BOREAL ENVIRONMENT RESEARCH 3: 321–328
Helsinki 19 January 1999
ISSN 1239-6095

Herring fishery in the Bothnian Sea (southern Gulf of Bothnia) and the North Sea: similarities and differences

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Parmanne, R. 1998. Herring fishery in the Bothnian Sea (southern Gulf of Bothnia) and the North Sea: similarities and differences. *Boreal Env. Res.* 3: 321–328. ISSN 1239-6095

In recent years, herring catches have increased in the Bothnian Sea (southern Gulf of Bothnia, northern Baltic). The assessment of a fish stock by virtual population analysis (VPA) is sensitive to the input values used, and thus the results include uncertainties. In this paper I examine, also independently of the results of the virtual population analysis, if there are signs of overfishing in the Bothnian Sea herring stock. The situation there is compared with that in the North Sea, where changes in the fishery leading to the collapse of the herring stock are well documented. Results from the Bothnian Sea show that changes in the herring catch composition, growth, maturity and larval abundance due to fishing have been minor. According to VPA and the other parameters measured, so far there are no obvious biological signs of the herring overfishing in the Bothnian Sea.

Introduction

In the North-east Atlantic, all the major herring stocks collapsed in the 1960s and 1970s due to overfishing. In order to prevent the same development in the Baltic Sea, all Baltic states on 13 September 1973 ratified the Convention on Fishing and Conservation of the Living Resources in the Baltic Sea and the Belts. The International Baltic Sea Fishery Commission was established in 1974 in order to execute the intentions of the Convention. The Commission regulates the fishery by catch limitations and fishery rules. Advice on the appropriate levels of stock sizes and catches in assessment units is issued yearly by the International Council for the Exploration of the Sea (ICES). One of the Baltic herring assessment units is the southern Gulf of Bothnia, hereafter called the Bothnian Sea (Fig. 1).

In the North Sea, the herring catch was greatest in 1965. As much as 2 tonnes km^{-2} were caught. The North Sea herring stock suffered from too effective fishing; the changes in stock size, herring growth, maturity and larval abundance followed. In 1996, the North Sea herring catch was only 0.5 tonnes km^{-2}.

In the Bothnian Sea, herring catches have increased in recent years to record highs; in 1996,

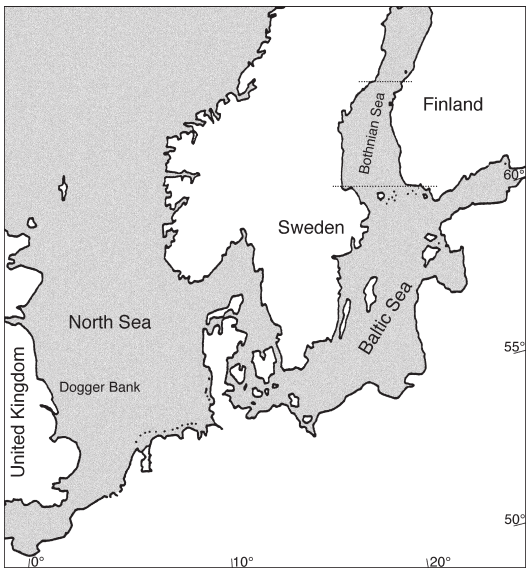

Fig. 1. The locations of the North Sea and the Bothnian Sea (southern Gulf of Bothnia, Baltic Sea).

0.9 tonnes km^{-2} of the herring were caught.

Clupeoids are susceptible to overfishing (Blaxter and Hunter 1982). The assessment of a fish stock with the virtual population analysis (VPA) is sensitive to the input values used. Data concerning fishing mortality in the last years of the analysis and natural mortality are often sparse. The aim of this study was to examine, also independently of the results of VPA, if there are any signs of overfishing in the Bothnian Sea herring stock. The situation in this area is compared with that in the North Sea, where changes in the fishery leading to the collapse of the herring stock are well documented.

Material and methods

Random samples taken from the Finnish trawl and trap-net catches between 1973 and 1997 were used for examination of the composition of herring catches in the Bothnian Sea, southern Gulf of Bothnia (Baltic Sea) (Fig. 1). A sample size varied from 50 to 100 fish. Altogether 99 000 herrings were collected, measured and aged.

