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Impact of environmental conditions on smelt catch fluctuations in the Nemunas River and the Curonian Lagoon

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The current article presents statistical data on smelt catches in the Curonian Lagoon and the lower reaches of the Nemunas River for the 1927–2006 period and biological indices of spawners for the period 2002–2006. The impact of natural conditions on the efficiency of smelt fishery and catches in the second half of the 20th century as well as the plausible causes of stock fluctuation are analysed. It was ascertained that during the last four decades of the 20th century smelt catches were flood date-dependent. Also, smelt stock reproduction and generation size were found to be favourably affected by late spring, i.e. low water discharge and low air temperature in March. A great abundance of cods in the Baltic Sea had a depressive impact on smelt stock. Meanwhile, an increase in stocks of sander and smelt was recorded in the same year. The analysis of long-term data allows us to propose that fluctuations in smelt stock and catches are climate change-related. The following regularity was observed in Lithuania over several decades of the second half of the 20th century: a period of severe winters was succeeded by that of mild winters every four years. Abundant generations of smelt were formed during late, watery, warm springs. An early, long and cold spring to come after four years enabled fishermen, especially those of the Kaliningrad Region, to make maximum use of the stock.

Key words: smelt, the Curonian Lagoon, stock, catches, reproduction conditions

INTRODUCTION

Two forms of European smelt occur in the Curonian Lagoon and the lower reaches of the Nemunas River: salt-water diadromous or smelt (*Osmerus eperlanus eperlanus*) and freshwater dwarf smelt (*Osmerus eperlanus* m. *spirinchus* Pallas). These fishes differ not only in growth rate, maturation age, feeding habits and migration cycles, but also in population size and fluctuation in yearly catches. According to the comparative and absolute weight of catches, smelt have been performing the most significant role in fishery for several decades. Yearly catches of dwarf smelt in the Curonian Lagoon amount only to several tons. Meanwhile, yearly catches of smelt in the Lithuanian zone of the Curonian Lagoon and the lower reaches of the Nemunas River fluctuate within the range 100–200 t. Total catches of the fish in Lithuania together with those in the Kaliningrad Region make up 200–300 t. Total catches of smelt, including those in the coastal zone of the Baltic Sea, amount to 400–550 t. These figures prove that current catches of smelt are among the largest ones recorded over the last 50 years and, naturally, they cause concern over sustainable exploitation and preservation of smelt stock. All diadromous fish are very susceptible to environmental changes (Repečka, 2003). Their complex life cycle can be significantly affected not only by climate change in Lithuania, but also by human economic activity. Therefore, the ecology of diadromous smelt, as an important object of fishery, has been extensively investigated. Numerous publications and articles on the biology and migration of smelt (Maniukas, 1959; Gaigalas, 2001; Gaigalas, Mištautaitė, 1980; Repečka, 2003), peculiarities of fishery (Gaigalas, Rudzianskienė, 1996) and investigations into smelt larvae and juveniles (Žiliukienė, 2003) have been publicized. However, it is still very difficult to forecast smelt stock and to set quotas for catches. So far no one, with the exception of the author of the current article (Švagždys, 1998), has thoroughly studied fluctuations in smelt catches and stock and the efficiency of smelt fishery with regard to environmental factors. So, that is the aim of the current study.

MATERIALS AND METHODS

Preliminary biological data on smelt were collected from commercial fishermen's gear in the Curonian Lagoon and the lower reaches of the Nemunas River. In the Curonian Lagoon, biological material was collected episodically from 120 m long, 12 mm mesh size smelt trap nets. In the lower reaches of the Nemunas River, material for smelt studies was collected in spring from river trawl nets. Their length varied from 30 to 150 m, the sack mesh size was 12 mm. In the period of pre-spawning and spawning migration, data in the Nemunas River delta were collected daily. The total number of smelt individuals collected for investigations since 1991 yearly amounted to 500–1,500 each year.

The collected ichthyological material was processed employing typical methods (Pravdin, 1966; Thoresson, 1993). The body length of smelt was measured according to l_{smitt}, age was determined by otoliths.

Statistical data on commercial catches of smelt were obtained from the Natural Resources Department of the Ministry of the Environment and the Department of Fishery of the Ministry of Agriculture.

The analysis of smelt fishery efficiency was based on fishing reports of the Rusnė fishery farm.

To investigate the impact of natural conditions, daily observation data (fluctuations in water level and water temperature) of the Nemunas River delta, collected by the author, were used. The mean monthly variations in the Nemunas River discharge (data of the Smalininkai station) and air temperatures of central Lithuania were obtained from the Archives of Lithuanian Hydrometeorological Service.

Excel software package was used for the statistical processing and analysis of material, and Statistica TM and Brodgar software packages were employed for univariate and multivariate regression analysis.

RESULTS

Dynamics of smelt catches

The first statistical data on smelt catches come from the third decade of the 20th century. In the interwar period (1927–1938), statistical yearly catches of smelt (including dwarf smelt) in the Curonian Lagoon and the lower reaches of the Nemunas River ranged from 1.97 to 8.83 thousand t, the mean catch equalling 4.84 thousand t. At that time, catches of smelt and dwarf smelt on average made up 56% of all the amount of caught fish. Marre (1931) noted that catches were even several times bigger in 1924–1925. We can only speculate about the share of smelt in catches of that time. However, on the basis of separate episodical data, we can conclude that smelt catches were relatively smaller than those of dwarf smelt.

The second half of the 20th century saw a marked decline in smelt catches and a significant fluctuation. There were several catches amounting to 800–1,000 t, but several fishing seasons preceding and following them were marked by exceptionally low catches: just several tons of fish (Fig. 1).

The largest catches of Lithuanian fishermen were recorded in post-war years and in the last decade (over 200 t). The largest hauls of fishermen of the Kaliningrad Region were observed in the 8th decade (600–800 t). On average, smelt catches made up 3–10% of the total fish amount caught in the Curonian Lagoon and the lower reaches of the Nemunas River. Up to 1995, 90% of smelt was caught in the lower reaches of the Nemunas River during spawning migration.

