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CHANGES OF THERMAL AND OXYGEN CONDITIONS IN A DYSTROPHIC LAKE SMOLAK IN 1953-1995

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A B S T R A C T. Thermal and oxygen conditions in the dystrophic Lake Smolak in 1993-1995 were typical of a bradymictic lake type: short period of spring overturn, stable summer stratification, shallow (0-1 m) and well oxigenated epilimnion, and bottom-reaching metalimnion with a strong thermocline. In summer, the near-bottom layers were characterised by total oxygen depletion and the appearance of hydrogen sulphide. Such pattern, however, was not observed in all years of the study. In 1953 and 1955 there was an overall homothermy, and oxygen content was high in the entire water column. In 1961 and 1962, and during mineral fertilisation and liming (1971-1974), epilimnion comprised 80% of water column, and a much warmer metalimnion developed from the depth of 4 m to the bottom.

Key words: DYSTROPHIC LAKE, TEMPERATURE, OXYGEN CONTENT

INTRODUCTION

Smolak Lake is a shallow (maximum depth 5.7 m), and small (5.3 ha), forest, dystrophic lake, situated in the north-east of Mazurian Lakeland. Lake morphometry and its location in an over a hundred years old pine forest considerably limit water circulation induced by wind action. In the fifties, following the „Management project for Smolak Lake" (Inland Fisheries Institute, 1958), some trees were cut down at the north-east lake shore. In 1964 or 1965, north-west shore was exposed due to forest cutting down. In 1966 the clearing was planted with birch.

In early seventies (1971-1974), the lake was fertilised and limed, which considerably changed the biocenosis structure and dynamics (Zdanowski 1974, 1976, Bnińska, Zdanowski 1978, Zdanowski et al. 1977, 1978). The following amounts of fertilisers were introduced over the period of 4 years: 15840 kg ha^{-1} of 35% meadow lime, 980 kg ha^{-1} of 50% potassium salt, 578.4 kg/ha of 34% ammonium nitrate, and 233.9 kg ha^{-1} of 28% Thomas slag. The experiment resulted in an increase of calcium concentration in the surface water from 1.5 mg dm^{-3} in 1970 to 31 mg dm^{-3} in 1974, and over the bottom – from 3.0 to 34 mg dm^{-3} (Zdanowski et al. 1978). Average concentration of phosphates and total phosphorus in surface water increased almost two fold (from 0.020 to 0.034 mg dm^{-3}, and from 0.056 to 0.110 mg dm^{-3} respectively), and at the bottom at least three fold (from 0.020 to 0.073 mg dm^{-3} and from 0.059 to 0.182 mg dm^{-3} , respectively). Potassium fertilisation was the most effective. Potassium concentration increased from 0.7 to 8.7 mg dm^{-3}, and was twice higher than a single dose of this element (Zdanowski et al. 1977, 1978).

After the experiment, a systematic decrease of calcium, potassium, sodium, and bicarbonate ion concentration was observed, which followed an exponential curve. In the early nineties the concentration of these ions was by two-thirds lower than in 1974 (Zdanowski, Hutorowicz 1998).

MATERIAL AND METHODS

Temperature and dissolved oxygen concentration measurements were carried out from March to the end of September, in 1993 and 1994, and to November in 1995, at 1 m intervals from the surface to the bottom, at the deepest point of the lake. In 1993 the measurements were performed with 0.1°C accuracy, using a thermometer placed inside a glass sampler „Toń" of 5 dm^3 capacity. Dissolved oxygen (DO) was measured using a modified Winkler's method. In 1994 and 1995, temperature and DO were measured using DO-meter YSI 58. Data by Patalas (1960), Korycka (1969), Zdanowski (1974, 1976), Zdanowski et al. (1978), and unpublished data obtained from Dr. Jerzy Zachwieja were also included in the present paper. Meteorological data of 1953, 1955 (Mikołajki Meteorological Station), 1961 and 1962 (Giżycko Meteorological Station) were taken from the Meteorological Annals of the State Institute of Hydrology and Meteorology.