Herring weights were determined to the nearest gram and their total length was measured and rounded down to the nearest millimetre.

The age of herrings was determined from otoliths illuminated from above against a dark background; the number of hyaline rings was counted. An individual was moved to the next age group on 1 January.

Thirty-four samples comprising usually 100 herrings 11–20-cm long, were taken from the trawl catches before the beginning of the spawning season in 1982–1997, and the age of the fish and the maturity stage of the gonads of 3 250 herrings were determined.

About 2 200 weekly samples taken in May–August 1974–1996 with the modified Gulf V sampler (Nellen and Hempel 1969) were used for assessments of the abundance of herring larvae in the Bothnian Sea. The sampling techniques, and places were described earlier by Sjöblom and Parmanne 1975, and Sjöblom and Parmanne 1976, respectively.

Data concerning the catch composition as well as the growth and maturity of herrings in the Bothnian Sea were used for stock assessment purposes. The development of a herring catch, stock size, fishing mortality, recruitment, age composition and growth in the North Sea and the Bothnian Sea were compared according to the ICES assessment working group reports (ICES 1997a, 1997b).

Results and discussion

Herring catches

Just prior to World War I, herring catches in the North Sea were over 600 000 tonnes per year (Burd 1985), but declined during the war. Catches increased again in the 1920s and 1930s. A major development in herring trawl fishing took place in the late 1930s (Burd 1991). In the 1950s, demersal trawlers that had fished earlier in the Arctic areas, started to fish for the spawning herring in the North Sea. The invention of pelagic trawls further increased fishing opportunities and fishing mortality. As a result of overfishing the herring stock declined. An efficient purse seine fishery in the North Sea was begun in 1963. In 1965, a record high herring catch of over 1 168 800 tonnes, consisting of largely immature herrings, was recorded. This led to the collapse of recruitment in the North Sea (Burd 1991). In 1975, the North-East Atlantic Fisheries Commission (NEAFC)

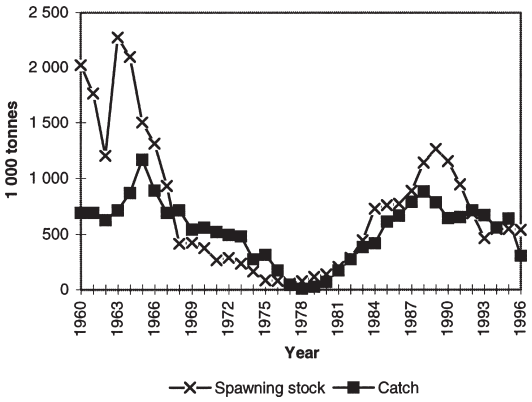

Fig. 2. Herring catch and spawning stock size, 1960–1996, in the North Sea (ICES 1997a).

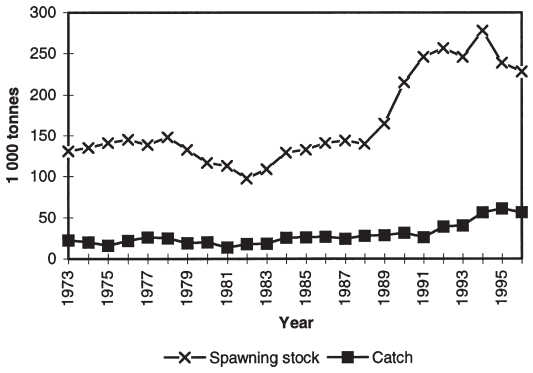

Fig. 3. Herring catch and spawning stock size, 1973–1996, in the Bothnian Sea (ICES 1997b).

banned the industrial herring fishing in the North Sea; a total ban on the hering fishing in this area was introduced in February 1977.

A recovery of the North Sea herring's recruitment took place in the late 1970s. The European Commission reopened the fishery in October 1981. In recent years, total allowable catches (TAC) of the North Sea herring have been exceeded (ICES 1997a). In 1996, the catch was 306 000 tonnes (Fig. 2). For 1998, the Advisory Committee on Fishery Management (ACFM) of the ICES recommended that the fishing mortality should be reduced, because, according to VPA, the spawning stock biomass had fallen to 539 000 tonnes in 1996, while the minimum biologically acceptable level for the North Sea herring stock is 800 000 tonnes (ICES 1997c).

