two years in lake (Fig. 3). Therewith, the mean distance of recaptures from the release points varied significantly between stocking seasons and areas and was affected by the interaction of season and area and season and method of stocking, but not by the method of release and the size of fish at release (Table 2). Namely, common carp released in autumn were recaptured at highest mean distance (23.0±17.1 km) from the stocking point, followed by spring (18.5±15.3 km) and summer-released fish (10.5±11.5 km; Tukey HDS, P<0.05). Individuals stocked at Szemes moved a longer mean distance (18.2±11.9 km) than those released at Siófok (13.9±13.4 km) and Keszthely (14.3±18.0 km; Tukey HDS, P<0.05). Further, in the summer stockings, fish released offshore were captured at a slightly longer mean distance (11.7±13.3 km) from the stocking site than those released from the shore (9.4±9.7; Tukey HDS, P<0.05).

Lake area covered by 50, 75 and 90% of recaptures also varied significantly between releasing strategies, and it was influenced by the season and area of release. Recaptures dispersed in space more in autumn and spring and Szemes stockings than in summer and Siófok and Keszthely stockings (Table 3, Fig. 4).

Discussion

The present study is the first reporting relative effects of different stocking strategies for large lake put-and-take recreational common carp fishery. In Lake Balaton, total reported recapture rate was 17.5%, which falls within the upper range observed by other tagging studies. Tagged common carp were recaptured at a rate of 16.6% in the Lipno reservoir and 15.0% in the Vlatava River, Czech Republik (Vostradovský, 1991), 8.3% in the Monelho Reservoir, Czech Republik (Baruš et al., 1997) and 8.8% in an Australian river (Stuart and Jones, 2006). The total 787 reports of recaptured fish along with the symmetrical study design provided an excellent opportunity to evaluate the relationship between particular stocking strategies (i.e. season × lake area × method × fish size-group) and recaptures by anglers. It was shown that stocking strategy influenced both recapture rate and the extent of the lake area over which recaptures distributed.

Fish released in summer and spring were much more likely to be recaptured than those released in late autumn. This result is in accordance with findings of Vostradovský (1991) in Lipno Reservoir and indicates an overwintering risk on recapture. In winter, Lake Balaton is not a benign habitat, especially not for freshly-stocked fish unfamiliar with the environment. This large, shallow and open lake is heavily exposed to strong winds disturbing the water to the bottom. Pond-reared common carp stocked into the lake in late autumn have little chance to find appropriate wintering sites rapidly and thus have to waste their energy reserves moving against the exposed, turbid water in ice-free periods (c.f. Ruuhijärvi et al., 1996). In addition, fish are generally released along the southern shore line of the lake, which is the shallowest and most wind-exposed part of the lake with very few wintering sites and poor food resources. Most of the wintering sites occur along the northern shore line, which is less exposed to dominant northern winds and has ideal water depth (1.5-3 m) and richer food resources. However, those sites are located far from the culture ponds established on the southern inflows of Lake Balaton, and therefore it would be much more costly to transport and release fishes there. On the contrary, common carp stocked in spring and especially in summer can immediately feed, and thus, are less exposed to starvation and related mortality.

Although the offshore area of Lake Balaton is not a preferred habitat of common carp (Specziár et al., 2013), individuals released there were recaptured at the same rate as those released from the shore. This observation along with the finding that common carp were captured only sporadically offshore indicated that stocked fish moved rapidly to the littoral zone. Dispersion of stocked fish is very important for consistent angling facility. Since most anglers knowing habitat preference of common carp fish it in the littoral zone, and thus, fisheries managers assumed that offshore stocking could provide more time to fish dispersing before reaching the preferred angling areas. Therefore, a part of the annual stocking quota now is released offshore. However, individuals released offshore did not disperse over larger areas than those released from the shore, except in summer when recaptures were most rapid. Accordingly, instead of the costly offshore stockings, it would be more beneficial to distribute stocking quotas among more shore sites. Prevalence of the latter strategy is also supported by that there was no difference in the recapture rate between stocking areas.