Biological characterisation of migrating smelt spawners

Solitary specimens of smelt mature in their second year of life with the body length of 12.2 cm and the body weight of 13.8 g (Gaigalas, Mištautaitė, 1980; Virbickas, 1986; Gaigalas, 2001). Mass migration to spawning grounds is undertaken by 3–5-year-old spawners, while 6–7-year-old individuals migrate

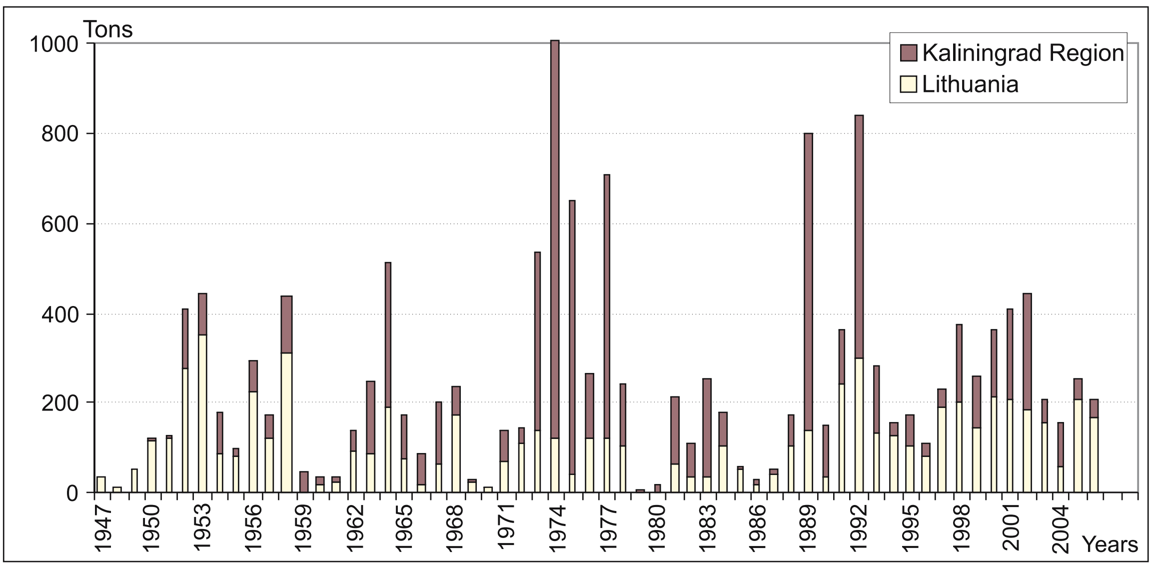

Fig. 1. Smelt catches in the Curonian Lagoon and the lower reaches of the Nemunas River in 1947–2006

Table 1. **Age structure (%) of smelt spawners in the Nemunas River delta in 2002–2007**

Age	2007		2006		2005	
	Of the total fish number (%)	**According to fish weight (%)**	**Of the total fish number (%)**	**According to fish weight (%)**	**Of the total fish number (%)**	**According to fish weight (%)**
2	10	4	34	18	4	1
3	51	41	49	51	34	22
4	33	43	16	28	41	44
5	6	11	1	3	19	28
6	+	+	+	+	2	4
Mean (years)	3.4	3.6	2.9	3.2	3.8	4.1
Age	**2004**		**2003**		**2002**	
	Of the total fish number (%)	**According to fish weight (%)**	**Of the total fish number (%)**	**According to fish weight (%)**	**Of the total fish number (%)**	**According to fish weight (%)**
2	24	19	5	2	22	10
3	64	66	38	26	47	42
4	9	11	39	42	26	38
5	4	5	17	27	4	6
6	+	+	1	2	1	4
Mean (years)	2.9	3.0	3.7	4.0	3.1	3.5

more seldom. According to the relative number, catches are dominated by fish aged between three and four and according to weight by fish aged four and sometimes five (Švagždys, 1998). The 2002–2007 period witnessed the rejuvenation of smelt population. According to the number of fish in the Nemunas River delta, average fish age varied within the range 2.9–3.8 and according to weight within the range 3–4.1 every year. The average age (of the number of spawners) was 3.3 and 3.6 (of their weight) (Table 1). The average body length and age of smelt at spawning grounds began to decrease after intensive fishing of more mature fish had been undertaken using selective fishing gear in the coastal zone of the Baltic Sea where large-sized fish aged between 4 and 5 is caught with 18–20 mm mesh size gill nets (Statkus, 1998).

Analysis of smelt spawning migrations showed that males, which approximately constitute 2 / 3 of all spawners, are the first to migrate from the lagoon to rivers. The number of smelt females gradually increases, and before spawning it is females that constitute the major part of catches landed by fishermen in river deltas (Fig. 2).

Males are smaller in size than females (Gaigalas, 2001). As a result, at the beginning of spawning when spawners are dominated by males, smaller fish prevail in fishermen's catches rather than during the peak of migration. At the end of migration, younger and relatively weaker spawners move towards spawning grounds. Consequently, the harvested smelt are smaller in size. These regularities in the sex and size structure of migrating smelt spawners become apparent if