In the Bothnian Sea, annual herring catches in the 1970s and 1980s varied from 13 000 to 29 000 tonnes (ICES 1997b). At the beginning of the 1980s, most of the catch was taken with trap-nets (Parmanne 1989), at which point, the share of the pelagic trawls started to increase. In recent years, more than half of the herring catch has been taken with pelagic trawls, with the catch taken with trap-nets being less than 10% of the total. The herring catches have increased due to the fact that with the pelagic trawls small non-mature herrings can also be caught. The biggest catch to date, 61 000 tonnes, was taken in 1995 (ICES 1997b). In 1996, the total catch was 56 000 tonnes (Fig. 3). According to preliminary data, the catch in 1997 was even slightly above that of 1995. For herring in the Bothnian Sea, the ACFM recommends *status quo* fishing mortalities for 1998 (ICES 1997d).

Assessment of the stock size and fishing mortality

In the North Sea, the herring stock assessment (ICES 1997a) is made on the basis of the integrated catch-at-age model, using catches in number at age and year, acoustic survey data, bottom trawl survey catches, fine-meshed ring-net survey catches, and larval abundance. The North Sea herring stock collapsed in the second half of the 1970s and increased in the 1980s. According to the assessment, the spawning stock biomass declined again in the 1990s (Fig. 2) and recruitment varied more or less simultaneously with the spawning stock (Fig. 4).

In the analytical assessment of the Bothnian Sea herring (ICES 1997b), the tuning of VPA is based on the catch-per-unit-of-effort data. Changes in the design and use of trawls, such as the obvious increase in trawl size, may change the catchability and bias the results, especially from the most recent years. Between annual assessments, variations in the levels of stock parameters have been large, but the trends are uniform (Parmanne *et al*. 1994, ICES 1997b). According to a recent analysis, the estimated spawning stock biomass (Fig. 3), recruitment and fishing mortality (Fig. 5) in the Bothnian Sea in the 1990s have been larger than earlier.

In the North Sea, a large variation between the size of year classes (Fig. 4) is apparently caused by large simultaneous changes in the spawning stock biomass (Fig. 2). Catches have been at the same level as the spawning stock biomass (Fig. 2). In the North Sea the herring stock is considered to be outside safe biological limits (ICES 1997c).

According to the assessments, the fishing mor-

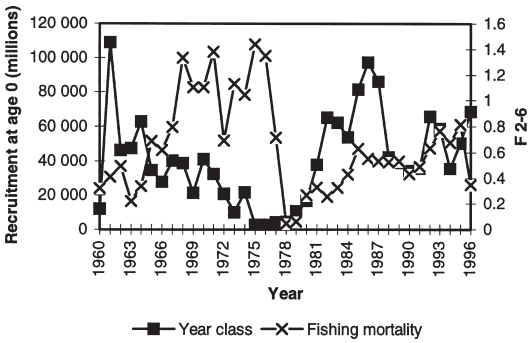

Fig. 4. Fishing mortality and recruitment of herring, 1960–1996, in the North Sea (ICES 1997a).

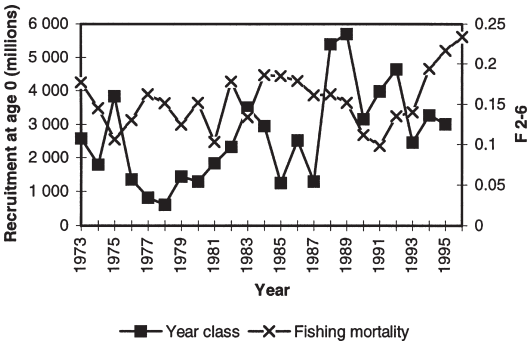

Fig. 5. Fishing mortality and recruitment of herring, 1973–1996, in the Bothnian Sea (ICES 1997b).

tality of herring in the Bothnian Sea is smaller than in the North Sea (Figs. 4 and 5). In the Bothnian Sea, there is no apparent correlation between year classes and the spawning stock size (Fig. 3). The catches have been small as compared with the spawning stock size (Fig. 3), and the stock in the Bothnian Sea is within safe biological limits (ICES 1997d).

Catch composition

When herring catches increased in the North Sea, the proportion of older herrings in the catches decreased (Cushing and Burd 1957, Burd 1991).