Since body size is a crucial factor in most ecological processes influencing mortality of fish (Houde, 1997; Schultz and Conover, 1999), we supposed that fish size will have a positive effect on the recapture rate. However, results did not prove a definite size-specific pattern within the studied size range. Present results also contradict our preliminary observations based on series of individual stocking trials (with limited comparability) with much more variable size-groups of common carp (Specziár, 2010), which indicated a strongly decreasing recapture rate below 500 g *M* stocking size and with practically no recaptures at <150 g *M*. Similarly, size of fish at release did not affect the time of recapture or the distribution of individuals.

Recaptures depleted at a rate of 89% year^{-1}, which is concordant with the results of all preliminary common carp tagging experiments in Lake Balaton (Specziár, 2010). Similarly, rapid depletion of recaptures was observed in other preferred game fishes, such as for instance in the white bass, *Morone chrysops* (Rafinesque), in the Brazos River and Whitney Reservoir, Texas USA (Muoneke, 1992) and in the red drum, *Sciaenops ocellatus* (L.), in South Carolina and Georgia estuaries, USA (Denson et al., 2002). Although tag loss (discussed below) and natural mortality might also contribute to this pattern, in our opinion this primarily indicated the extremely high angling pressure on common carp in Lake Balaton.

The mean distance between the release and recapture locations and the extent of the lake area over which recaptures distributed depended clearly on the mean time that stocked common carp spent in lake. Namely, fish moved longer distances and dispersed over larger areas in cold water stockings (i.e. in late autumn and spring) than in summer stocking when mass recaptures started immediately. Moreover, common carp released in the middle of the lake (i.e. at Szemes) dispersed over larger areas than those released at either end (i.e. at Keszthely or Siófok) of the elongated-shaped lake. In the present study, common carp dispersed over larger distances than in most other experiments. For example, Stuart and Jones (2006) found that 66% of the recaptured common carp remained within 1 km of their release location and only 20% of fish were recaptured at >5 km distance over 1107 days of monitoring in the Murray River, Australia. However, in that study, experimental fish were caught from the river near the release site, and therefore those wild individuals were familiar with their environment and might have defined home ranges to which they held to after release as well. Site fidelity is characteristic for common carp (Jones and Stuart, 2007) and its strength was also proved by the homing behaviour of displaced wild-caught individuals (Schwartz, 1987). On the other hand, Vostradovská and Vostradovský (1980) found that pond-reared common carp stocked into the River Vltava also stayed in <5 km vicinity of the release site and few specimens migrated up to 20 km either upstream or downstream. Accordingly, further studies are needed to explore factors influencing the dispersion of stocked and wild common carp.

Unavailability of detailed data on the rate and pattern of tag loss, anglers' reporting level and fishing effort generally limits evaluation of the processes underlying the observed recapture patterns in larger waterbodies (Denson et al., 2002; Booth and Weyl, 2008). However, in the present study, thanks to the symmetrical study design and problems tested, it was not essential to know the reporting level and fishing effort. Note, that this study did not ask any questions about stock size, mortality rate, vulnerability of fish to angling and total angling catch per unit effort or yield; simply, it was asked which stocking strategy yields most recaptures from the largest area and time interval under the given and not exactly known fishing activity. The only required assumption in this respect was that the reporting level did not change systematically among stocking strategies tested, a criterion that was very likely to be met considering the short time-frame and the design of the experiment. Nevertheless, it remains a weakness of this study that individual effects of biotic (i.e. mortality and behavioural variations of fish) and human factors (i.e. variations of fishing effort) could not be identified just their resultant. On the other hand, tag loss could influence the result at least in one respect. Namely, fish released in late autumn spent significantly longer periods in lake and thus were more exposed to eventual tag loss than those released in spring and especially in summer. This bias might cause an underestimation of recapture rate for fish released in late autumn. However, recapture rates differed so much between the late autumn and spring and summer stockings (1.7 and 2.5 times, respectively) that the observed deviation was very unlikely to be an artefact caused only by the tag loss. In addition, several studies proved that with well-experienced staff and proper insertion of tag and handling of experimental fish, very high tag retention up to 89-96% year^{-1} can be achieved with T-bar anchor type tags (Ebener and Copes, 1982; Buzby and Deegan, 1999; Livings et al., 2007). High tag retention rate was also supported by lifespan recaptures of asp, *Aspius aspius* (L.) and tench, *Tinca tinca* (L.) in Lake Balaton (Specziár, 2010). However, a little bit lower, 71%, tag retention rate was assed for wild captured common carp in an Australian river (Stuart and Jones, 2006).