RESULTS

Thermal stratification developed in Smolak Lake at the end of April. The highest temperature difference between surface and bottom water layers was observed in July (Fig. 1). The lowest difference between these layers was 7.8°C (1993), and the highest – 14.0°C (1994). Thermocline was very thick: it extended from 1 m depth to the bottom. In 1993 the maximum thermal gradient (3.4°C) occurred between 1 and 2 m depth, and in 1994 – 4.9 °C - between 4 m and the bottom. The

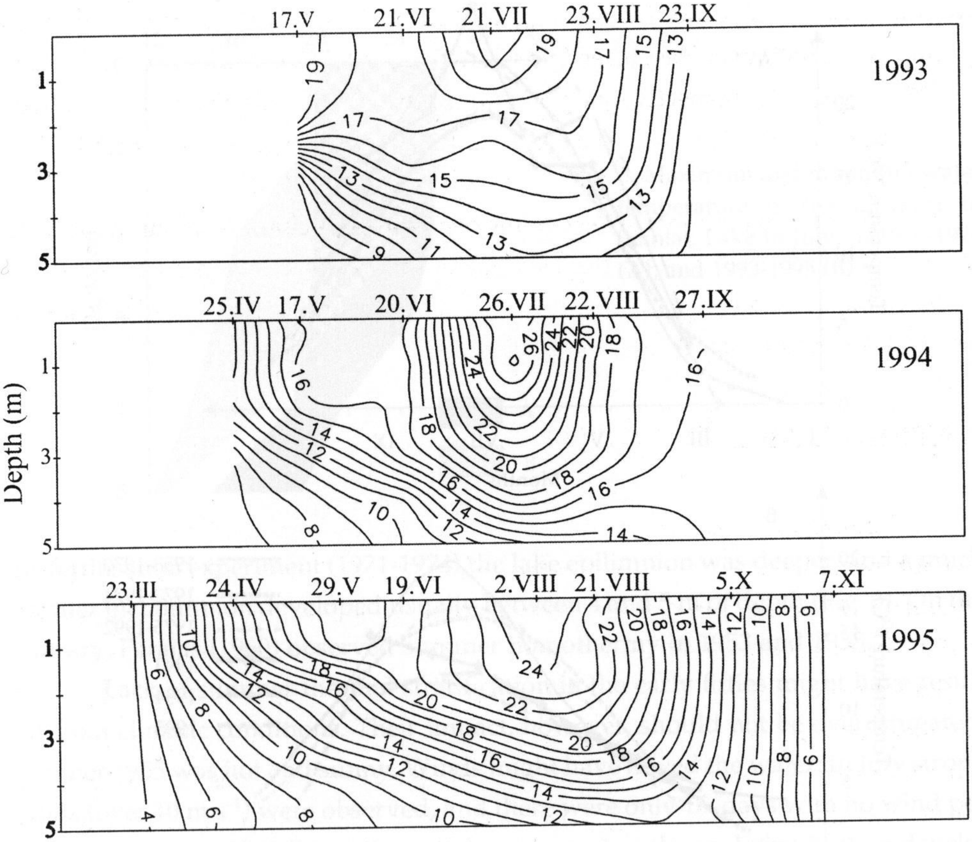

Fig. 1. Thermal stratification of Smolak Lake in 1993-1995

first symptoms of thermal stratification breaking-up – i.e. epilimnion cooling – took place in the third decade of August. In late September and early October the average water temperature fluctuated from 11.4°C (1993) to 15.7°C (1994). Full homothermy, at 4.1°C, was observed in early November 1995 (Fig. 1). In 1993 and 1994 the lake was frozen until the end of March or the beginning of April. Bottom water temperature in 1993 was 4.5°C, and in 1994 - 2.5°C. In 1995 the ice cover melted at the beginning of the third decade of March, and temperature of the entire water column was 3.7°C.