In the Bothnian Sea, the average age of herrings caught with different gear in 1973–1996, varied without a distinct trend (Fig. 6). With the mean age, the mean weight of the herrings also varied without any clear trend (Fig. 7). Despite

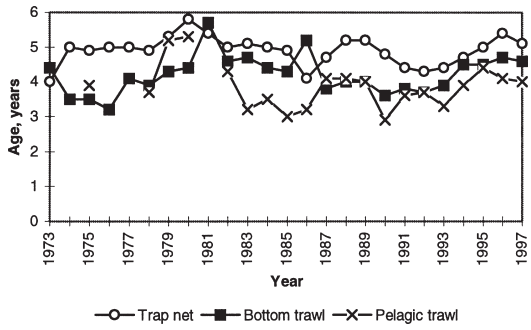

Fig. 6. Mean age of herring caught with various gear, 1973–1997, in the Bothnian Sea.

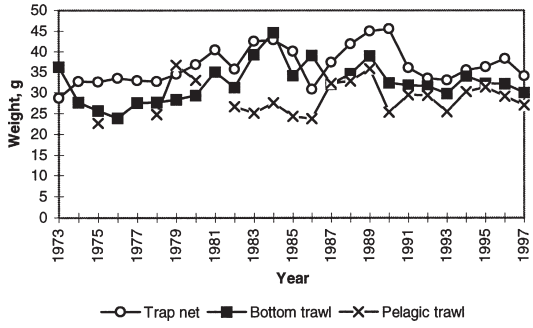

Fig. 7. Mean weight of herring caught with various gear, 1973–1997, in the Bothnian Sea.

the greater catches, the average age and size of the individuals caught did not decline. This suggests that increased catches have had only a limited effect on the age composition of the stock.

Although in the Bothnian Sea, the average age of individuals caught with any given gear has been at the same level, the total catch of the herring nowadays consists of younger and smaller herrings than in previous years. This is because the trap-net was earlier the most important gear, whereas in recent years most of the herrings are caught with a pelagic trawl, and these fish are younger than those caught in trap-nets.

There is a considerable difference in the herring catch composition between the North Sea and the Bothnian Sea. In the North Sea, almost 80% of herrings caught as by-catch in the small meshed industrial fishery (ICES 1997a), belong to the age groups 0 and 1. In the Bothnian Sea in recent years, the share of 0 and 1 group herrings has been 7% (Fig. 8).

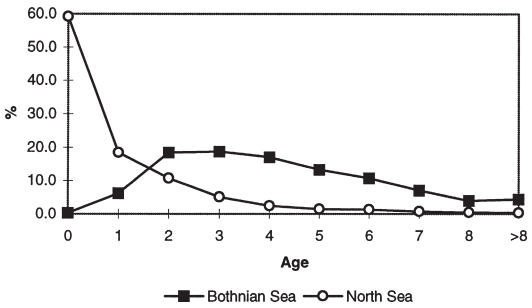

Fig. 8. The age composition (% by number) of herring catches in the North Sea and Bothnian Sea, 1992–1996 (ICES 1997a, 1997b).

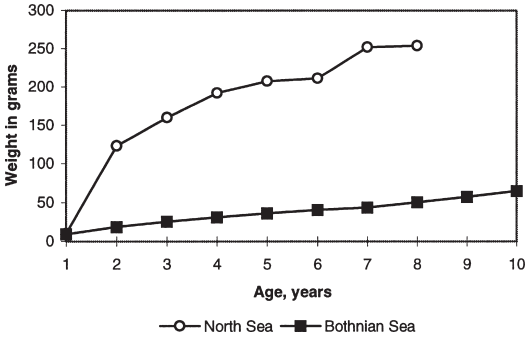

Fig. 9. Mean weight at age of herring in samples taken in the North Sea and Bothnian Sea in 1996 (ICES 1997a, 1997b).

Growth

The growth of the Baltic herring is slow as compared with that of the Atlantic herring. In 1996 in the abundant age groups 2–4, the mean weight of the Bothnian Sea herring was one sixth of that observed in the North Sea (Fig. 9).

