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The Forecasting of Oyster Harvest in Central Chesapeake Bay[a]

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A multivariate analysis of 40 years of data on the oyster (*Crassostrea virginica*) fishery in upper Chesapeake Bay reveals that variations in spat density and seed plantings of past years can explain 56% of the variation in annual harvest. The correlation allows the estimation of oyster harvest 4 years into the future. Spat density, in turn, is found to vary directly as the cumulative high salinity during the spawning season and inversely as the harvest of the previous season.

Introduction

The recuitment of oysters into the harvestable stocks is known to be related to spat-setting success several years past (Koganezawa, 1972; Colin Sumner, personal communication). Spat production in the upper Chesapeake, in turn, varies markedly from year to year (Meritt, 1977). As a result, oyster harvests over the past 40 years have varied by some 50% from the mean and as much as 200% over the short term (see Figure 1).

Since 1972, spat production has fallen markedly throughout most regions of the Bay (*ibid.*), thereby endangering the fishery and focusing concern upon management efforts to maintain the stocks and harvest at a viable level. Despite the critical situation, no reliable method of forecasting oyster harvests beyond the next season existed prior to this study. The effect of any rise in spat production upon subsequent harvests 3–6 years in the future could not be gauged.

To provide a reasonable estimator of future harvests, the office of the Maryland Sea Grant commissioned this study, the prime objective of which was to correlate over 40 years of annual harvest records with corresponding data on spat production, fishing effort, management effort and environmental conditions. Although the primary intent was to create an oyster forecasting tool, the hope was entertained that significant qualitative relations among the variables describing the fishery would also be revealed.

Data used

The Maryland Department of Natural Resources keeps records of the annual numbers of bushels harvested, cultch planted, and seed planted going back into the 1920s. Fishing effort,

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in terms of the number of licenses issued yearly, was also available. Records of spat-setting success were initiated in 1938 by Francis Beaven of the Chesapeake Biological Laboratory (CBL). The density of new spat, recorded in spat per bushel, was measured each year for a wide variety of bars in the Maryland subestuaries of the Bay. Seeding effort was transcribed as the number of bushels of spat-bearing cultch from areas of good setting which were moved to other regions during the given year.

More intensive time series of environmental data exist, but were recorded only at selected locations in the Bay. Water temperature and salinity have been measured daily at Solomons since 1938. Because Solomons is central to most of the oyster fishery, we chose to assemble all environmental data from CBL and the nearby Patuxent Naval Air Test Center. Environmental data collected include salinity, water temperature, air temperature, and precipitation.

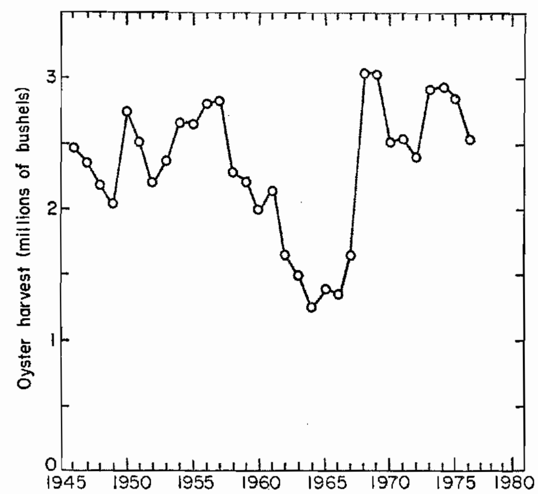

Figure 1. Harvest of oysters from the Maryland portion of the Chesapeake Bay in millions of bushels per year.

Approaches

Several methods for predicting fisheries yield through correlations are possible. In instances where a single variable appears to be the controlling factor, a simple linear regression will serve to illustrate the relation. Thus, Dow (1977) presents a tight relationship between temperature and the landings of 24 species of finfish, crustacea and mollusks off the coast of Maine, and Sutcliffe (1972) correlates fisheries production in St. Margaret's Bay with freshwater input. When catches exhibit a distinct periodicity, autocorrelations are helpful in forecasting future harvests (Jensen, 1976). Generally, however, variations in harvest can only be accounted for by combinations of intrinsic cycles and external factors (e.g. Driver, 1976).

The oyster fishery proved to be an example of the general case, and three major efforts at multivariate correlation were attempted. First, the spat density was regressed against the 26 environmental variables (see below) to examine whether the factors controlling spat production could be identified. Thereafter, an age-class population model common in fisheries research (Watt, 1956) was employed to derive a relationship which would allow the forecasting of harvests based upon the spat production of years past. Because the model we developed was incapable of accurately predicting harvests in the last decade, a third effort was initiated to uncover additional factors which might explain the failure to predict recent oyster production adequately.

Factors affecting spat production

As the oyster spends its first days as a member of the planktonic community, it is no surprise that heaviest mortality rates are encountered before and during metamorphosis into the benthic form. Spat production is apparently controlled by abiotic factors and predators. Because historical data on predator populations are unavailable, it became necessary to assume that lumped predator effects were, in turn, delimited by environmental variables. Hence, our intentions were to seek a multiple, stepwise regression of annual spat production against variables characterizing the environment of each year.

The raw environmental data are daily measurements, whereas spat production is an annual figure. It was necessary, therefore, to condense or abstract yearly figures from each annual record to characterize the physical impact each variable might have had upon spat success for the year. Effects might be cumulative, i.e. occurring over the whole season, or they might be acute responses to short-term events or extremes in the physical surroundings. Accordingly, we abstracted 26 sets of annual figures from the daily time series of the four environmental factors studied. These 26 variables fall into three classifications—cumulative, extreme, and episodic.