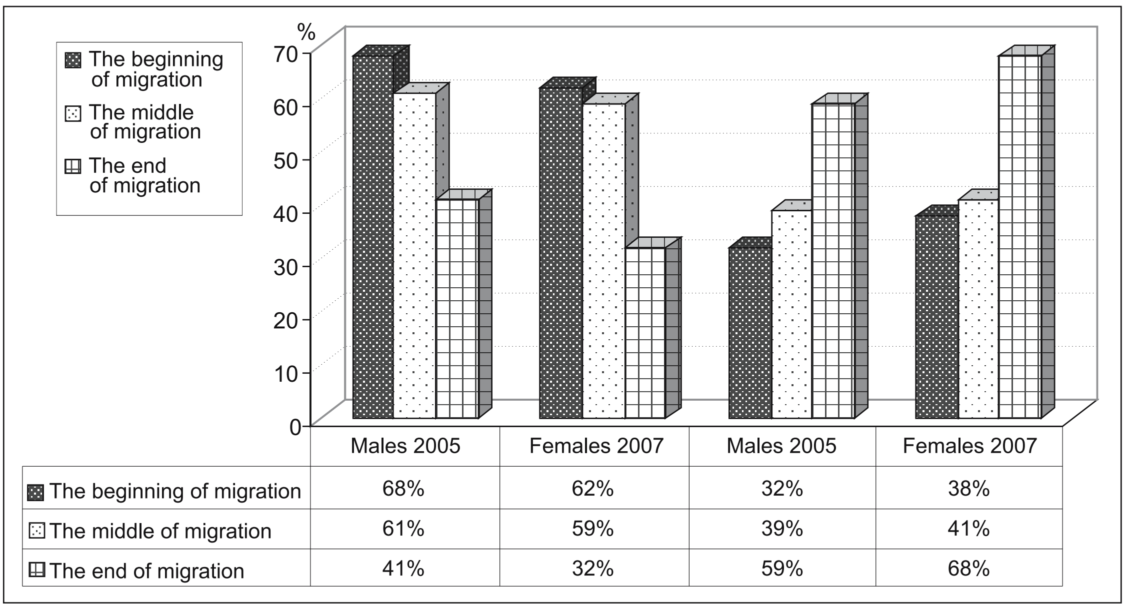

Fig. 2. Sex structure of smelt during their spawning migration in 2005 and 2007

smelt migration occurs in conditions of a rapidly warming spring. In case of a cool and lengthy spring, smelt migrate towards spawning grounds in small schools and their sex-age structure varies.

Impact of environmental conditions on fluctuation in smelt catches

In the region of the Baltic Sea, smelt migration is temperature dynamics-related. Therefore spawning migrations start and come to an end earlier in the southern areas of the sea (Spilev et al., 2005). Smelt start migrating from the Curonian Lagoon to spawning grounds in the lower reaches of the Nemunas River when ice-drift is over and water temperature in the river has risen to 1–3 °C. According to reports of fishery farms and observation data, in the last five decades the latest migration of smelt spawners to rivers, i. e. in the second ten days of April, was recorded in 1958 and 1996. Early spawning migrations (the third ten days of February) were observed in 1989, 1990, 1995. In 1994, smelt were already reported in the delta of the Nemunas River after the winter flood in January. Normally, migration of smelt to rivers as well as commercial fishery starts at the end of March – beginning of April and lasts for two–three weeks. Smelt fishery and catches are affected by environmental conditions. However, not always has the size of catches been proportionate to smelt stock (Švagždys, 1998). Up to the last decade of the 20th century, the largest amount of smelt, and at present over half of it, has been captured in the lower reaches of rivers during fish migration. Such natural conditions as spring water level and temperature dynamics still have a significant impact on fishing efficiency. For instance, in 2001 the mass migration of smelt started on March 12 when water temperature had reached 3 °C (Fig. 4). The peak of migration was recorded on 16–18 March. Judging from fishermen's catches, migration of smelt schools to spawning grounds in those days was most intensive, despite a cold spell which began during the peak of migration and affected water temperature. Due to the prolonged spell of cold weather, migration of smelt to rivers in the third ten days of March was very weak. It was noticed that the intensity of smelt migration and the size of their catches increased with the rise of water temperature. When water temperature rose

Fig. 3. Length structure of smelt in 2005 and 2007

to above 6–7 °C, most smelt had already migrated from the lagoon to rivers and were congregating at spawning grounds. Consequently, fishermen's catches in the Nemunas River delta decreased.

In 2000, upstream migration of smelt to rivers started in the first days of March. However, the prevailing cold weather with water temperature not exceeding 3 °C did not stimulate migration. Just like in 2001 the largest catches of smelt were recorded after water temperature had risen above 3 °C (the third ten days of March). Smelt fishing was over after water temperature had risen above 6–7 °C (Fig. 5).

Due to the lengthy winter and cool March, smelt migration was even twenty days late in 2006 in comparison with migration dates over the last several decades (Fig. 6). After the late ice-drift, which started on 5 April, water was fast warming up under the impact of hot sun and rather high air temperature. In the Nemunas River delta, smelt appeared on 10 April, after water temperature had risen to 3 °C. If at the beginning of migration a team of fishermen caught several hundred kg of smelt per day, during its peak, which lasted from 13 to 15 of April daily catches of smelt amounted to 1–5 t. Fishermen's weekly catches of smelt exceeded 131 t.

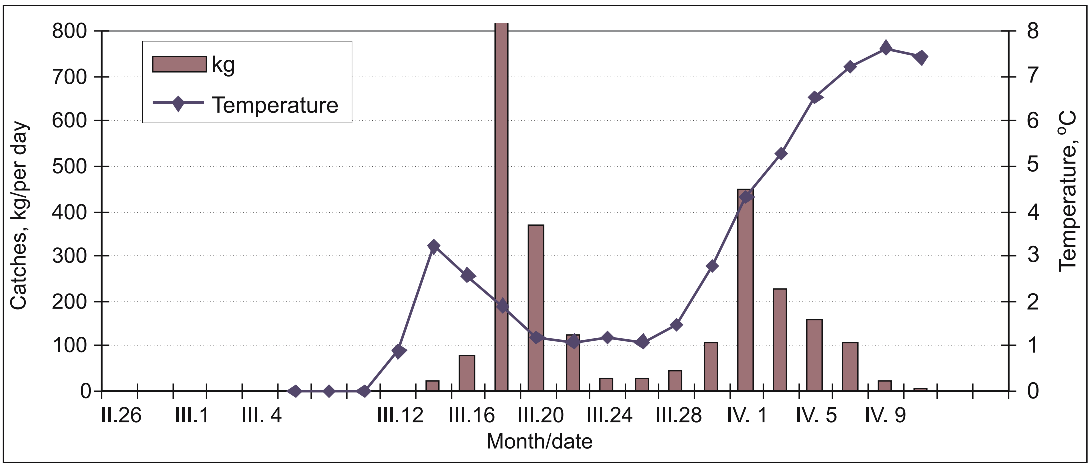

Fig. 4. Efficiency of smelt fishing and water temperature in the Nemunas River in spring 2001