To conclude, the present study provided valuable information for improvement of recreational fisheries management in Lake Balaton, especially how to disperse annual stocking quotas across seasons and lake areas to achieve highest rate and distribution of recaptures. It is suggested that the more costly offshore stocking might be beneficial only in summer, when it may facilitate initial dispersion of common carp before recaptures. It is also suggested that in summer fish should be released at several sites distributed evenly along both the southern and the northern shore lines of the lake. On the contrary, cold water spring stockings may be optimized for transport cost and made at fewer easily accessible sites in each lake basin along the southern shore line close to rearing ponds. However, late autumn stockings should be avoided, and the capacity of effective wintering ponds is suggested to be developed. The present study also provides a good framework for testing fisheries management alternatives in other intensively fished habitats.

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Table 1

Specifications of stocking trials including season, area and method of release, water temperature (*T*), number (N_r), standard length (*SL*) and body mass (*M*) of fish released and total number of reported recaptures within 730 days by anglers (*N*) in Lake Balaton, Hungary.

Release										Recapture	
No.	Date	Area	Method	*T* (°C)	N_r	*SL* (mm)		M (g)		$N_{730days}$	%
						Mean±SD	Range	Mean±SD	Range		
1.	30.03.2010	Keszthely	shore	8.2	250	254±19	200-300	457±85	243-710	38	15.2
2.	30.03.2010	Keszthely	offshore	8.2	250	255±18	190-300	434±81	225-625	42	16.8
3.	30.03.2010	Szemes	shore	8.2	250	259±20	200-310	485±92	274-781	43	17.2
4.	31.03.2010	Szemes	offshore	8.2	250	254±20	200-310	492±99	236-831	43	17.2
5.	31.03.2010	Siófok	shore	8.2	250	250±18	200-285	478±99	234-769	30	12.0
6.	31.03.2010	Siófok	offshore	8.2	250	255±21	190-310	506±117	240-968	54	21.6
7.	13.07.2010	Keszthely	shore	23.6	250	265±21	220-330	554±122	300-897	67	26.8
8.	13.07.2010	Keszthely	offshore	23.6	250	256±27	190-340	463±151	187-1025	61	24.4
9.	13.07.2010	Szemes	shore	23.6	250	268±21	220-320	565±127	300-960	65	26.0
10.	12.07.2010	Szemes	offshore	23.3	250	269±21	200-330	586±123	193-890	43	17.2
11.	12.07.2010	Siófok	shore	23.3	250	272±20	230-330	601±117	350-922	80	32.0
12.	12.07.2010	Siófok	offshore	23.3	250	274±18	230-330	616±124	385-1015	74	29.6
13.	23.11.2010	Keszthely	shore	3.4	250	233±25	170-300	367±117	174-764	23	9.2
14.	23.11.2010	Keszthely	offshore	3.4	250	234±28	170-320	375±133	158-825	31	12.4
15.	23.11.2010	Szemes	shore	3.4	250	245±27	200-350	421±138	222-1110	31	12.4
16.	07.12.2010	Szemes	offshore	3.3	250	228±27	180-330	355±138	172-1435	22	8.8
17.	07.12.2010	Siófok	shore	3.3	250	225±26	180-310	335±110	160-698	27	10.8
18.	07.12.2010	Siófok	offshore	3.3	250	234±30	180-340	378±149	179-1020	13	5.2
	Total				4500					787	17.5

Table 2

Results of the ANOVA on the effect of stocking season, lake area, method (i.e. shore and offshore stockings) and fish size on arcsin square root transformed 730 days recapture rate by anglers (%), and $\log_{10}(x+1)$ transformed days spent in lake and distance travelled between releasing and recapturing sites of tagged common carp in Lake Balaton.