Thermal conditions in Smolak Lake were similar to those observed during summer stagnation in humic lakes of the Wigierski National Park. Relatively small water surface and protection from winds resulted in the fact that thermal conditions

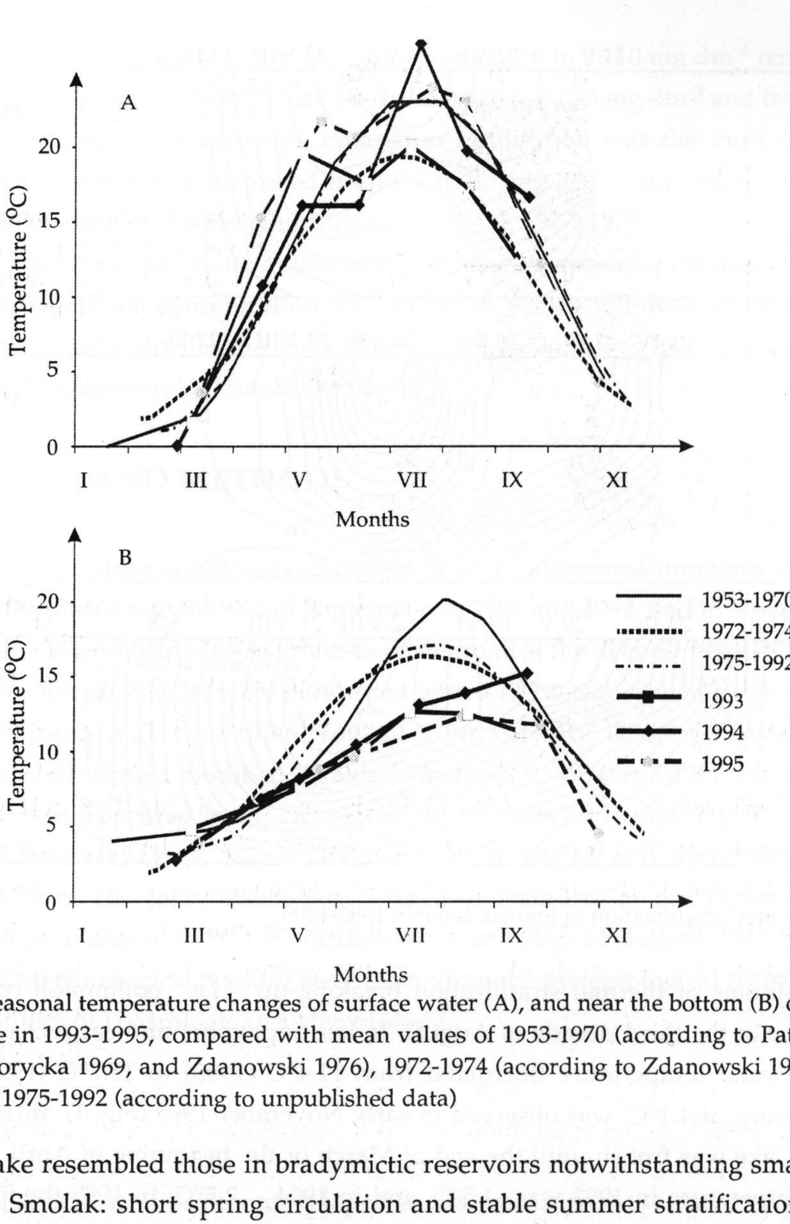

Fig. 2. Seasonal temperature changes of surface water (A), and near the bottom (B) of Smolak Lake in 1993-1995, compared with mean values of 1953-1970 (according to Patalas 1960 a, Korycka 1969, and Zdanowski 1976), 1972-1974 (according to Zdanowski 1976, 1978), and 1975-1992 (according to unpublished data)

in the lake resembled those in bradymictic reservoirs notwithstanding small depth of Lake Smolak: short spring circulation and stable summer stratification with a sharp thermocline, and very shallow epilimnion. The lake, however, lacked hypolimnion and had a very long autumn circulation, beginning already in mid-September.

Such pattern of thermal conditions was not always observed. Bottom water temperature in 1993-1994 was the lowest over the period 1953-1995 (Fig. 2). During

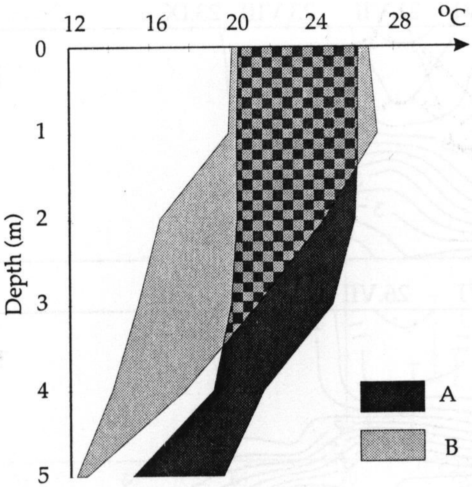

Fig. 3. Maximum and minimum water temperature in 0-5 m layer in Smolak Lake in July, in 1970-1974 (A), and 1993-1995 (B)

the fertilisation experiment (1971-1974) the lake epilimnion was deeper, and a much warmer metalimnion developed usually between 4 and 5 m of depth (Fig. 3). On the contrary, Patalas (1960) observed summer homothermy in 1953 and 1955.