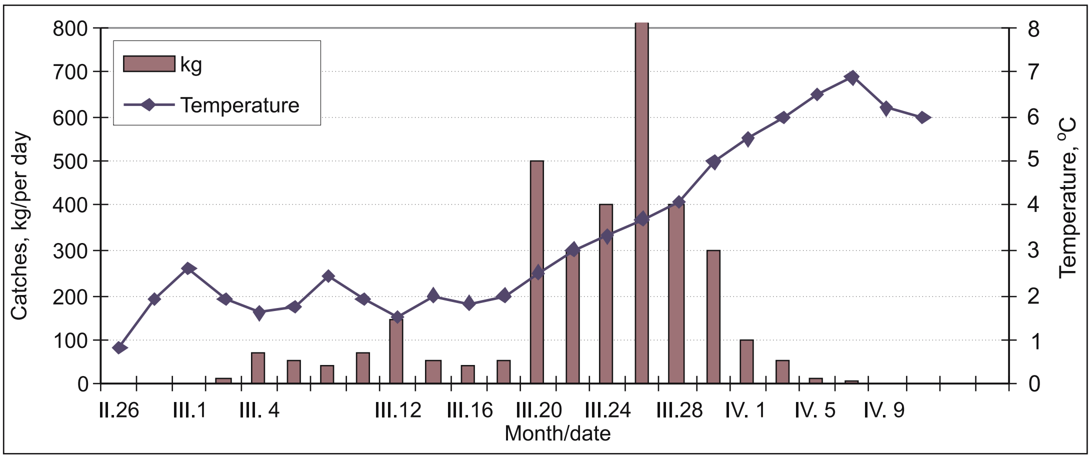

Fig. 5. Efficiency of smelt fishing and water temperature in the Nemunas River in spring 2000

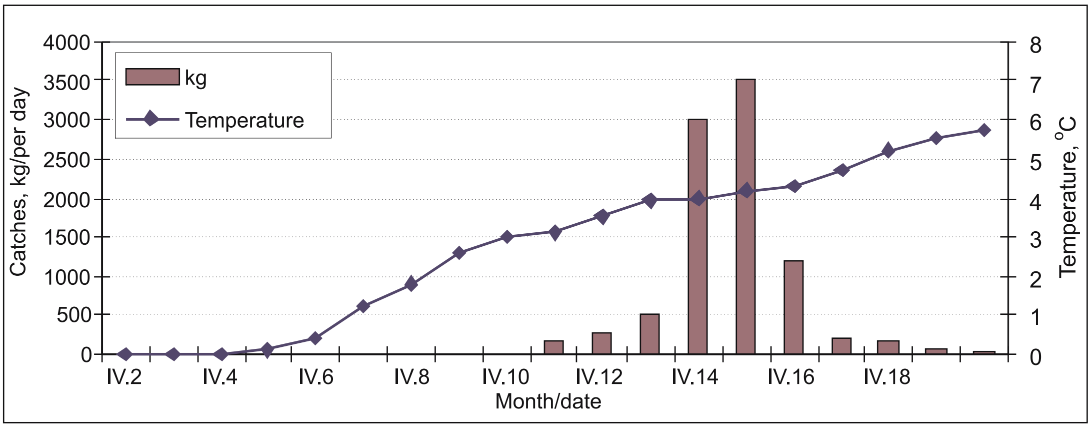

Fig. 6. Efficiency of smelt fishing in the Skirvytė River in spring 2006

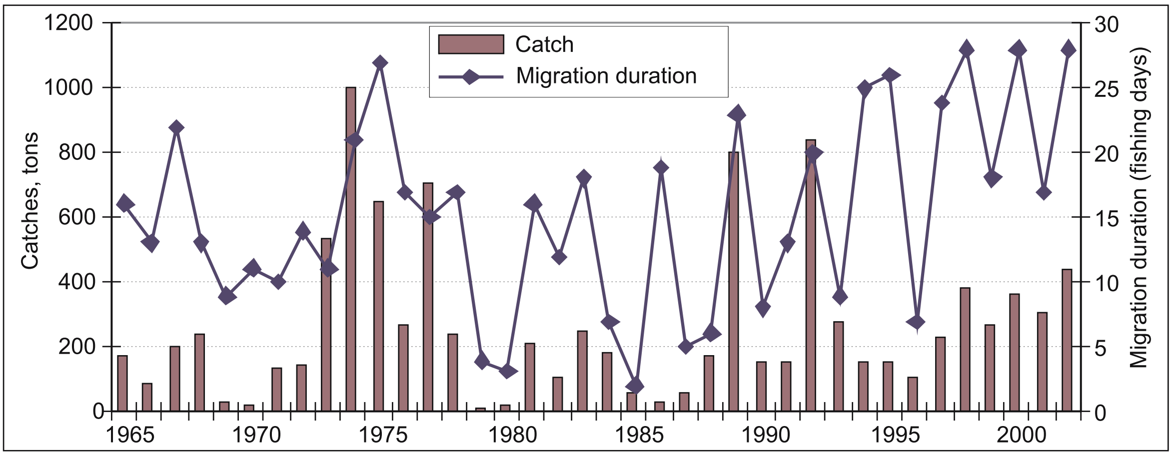

Fig. 7. Smelt catches and their migration duration in a river

So, mass migration of smelt upstream to rivers starts after water temperature has reached 3 °C and, despite successive cooling of water, successful fishing of smelt can be undertaken in rivers. Smelt spawners do not linger at spawning grounds if spring is warm (late), as was the case in 2006, and water temperature is constantly rising. Then onetime catches may be abundant, but is impossible to catch a lot of fish over a short fishing period.

During a cold, lengthy early spring (e. g. 2000) smelt migrate to spawning grounds slowly in separate diffused schools. Then fishery efficiency deteriorates, but due to the longer fishing period the total catch increases.

Analysis and a comparison of total yearly smelt catches with the duration of smelt upstream migration to rivers (and also the number of fishing days) reveal an interdependence (coefficient of linear correlation $r = 0.5$, $p < 0.001$) (Fig. 7).