	Recapture rate			Days in lake			Distance travelled		
	d.f.	F	P	d.f.	F	P	d.f.	F	P
Season	2	36.1	<0.001	2	70.7	<0.001	2	41.3	<0.001
Area	2	1.2	0.327	2	1.6	0.209	2	19.5	<0.001
Method	1	0.1	0.821	1	0.1	0.807	1	0.0	0.901
Fish size	1	2.9	0.109	1	0.7	0.397	1	1.4	0.242
Season × area	4	1.5	0.257	4	2.9	0.021	4	3.6	0.007
Season × method	2	2.2	0.146	2	0.7	0.508	2	5.4	0.005
Area × method	2	1.2	0.341	2	2.4	0.092	2	0.4	0.649
Season × fish size	2	0.1	0.894	2	0.2	0.787	2	0.2	0.828
Area × fish size	2	1.5	0.248	2	1.5	0.220	2	2.0	0.135
Method × fish size	1	0.6	0437	1	0.0	0.979	1	2.5	0.115
Error	16			767			760		

Table 3

Results of the ANOVA on the effect of stocking season, lake area and method (i.e. shore and offshore stockings) on $\log_{10}(x+1)$ transformed shore line length data covered by the first 50, 75 and 90% of common carp recaptures according to their distance from the release point in Lake Balaton, Hungary. Results of the Tukey HDS post hoc tests are reported for significant single factor effects (at P<0.05) in total shore line. Note that the effect of fish size could not be tested due to limited sample sizes, but fish ≤500 and >500 g body mass were recaptured at equal mean distances from the release point (Table 2).

		Southern shore line		Northern shore line		Total shore line		
	d.f.	F	P	F	P	F	P	Tukey HDS (P<0.05)
50% of recaptures								
Season	2	3.6	0.060	8.5	0.005	8.6	0.005	Autumn, spring > summer
Area	2	3.9	0.050	5.2	0.023	6.4	0.013	Szemes > Keszthely
Method	1	0.8	0.391	0.0	0.978	0.3	0.592	
Error	16							
75% of recaptures								
Season	2	9.2	0.004	12.8	0.001	13.0	<0.001	Autumn, spring > summer
Area	2	17.1	<0.001	9.5	0.003	14.6	<0.001	Szemes > Siófok, Keszthely
Method	1	1.7	0.210	3.9	0.072	3.4	0.090	
Error	16							
90% of recaptures								
Season	2	2.4	0.131	25.0	<0.001	11.1	0.001	Autumn, spring > summer
Area	2	9.0	0.004	14.9	<0.001	13.9	<0.001	Szemes > Siófok, Keszthely
Method	1	4.1	0.067	0.0	0.855	2.1	0.175	
Error	16							