Lack of summer thermal stratification in the early fifties might have resulted from climatic conditions. Their impact, however, should not be overestimated. Summer 1955 was hot and sunny. Winds might have mixed the water: in July strong winds (over 10 m s^{-1}) were observed, and there were only 15 days with no wind per month. In summer 1961 (June-August), however, when thermal stratification developed in the lake, there were even less calm days (4 per month in June, 9 in July, and 14 in August). It was also cloudy (60% of average insolation, 27 cloudy days, and only 6 sunny ones), and cool – the average air temperature was 20 % lower than a long term mean (Nowicka, Grabowska 1989, Hutorowicz et al. 1996). South-west winds prevailed (40/90), of an average speed 3.6 m s^{-1}, and south ones – 4.0 m s^{-1}.

In 1993-1994 the epilimnion was well oxygenated. In 1995 the oxygen content in the epilimnion ranged from 7.6 (2.08) to 7.9 (21.08) mg dm^{-3}, corresponding to 89-91% of saturation. Oxygen deficits at the bottom were, however, observed in all years of the study (Fig. 4). Drop of oxygen concentration near the bottom usually took place at the end of May: in 1993 – to 1.6 mg dm^{-3}, in 1994 and 1995 to 0. Hydrogen sulphide was always present in summer, in 1993 – at the end of August, in 1994 – in the third decade of June, and in 1995 – at the end of May. Complete water saturation with oxygen was observed only in late autumn (1995), at oxygen

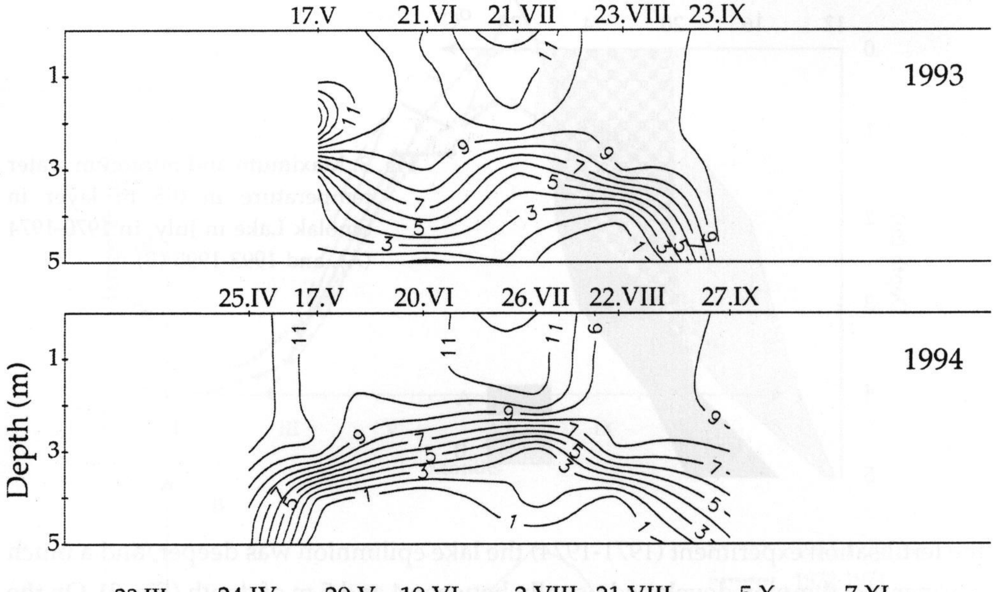

Fig. 4. Dissolved oxygen stratification in Smolak Lake in 1993-1995

content of 11.1 mg dm^{-3} (Fig. 4).