The analysis of this interdependence in Lithuania and the Kaliningrad Region separately shows that in the Kaliningrad Region in 1965–1993 when fishing of smelt was not conducted in the sea, fishermen's catches were more migration duration-dependent (correlation coefficient of regression analysis: Kaliningrad fishermen's $r = 0.6$, $p < 0.001$; Lithuanian fishermen's $r = 0.3$, $p > 0.05$).

The duration and time of smelt upstream migration to rivers are primarily affected by the date of spring ice-drift start in the Nemunas River (linear correlation $r = -0.5$; $p < 0.001$) (Fig. 8).

Hence, smelt catches may depend on the duration of smelt upstream migration to rivers. The later ice-drift starts and the more watery it is, the greater the probability that the total catch of smelt will be smaller.

Record catches were observed after extremely warm winters in 1973, 1974, 1975, 1977, 1989, 1992. The mean duration of smelt migration (fishing) in the above-mentioned years was 21 days and the mean catch equalled 800 t. However, Lithuanian fishermen's contribution to the total catch was modest: their catch amounted to 145 t or constituted only 18% of the total yearly catch.

Dependence of smelt catches upon climatic characteristics becomes clear when the n-years moving average method is applied for analysis. The impact of the mean air temperature on catches becomes evident after comparing mean air

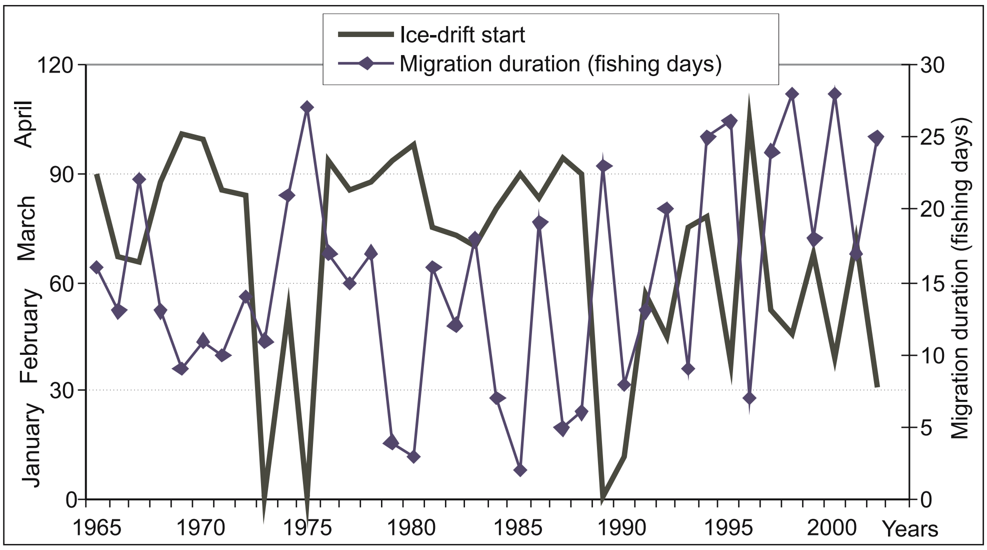

Fig. 8. Duration of smelt upstream migration to rivers and date of ice-drift start in the Nemunas River

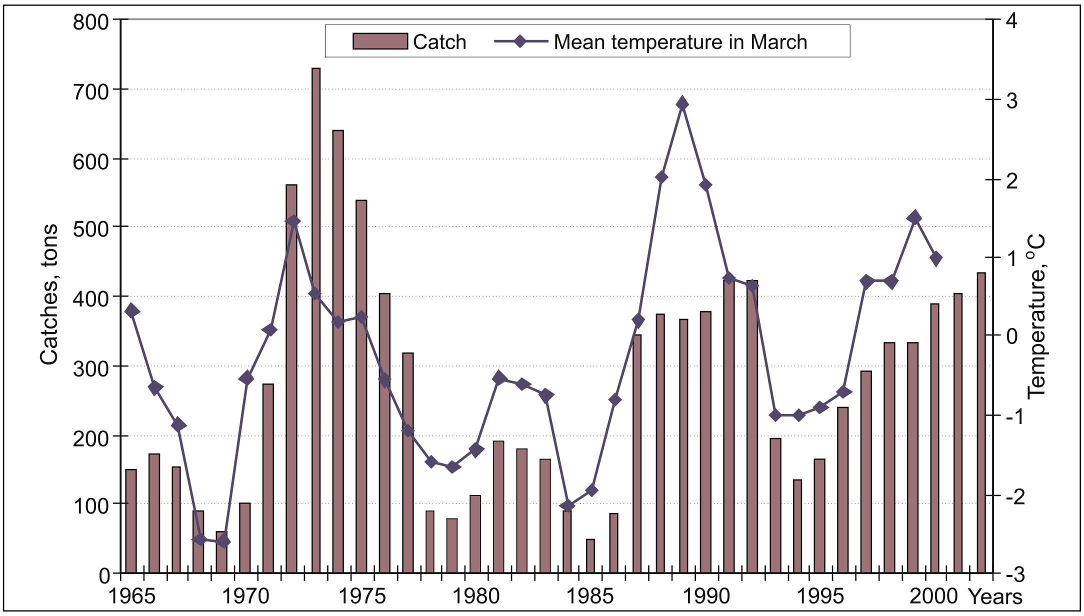

Fig. 9. Smelt catches (according to floating means of three years) and mean temperatures in March (according to floating means of four years) ($r = 0.7$, $p < 0.001$)

temperature in March with means of smelt catches by the n-years moving average method. Means of air temperatures are computed every four years as it has been noticed that an 8-year cycle is characteristic of the recurrence of severe winters, i. e. three–five winters are succeeded by several severe winters (Bukantis, 1996). The mean of smelt catches is calculated every three years, as catches are most often dominated by fish of three age groups (3–5 years of age). The reliable dependence obtained since 1965 (linear correlation $r = 0.7$, $p < 0.0001$) shows that when the mean air temperature in March was above (–2) –0 °C, the total smelt catch often exceeded 300 t (Fig. 9). It is also possible to assert that since that period smelt fishery in the lagoon and rivers has been properly developed and intensive.