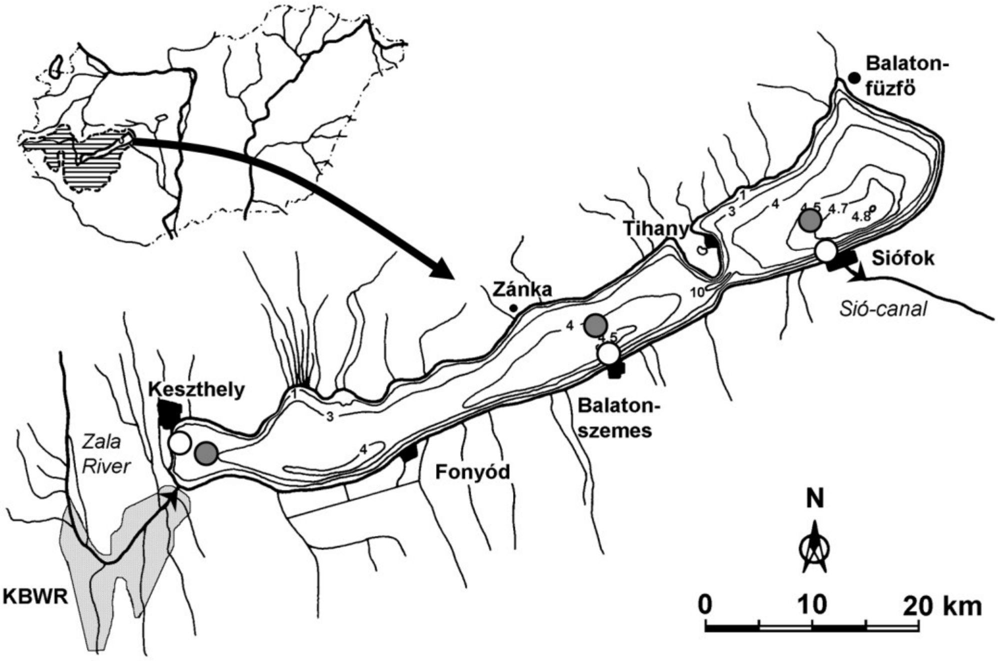
Figure captions

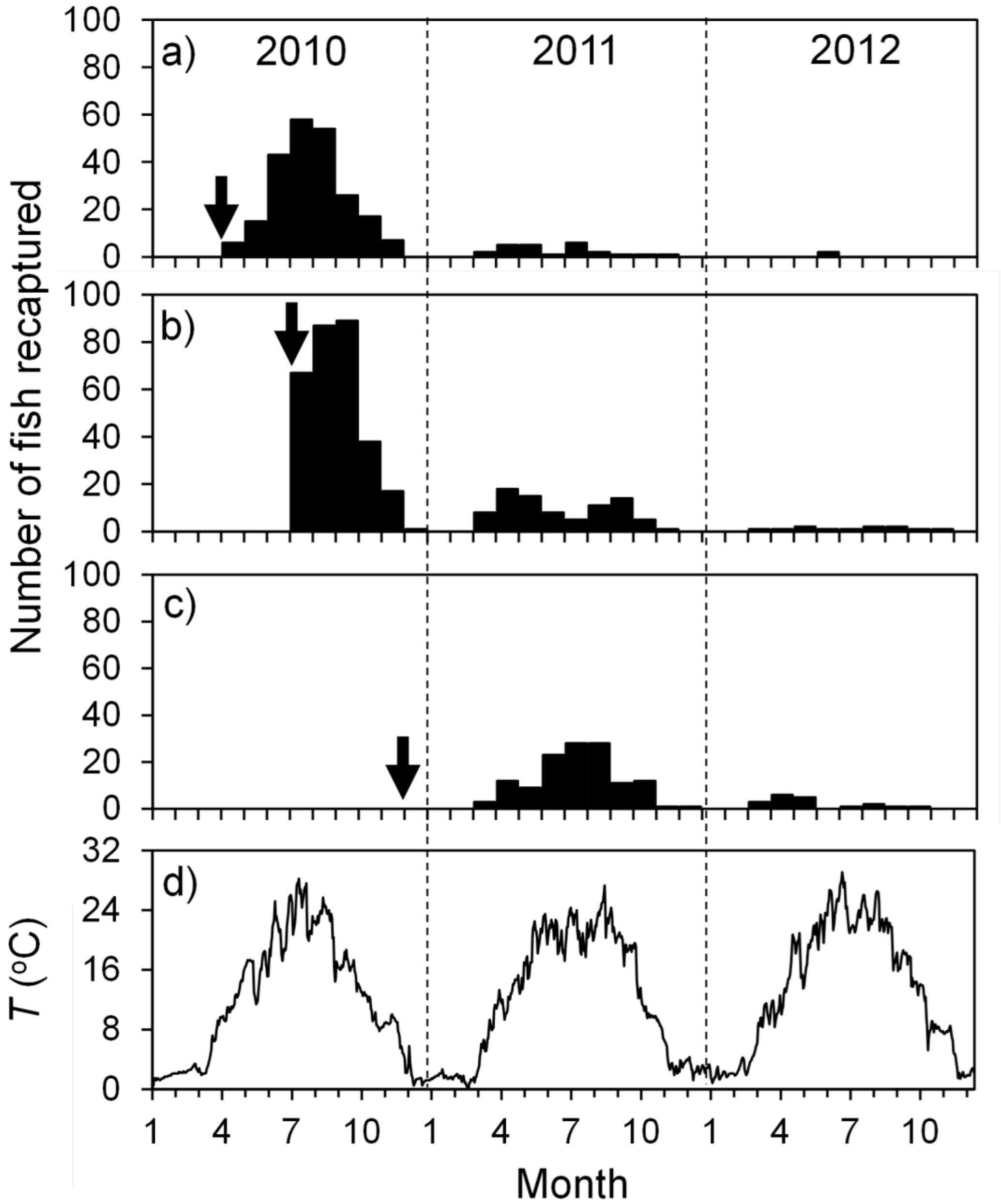
Fig. 1. Map of Lake Balaton (Hungary) and the major tributaries, with indication of shore (white circles) and offshore (grey circles) stocking sites.