Before fertilisation, in 1953 and 1955, when there was complete homothermy, the entire water column was well oxygenated (about 9 mg dm^{-3}) (Patalas 1960). In 1961-1962, and in 1970 oxygen concentration during summer stratification dropped to several mg dm^{-3}, near the bottom and in September 1961 even to 0. During fertilisation and liming, the longest oxygen depletion period was observed in the second year of the experiment – from mid-June to the end of July 1972. In the remaining years of the experiment (1971, 1973, and 1974) oxygen content in the bottom layer fluctuated and only sporadically dropped to zero. After the experiment, oxygen concentration near the bottom was relatively high (4.6-7.2 mg dm^{-3} in 1978 and 1979), this being due to exceptionally weak thermal gradient observed in the

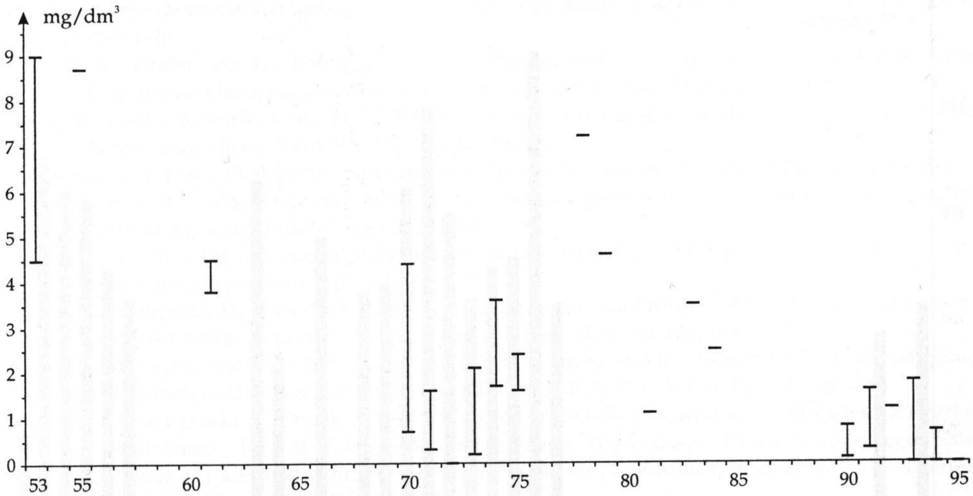

Fig. 5. Bottom water oxygen content in July and August 1953-1995

lake. In the early nineties, oxygen concentration during summer stratification was lower in the above-bottom layer than during mineral fertilisation and liming (Fig. 5).

Epilimnion of Smolak Lake was well oxygenated before, during , and after the experimental fertilisation and limig (Fig. 6). Oxygen content in water was higher than in polyhumic lakes, in which saturation of surface water with oxygen usually does not exceed 90%. In summer 1986, in humic lakes of the Wigierski National Park, the epilimnetic water saturation with oxygen ranged from 56% to 87% (Zdanowski et al. 1992). This resulted from considerable use of oxygen, which is bound by humic compounds, or ferrous compounds bound to the latter. Oxygen binding was higher than oxygen production in photosynthesis even in the trophogenic layer (Wojciechowski 1987). Surface water saturation with oxygen in Smolak Lake indicates prevalence of photosynthetic oxygen production. High photosynthetic activity of phytoplankton in the first year of the experiment (1971) resulted in considerable supersaturation with oxygen. Similar supersaturation was still observed after the experiment (1976), and in 1992-1994 (Fig. 6). Low oxygen content in 1995 might have resulted from a relatively low primary production of the phytoplankton (Hutorowicz 1998).