Smelt fishing efficiency in the Curonian Lagoon is also related to natural conditions. In cold winters, smelt migrate from the sea in small schools. Their locations constantly changing, ice-fishing is not as efficient as fishing with trap nets or nets in the open sea. Smelt catches in the Lagoon used to increase in the years when fishermen could use smelt trap nets and nets for intensive fishing of smelt, which after a mild winter or an early ice-drift had migrated from the Baltic Sea (Fig. 10).

In summary, it is possible to conclude that catches are already partially predetermined by natural conditions in winter and spring. However, the question arises as to why in recent years, distinguished for mild winters and a long period of fishing, catches have not always been large and what conditions the size of smelt stock.

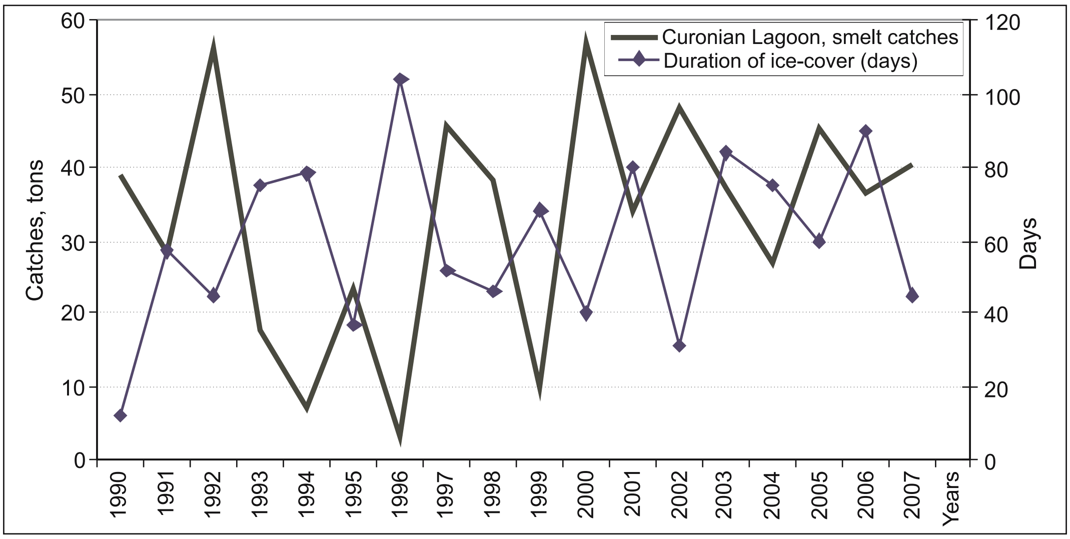

Fig. 10. Dependence ($r = -0.6$, $p < 0.05$) of smelt catches in the Curonian Lagoon on duration of ice cover

Impact of environmental conditions on smelt reproduction and stock

There are several different opinions about causes of changes in smelt stock in the Curonian Lagoon. Maniukas (1959) was the first to express the idea that the main factor behind a decrease in smelt catches in the 6th decade was a change in the hydrological regime and a decrease in water discharge. In the opinion of Gaigalas and Mištautaitė (1980), adjustment of the Nemunas River discharge had no influence on smelt catches and stock, in contrast to those of other diadromous fish. Quite on the contrary, it increased smelt stock and catches.

According to the long-term (1991–2007) observation data, the yearly size of smelt catches in the Curonian Lagoon and the lower reaches of the Nemunas River was related not only to fishing conditions (river flood date and duration), but also to the age–length structure of the population. Minimal catches were recorded in years when catches consisted of smelt individuals of younger age and shorter length groups. If the spawning structure of smelt was dominated by 4-year-old and older fish in weight, catches increased respectively (Fig. 11).

So, the size of commercial smelt stock is likely to have been predetermined by the reproduction conditions that prevailed four years before. So, reproduction conditions are likely to predetermine the size of commercial smelt stock four years in advance.

As smelt spawners swim to rivers upstream only for spawning, there is a presumption that the duration of smelt migration corresponds to the quality of reproduction conditions. The faster the process of water warming, the sooner smelt finish spawning and the more efficient it is.

Analysis of the impact natural conditions exert on the efficiency of spawning shows a regular relation between air temperatures in spring in the period of smelt reproduction and their stock size in later years. Differences between March and April temperatures during the spawning period have effect on the future smelt stock (catches) after 3–5 years. A comparison of air temperature means of four years and means of smelt catches of three years employing the n-years moving average method proves that this interdependence becomes apparent only after four years. The greater the difference between March and April temperatures was, the larger smelt catches were after four–five years. Differences in spring temperatures show the changeable character of spring course and faster warming of water which favour the development of nutritive base (Žiliukienė, 2003) and survival of smelt larvae (Fig. 12).

However, this dependence is not mathematically reliable. Reproduction conditions were identified with catches, and the latter, as mentioned above, could have depended on fishing intensity.

Another very important factor which is likely to affect the size of smelt stock greatly is the impact of predatory fish. In winter, smelt is prey for such predatory fish as sander and burbot in the Curonian Lagoon (Rudzianskienė, 1988, 1989) and for cods during the whole remaining period in the Baltic Sea (Voigt, 1987). A comparison of predatory fish catches with those of smelt suggests that smelt catches could have been greatly affected by sander and cod stocks (Figs. 13, 14). An increase in sander and cod stocks accounts for the recorded differences between decreased smelt catches and favourable reproduction and fishing conditions in the 1979–1987 period.

Group regression analysis of smelt catches landed during the last four decades of the 20th century singles out the following statistically reliable environmental factors. At the moment of fishing, smelt catches ($R^2 = 0.77$; $p < 0.001$) were flood date-dependent, while stock reproduction was noticed to have been positively affected by late spring four years before: low water discharge and low air temperature in March. An abundance of cods in the Baltic Sea had a depressive effect on smelt stock, while an increase in smelt and sander stocks was recorded in the same year (Table 2).