Fig. 2. Seasonal recapture dynamics of common carp stocked in spring (a), summer (b) and autumn (c) in relation to water temperature (d) in Lake Balaton, Hungary. In each stocking season 1500 tagged fish were released (Table 1). Stocking events are indicated by arrows.

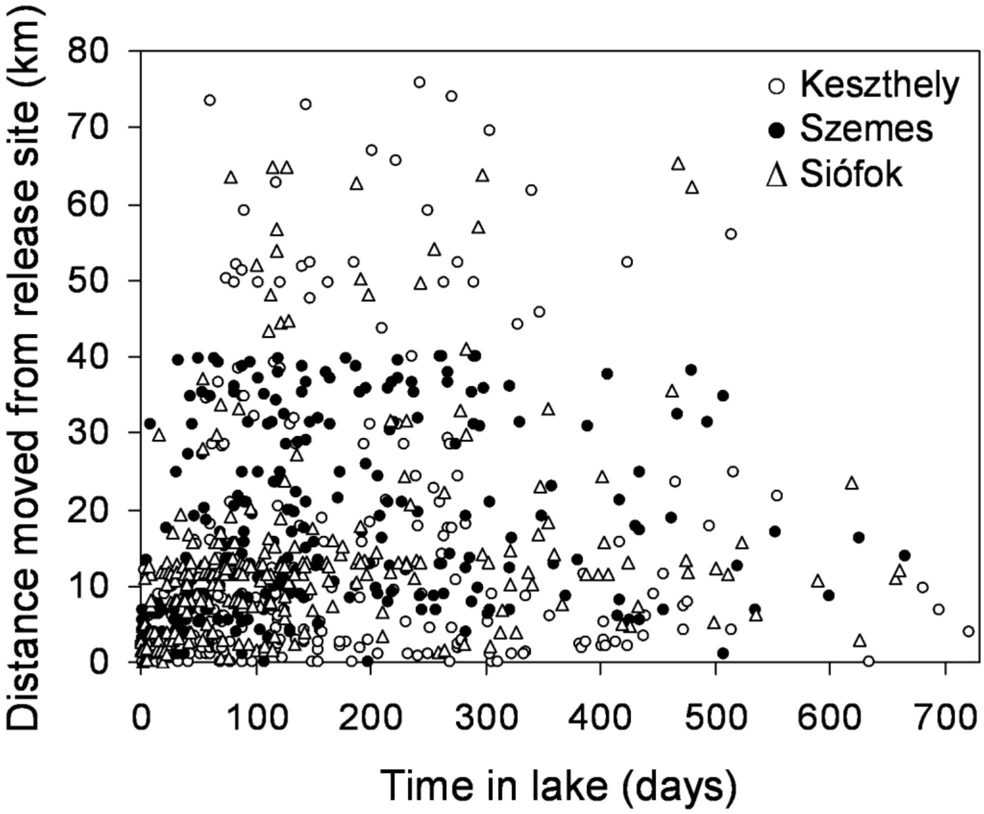
Fig. 3. Distance between the release (i.e. Keszthely, Szemes, Siófok) and recapture locations of stocked common carp in relation to days spent in Lake Balaton, Hungary. Note that Szemes is located approximately at the middle of the longitudinal axis of the lake and thus fish released here can move away maximum 40 km.

Fig. 4. Length (km) of northern and southern shore lines (i.e. fishing area) covered by the first 50, 75 and 90% of recaptures according to their distances from the release site in Lake Balaton, Hungary. Results indicated longer dispersion distances in spring and autumn than in summer and for fish released at Szemes (Sz) than at Keszthely (K) and Siófok (S) (for statistics see Table 3).