When the North Sea herring stock declined, the growth rate of the herring increased due to the density dependent growth (Parrish and Craig 1957, Cushing and Bridger 1966, Iles 1971, Burd 1985). There have been some changes in the herring growth (Fig. 10) in the Bothnian Sea as well. Despite of the large catches in 1992–1996, the mean weight-at-age was, however, smaller than earlier, especially in older age groups. The reasons for the observed changes in the herring growth are not well known. The small size-at-age of the herring in the Bothnian Sea can be caused by food-limited growth.

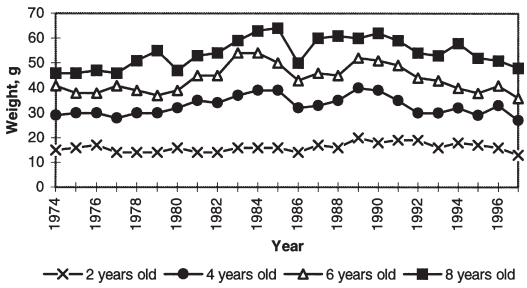

Fig. 10. Mean weight at age of herring in the Bothnian Sea, 1974–1997, April–June.

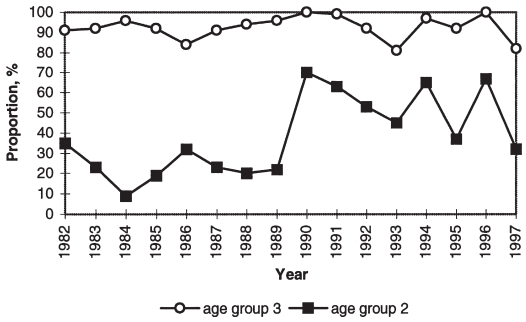

Fig. 11. Proportion of mature herring in age groups two and three, 1982–1997, in the Bothnian Sea.

Maturity

An increased size-at-age in the North Sea herring resulted in earlier sexual maturation (Parrish and Craig 1957). In the 1930s, herring recruitment was complete at five years of age, but the increased growth resulted in complete recruitment to the adult stock at three and even partial recruitment at two years of age (Burd 1962, 1991).

In the Bothnian Sea, herrings usually mature at the age of two or three years (length 14.5–15 cm; Parmanne 1990). A greater proportion of two-year-old herring has been mature in the 1990s than earlier (Fig. 11). This can be connected with the big size of two-year-old herring in 1989–1994 (Fig. 10). The share of mature herring did not increase in 1992–1997, i.e. the period of large herring catches in the Bothnian Sea.

Larval abundance

In the southern part of the North Sea, the abundance of herring larvae decreased between 1946

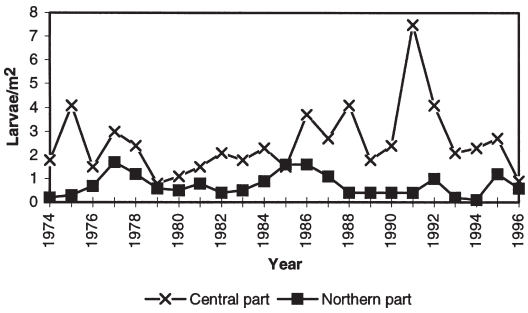

Fig. 12. Abundance of herring larvae < 10 mm, May–August, 1974–1996, in the Bothnian Sea.

and 1957, resulting in a decline in recruitment, explained as caused by fishing (Cushing and Bridger 1966). Internationally co-ordinated larval surveys were commenced in the North Sea in 1955 to get fishery independent information on changes in the size of the spawning stock (Burd 1991). No newly hatched larvae were taken in October Dogger Bank surveys in 1967–1970 (Burd 1991). When the North Sea herring biomass declined in the first half of the 1970s the larval abundance also declined (Wood and Burd 1976), and then both increased at the end of the decade (Corten 1986, Patterson and Beveridge 1994). In addition to the stock–recruitment relationship there may also be other reasons for the observed changes in the abundance of larvae, such as increased competition from other species and a change in North Sea circulation (Corten 1986).

The density of the herring larvae has been greater in the central (usually 1–4 larvae < 10 mm m^{-2}) then in the northern Bothnian Sea (0–2 larvae m^{-2}). No declining trend was observed during the studied period (Fig. 12).