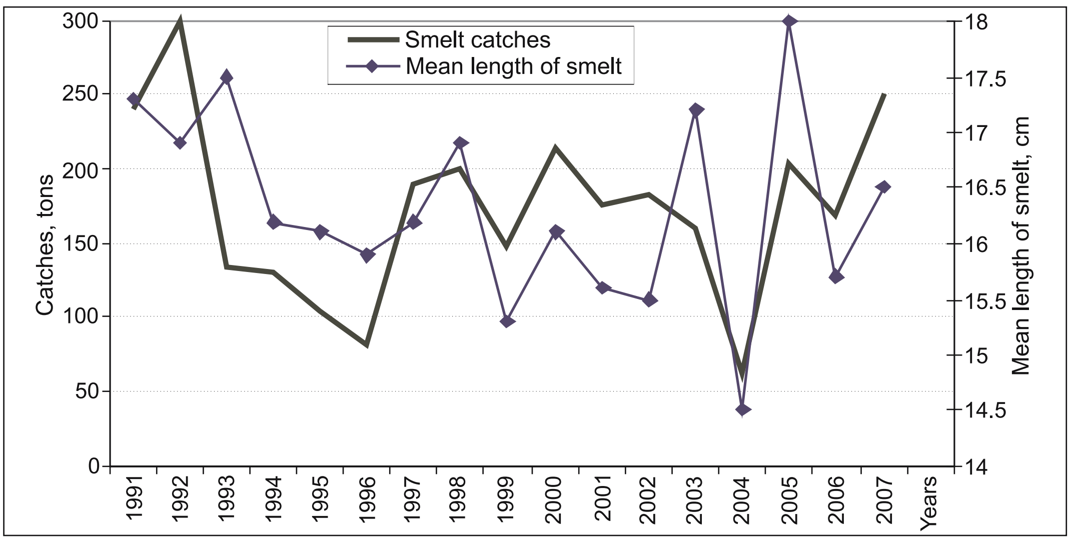

Fig. 11. Size of smelt catches and the mean length of spawners in 1991–2007

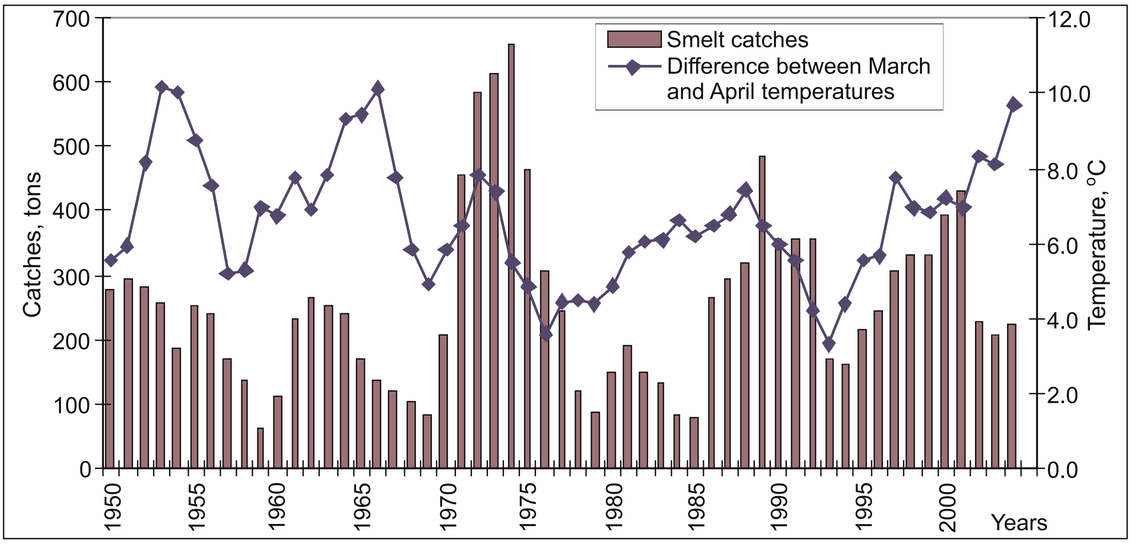

Fig. 12. Smelt catches (according to floating means of three years) and differences of March–April temperatures (four years before, according to floating means of four years)