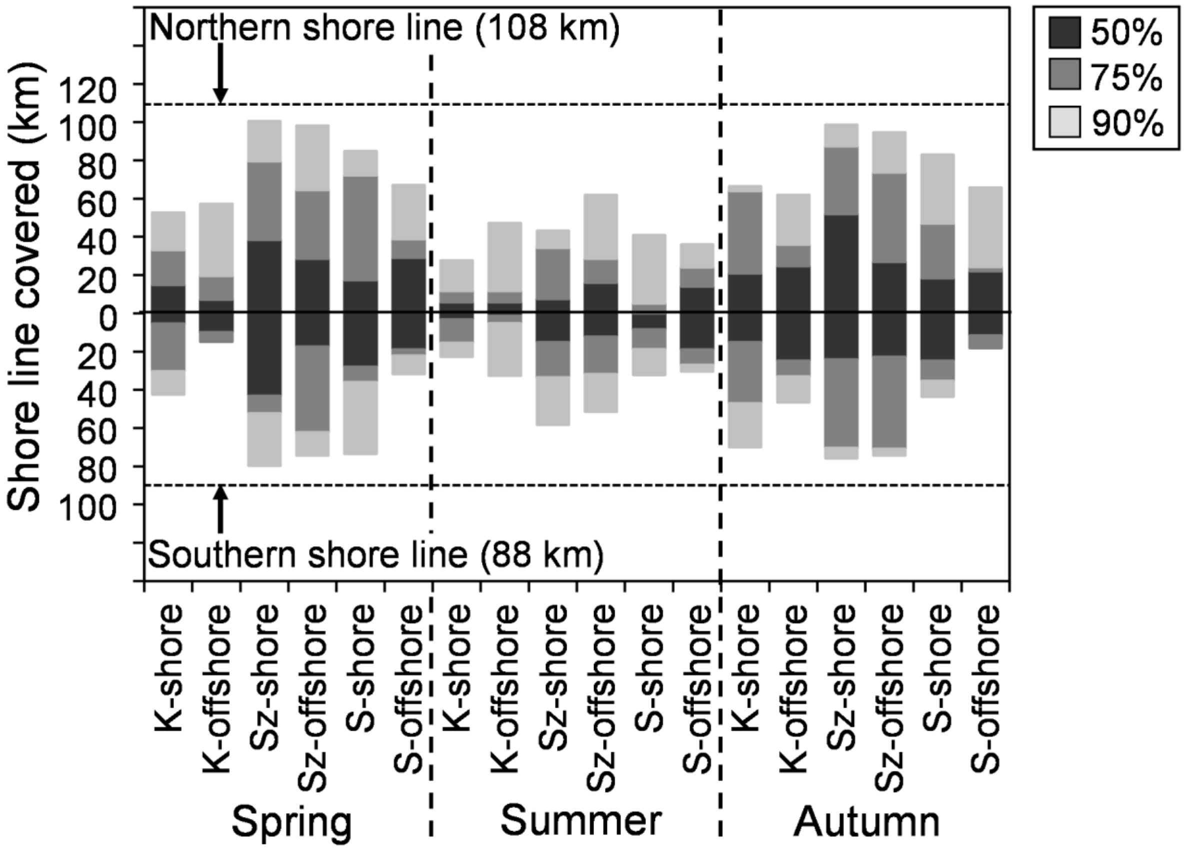

Balaton-
füzfő
Tihany
Siófok
Sió-canal
Zánka
Keszthely
Balaton-
szemes
Zala
River
Fonyód
KBWR
N
0
10
20 km



a)
2010
2011
2012
b)
c)
d)
Number of fish recaptured
T (ºC)
Month


Distance moved from release site (km)
0
10
20
30
40
50
60
70
80
Keszthely
Szemes
Siófok
0
100
200
300
400
500
600
700
Time in lake (days)

492



Northern shore line (108 km)
Southern shore line (88 km)
Shore line covered (km)
120
100
80
60
40
20
0
20
40
60
80
100
50%
75%
90%
K-shore
K-offshore
Sz-shore
Sz-offshore
S-shore
S-offshore
Spring
Summer
Autumn