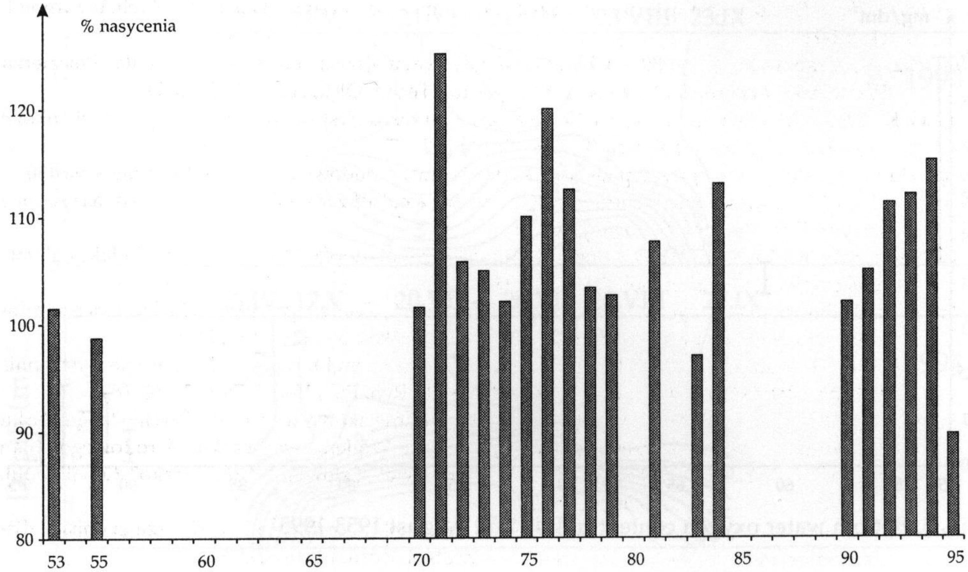

Fig. 6. Average DO saturation (%) of epilimnetic water of Smolak Lake in 1953-1995

CONCLUSIONS

Thermal and oxygen conditions twenty years after the fertilisation experiment revealed some symptoms of bradymixy: short spring circulation, stable summer thermal stratification with shallow epilimnion, sharp thermocline in the metalimnion, and high temperature difference between surface and bottom water layers. Oxygen stratification developed in the lake, reflected in well oxygenated epilimnion and a sharp metalimnetic decrease of oxygen content, with oxygen deficits near the bottom. Oxygen content in the epilimnion of Smolak Lake was higher than in other dystrophic, brown water lakes, in which oxygen concentration was low even in the trophogenic layer.

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STRESZCZENIE

ZMIANY WARUNKÓW TERMICZNO-TLENOWYCH W DYSTROFICZNYM JEZIORZE SMOLAK W LATACH 1953-1995

Warunki termiczne w dystroficznym jeziorze Smolak w latach 1993-1995 wykazywały cechy charakterystyczne dla bradymiskji. Po krótkiej cyrkulacji wiosennej, latem wykształcały się dwie warstwy: płytki i ciepły epilimnion oraz sięgający dna metalimnion charakteryzujący się dużym gradientem temperatury (Rys. 1). Temperatura wody w warstwie naddennej była niższa od notowanych w okresach przed, w czasie oraz po zakończeniu eksperymentu (Rys. 2).

W sierpniu 1953 i 1955 roku w jeziorze Smolak obserwowano całkowitą homotermię. W latach 1961-1962 oraz bezpośrednio przed eksperymentem nawożenia mineralnego i wapnowania (1970), a także w czasie jego trwania w jeziorze zakładało się uwarstwienie termiczne. Wykształcały się dwie warstwy: sięgający do 4 m głębokości epilimnion oraz stosunkowo ciepły, obejmujący warstwę wody o miąższości jednego metra metalimnion (Rys. 3).

W latach 1993-1995 epilimnion był dobrze natleniony, ale nad dnem zbiornika występowały długotrwałe deficyty tlenu (Rys. 4) i siarkowodór. Przed eksperymentem, za wyjątkiem 1953 i 1955 r. kiedy zawartość tlenu od powierzchni do dna wynosiła ok. 9 mg dm^{-3}, zawartość tlenu nad dnem jeziora w czasie stagnacji letniej obniżała się do kilku mg dm^{-3}. Podobne stosunki tlenowe panowały w trzech latach trwania ekperymentu nawożenia i wapnowania (1971, 1973, 1974), natomiast w 1972 doszło do długotrwałego wyczerpania tleniu nad dnem jeziora (Rys. 5).

Nasycenie tlenem wody powierzchniowej w jeziorze Smolak wskazywało na przewagę fotosyntetycznego uwalniania tlenu do wody nad intensywnością procesów rozkładu materii organicznej i wiązania tlenu przez substancje humusowe lub przyłączone do nich związki żelaza. Dobre natlenienie wody w epilimnionie (Rys. 6) odróżniało jezioro Smolak od jezior polihumusowych.

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