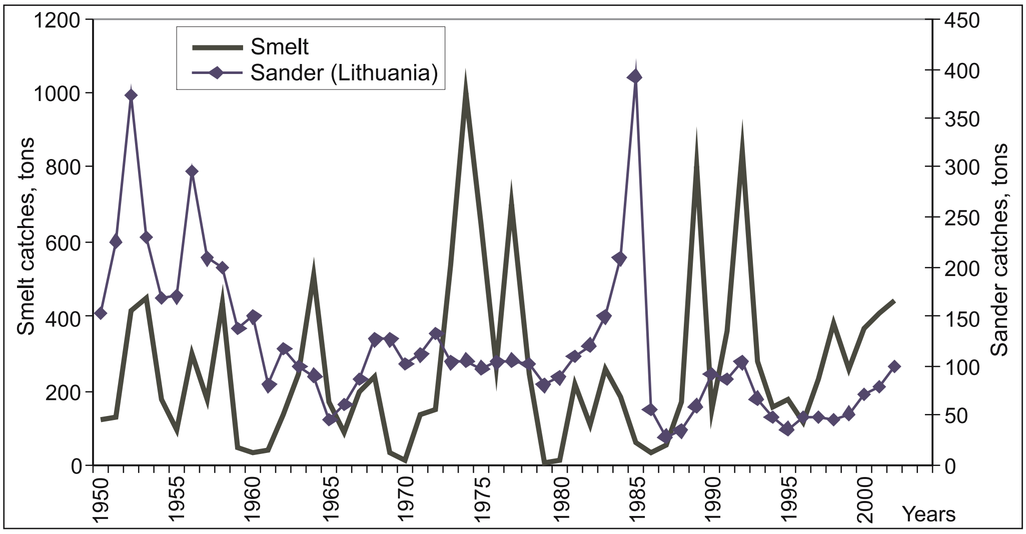

Fig. 13. Smelt and sander catches in the Curonian Lagoon and the Nemunas River

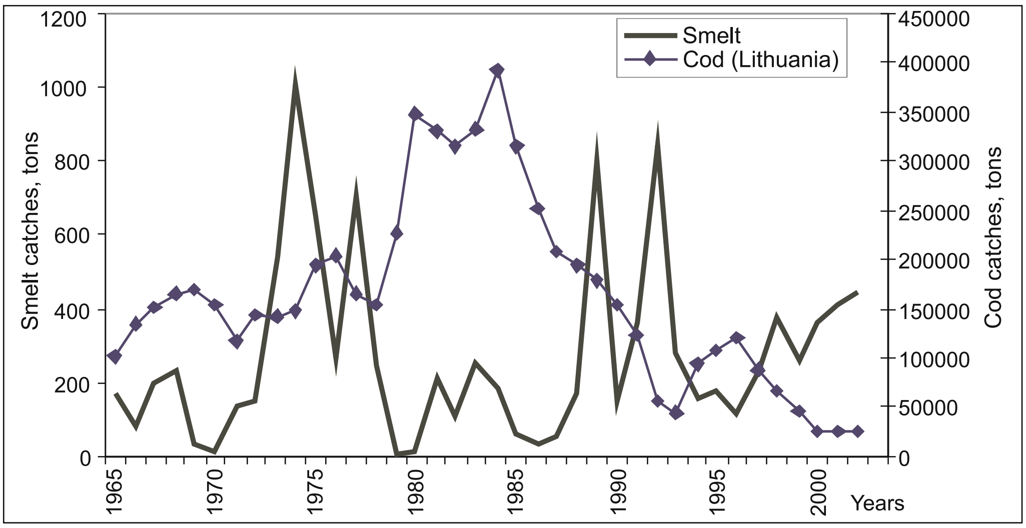

Fig. 14. Smelt (the coastal zone) and cod (fishing regions 25–32 in the Baltic Sea) catches

Table 2. **Beta and p coefficients standardised by independent factors of group regression. Dependent factor: smelt catches after four years**

Independent factors	Beta	p
Flood date in the year of fishing	–0.611247	0.000003 < 0.000
Sander catches in Lithuania	0.461959	0.00131 < 0.005
Cod catches in region 26 of the Baltic Sea	–0.480373	0.001887 < 0.005
Difference between April–March air temperatures four years before	–0.334299	0.001685 < 0.005
Water discharge in the Nemunas River in March four years before	–0.557839	0.000001 < 0.000

Climate warming has been negatively affecting smelt stock in most water bodies of the Baltic Region (Kangur et al., 2007). The analysis of long-term data performed by us suggests that fluctuations in smelt stock and catches reflect climate change. In the second half of the 20th century, the following tendency was observed in the course of several decades: a period of several severe winters was succeeded by mild winters every four years (Bukantis, 1994). Thus, abundant generations of smelt were formed during late, watery and warm springs and an early, long and cold spring to come after four years allowed fishermen (of the Kaliningrad Region in particular) to make maximum use of the abundant fish stock.

The above-mentioned changing climatic conditions and conditions of fishery and reproduction, predetermined by the latter, could have shaped an erroneous opinion that adjustment of the Nemunas River and decreased discharge did not have any impact on smelt stock.

As a result of climate warming, winters have become milder and less contrasting now. Fishing duration and commercial fishery conditions have become less changeable. Thus, total smelt catches vary within a smaller range. As fishing of older 4–5-year-old fish in the Baltic Sea has been carried out continually in winter, their share in river hauls has decreased. According to statistical data, as a result of intensive smelt fishing in the Baltic Sea, the Gilija (Matrosovka) offshoot of migrating large-sized smelt spawners has markedly decreased and so have fishermen's hauls in the Kaliningrad Region.

CONCLUSIONS

In the second half of the 20th century, yearly smelt catches varied from several to a thousand tons. Catches were dominated by 3–4-year-old spawners.

The efficiency of smelt fishing was water temperature-dependent. The most intensive upstream migration of fish was observed at a temperature of 3–5 °C.

The size of smelt catches depended on the duration of fishing in the lower reaches of the Nemunas River. Their stock had been greatly impacted by the reproduction conditions that prevailed 3–4 years before: the date / time of flood in the Nemunas River, dynamics of water temperature, extent of water discharge in spring.

Smelt stock was negatively affected by an abundant stock of cods, whereas the impact of the size of sander stock on that of smelt was not confirmed mathematically.

The intensified fishing in the coastal zone of the Baltic Sea could have exerted a negative effect on smelt catches in the Nemunas River and the Curonian Lagoon.

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Arvydas Švagždys

APLINKOS SĄLYGŲ ĮTAKA NEMUNO IR KURŠIŲ MARIŲ STINTŲ LAIMIKIŲ KAITAI

Santrauka

Pateikiami Kuršių marių, Nemuno žemupio 1927–2006 m. stintų laimikių statistikos duomenys ir 2002–2006 m. reproduktorių biologiniai rodikliai. Analizuojama, kaip gamtinės sąlygos XX a. antrojoje pusėje veikė stintų verslo efektyvumą ir laimikius, galimos išteklių kitimo priežastys. Nustatyta, kad per XX a. paskutinius keturis dešimtmečius stintų laimikiai žvejybos metu priklausė nuo potvynio datos, o išteklių reprodukcijai ir generacijos dydžiui teigiamą poveikį darė vėlyvas pavasaris: mažas kovo vandens debitas, žemos kovo oro temperatūros. Išteklius depresyviai veikė menkių gausa Baltijos jūroje. Tuo tarpu tais pačiais metais gausėdavo ir stintų, ir sterkų. Atlikta ilgalaikių duomenų analizė leidžia teigti, kad stintų išteklių ir laimikių fliuktuacijos atspindėdavo klimato kaitą. XX a. antrojoje pusėje kelis dešimtmečius kas ketveri metai po kelių šaltų žiemų laikotarpio Lietuvoje įsivyraudavo šiltos žiemos. Per vėlyvus vandeningus šiltus pavasarius susiformuodavo gausios kartos, o po ketverių metų prasidėjęs ankstyvas ilgas šaltas pavasaris leisdavo, ypač Kaliningrado srities žvejams, labai gerai panaudoti išteklius.

Raktažodžiai: stinta, Kuršių marios, ištekliai, laimikiai, reprodukcijos sąlygos