Spawning grounds

In the North Sea, where almost all the herrings are autumn-spawners, there is a small number of well-known, herring spawning grounds at the depths of 20–70 m (Harden Jones 1968, Postuma *et al*. 1977, Burd 1985); the average spawning depth is about 40 m (De Groot 1980). Fishing on these grounds has been intensive in the southern North Sea. Large shoals of ripe herrings were broken up and dispersed by the trawler fleet within two to three hours of their arrival at the spawning ground (Burd 1991). In addition, large quantities of spawn were brought up and destroyed. At the time of peak trawling, the spawning ground must have been ploughed four times per season by the trawl doors and ground ropes of the trawls (Burd 1991).

In the northern Baltic Sea, herrings are mainly spring-spawners, spawning on 1–6 m deep rocky or stony bottoms along the whole coast (Oulasvirta *et al*. 1985, Parmanne 1989). The scattered spawning in shallow water on uneven grounds has obviously protected herring stock from overfishing by making effective trawling on spawning grounds impossible. However, the fishing of pre-spawning herring shoals in the open sea is intensive. In the Bothnian Sea, half of the herring trawl catch is taken in the second quarter of the year, before and during the spawning period of the Baltic herring.

Apart from the fishing, other changes have taken place in the past few decades which may affect herring stocks in both the North Sea and the Bothnian Sea. For instance, the anthropogenic eutrophication has increased in both areas (Baltic Marine Environment Protection Commission 1990, North Sea Task Force 1993). In the northern Baltic Sea in some eutrophicated inner zones of bays, original littoral hard bottoms have changed to soft, muddy bottoms unsuitable for herring spawn, and trap-net catches have decreased (Kääriä *et al*. 1988). In the North Sea, the main spawning grounds have been targets for sand and gravel extraction, and little larval production has been observed there since (Burd 1991). In the Bothnian Sea, the extraction of sand and gravel has been slight on the dispersed spawning grounds in shallow water.

Conclusions

Given the general low productivity (c.f. Elmgren 1984) of the Bothnian Sea, herring catches are fairly large as compared with the present herring catch in the North Sea. The large catch is affected by the fact that in the northern part of the Baltic Sea, the herring is the only abundant fish species, whereas in the North Sea, there are other big fish stocks competing with the herring and feeding on it.

According to the herring morphology, growth differences and tagging results, its migrations between the Bothnian Sea and the neighbouring

areas are rather rare (Parmanne 1990). The stationariness of the herring and lack of large predators or competing fish stocks facilitate the assessment of the herring in the Bothnian Sea. Unlike the Atlantic herring, the Baltic herring stocks have not collapsed. A moderate catch level as compared with the estimated spawning stock size, small share of young specimens per catch and scattered spawning in the archipelago in shallow waters unsuitable for trawling have protected herrings in the Bothnian Sea.

When the major herring stocks in the north-east Atlantic collapsed, management actions came too late and were not sufficiently restrictive (Jakobsson 1985). In the North Sea, the herring fisheries include both trawlers and purse seiners, but herrings are also harvested as a by-catch in small-mesh industrial fisheries for sprat, Norway pout and sandeel. The serious state of the herring stock was known in the 1960s and 1970s, but the large number of nations involved in fishing delayed protective decisions (Burd 1991).

In the Bothnian Sea, herring fishing is mainly a single-species trawl-fishery, where by-catches of other species are usually of minor importance (Parmanne 1988). Thus possible additional regulative measures would only have a slight effect on the fisheries of other species. Additionally, only Finland and Sweden exploit the herring in this area. In 1996, the Finnish share was 96% of the total herring catch in the Bothnian Sea (ICES 1997b).

The results presented concerning fishing mortalities and stock size are based on the VPA and may thus have low precision especially for the most recent years.

In the Bothnian Sea, fishing has had only a minor effect on the catch composition, growth, maturity and the larval abundance of herring. Despite increased catches in 1992–1996, the herring stock size estimated with the VPA was large. Therefore, there are no biological signs of herring overfishing. The present situation may, however, change rapidly if the herring recruitment fails in successive years due to the fishing or to environmental conditions.

Acknowledgements: The author wishes to thank the personnel of the Fishery Research Units (Åland, Kustavi, Reposaari and Vaasa) of the Finnish Game and Fisheries Research Institute for collecting the material for the study. Ms Kathleen Tipton checked the English language.

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Received 20 November 1997, accepted 10 October 1998