TABLE 1. Parameters used in calculating cumulative variables and episodes

Variable	High bias	Low bias
Salinity	16·2‰	10·5‰
Water temperature	26·5 °C	4 °C
Air temperature	30 °C	0 °C
Precipitation	3 cm d^{-1} [a]	0 cm d^{-1}

[a]This value becomes 0·01 cm d^{-1} in calculating rain episodes, i.e. any day it rains is counted.

Annual averages are the most obvious form of a cumulative variable. But averaged values often do not characterize cumulative stress or growth opportunity accurately. So in addition to the four annual means, seven additional variables were abstracted characterizing the integrated amounts during the year that each of the variables exceeded set upper or lower bounds. The derived variables are analogous to conventional growing and heating degree-days.

Very short-term, acute stresses are likely to be characterized by the extremes in the daily values of the environmental variables. While eight annual series of the extreme values are possible, the minimum daily precipitation will be zero for each year and conveys no useful information. Hence, only seven series of annual extremes were compiled.

Longer-term stress on a population is characterized not only by its magnitude, but also by its duration. For each of the four original variables, therefore, we have compiled the longest lengths of time its value remained above an upper bias level and below a lower bias point respectively. In this way episodes of stress or growth opportunity are quantified.

High and low bias levels were arrived at by judgement, taking into consideration both statistical and physiological aspects. Clearly, we wished to choose a bias level which was not so extreme that the probability of deviations exceeding that level during the year was very small. Conversely, a bias level too near the mean would have resulted in measures conveying little information. Rather than set a level based purely on statistics, we tempered our choices by what we felt would be indicative of physiologically or biologically relevant circumstances. For example, when salinity at Solomons drops below 10·5‰, the corresponding values at low-salinity bars would drop below 5‰. Also, when salinities at Solomons rose above 16·2‰

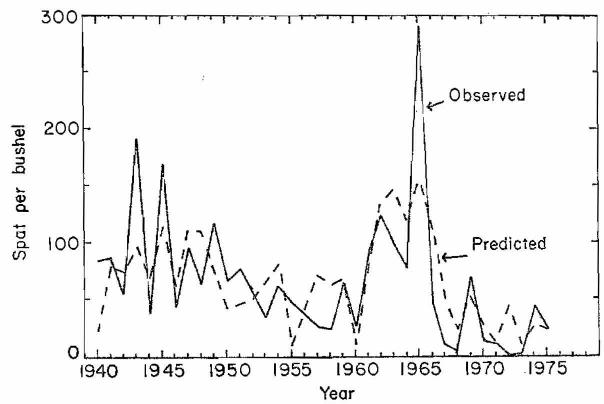

Figure 2. Observed spat set (———) and that predicted by correlation with environmental variables (— — — — —).

predation of juvenile oysters by polyhaline predators in the lower Maryland Bay waters would likely increase. Bias levels for the four original variables are shown in Table 1. The 26 derived series of annual variables are displayed in Table 2.

When a stepwise multiple regression of spat production on the environmental variables and the harvest record was attempted, it was found that 53% of the variation in success could be explained by the logarithms of four variables: cumulative excess salinity, episodes of drought, extreme of rainfall during the previous season, and harvest.

The regression equation is

$$P = 63{\cdot}7 + 24{\cdot}9 \log(\mathrm{Sal}) - 114 \log(\mathrm{RM}) - 104 \log(\mathrm{RX}) - 153 \log(H),$$

where P = spat per bushel, Sal = the number of salinity days above 16·2 p.p.t. at Solomons, RM = the length in days of the maximum episode of no rain, RX = the maximum daily rainfall (mm) recorded during the entire year, H = the bushels of oysters harvested during the season. The F-value of the regression is 9·152 with 32 degrees of freedom in the residual sum of squares and 4 degrees of freedom in the regression sum of squares ($\alpha < 0{\cdot}025$). A plot of the observed and predicted spat densities is shown in Figure 2.

Twenty-one per cent of the variation was explained by a positive correlation with the cumulative excess salinity. This agrees with the common notion that spawning seasons with higher salinities tend to be more productive of spat. The remaining three variables correlate negatively. That extreme rainfall and harvest should depress spat production is straightforward. Most of the diseases and predators of oysters are less tolerant of low salinities than are oysters themselves. Therefore, one would expect spat to correlate negatively with episodes of drought, especially below the mouth of the Patuxent.

Fisheries prediction model

Initial efforts to create a fisheries age-class model to predict harvest met with little success. The theory behind the age-class model was documented earlier (Ulanowicz *et al.*, 1978). It consisted of regressing the harvest of any arbitrary year on the total number of spat produced during a 5-year period starting 3 years in the past. The total number of spat produced was assumed to vary jointly with the observed spat density and the amount of cultch available. Available cultch, in turn, was assessed by the density of the stock, i.e. the harvest per unit effort (license) for the given year. The regression attempts did not succeed in explaining more than 10% of the total variation in annual harvest.

This unsuccessful effort is mentioned only in that the particular way in which the attempt failed proved most interesting. It was possible to use the spat and catch per unit effort data to arrive at reasonable estimates of harvest prior to 1970. Thereafter, all predictions uniformly and greatly underestimated the actual catch. The implication was that some factor outside our consideration was maintaining the harvests at elevated levels in recent years.

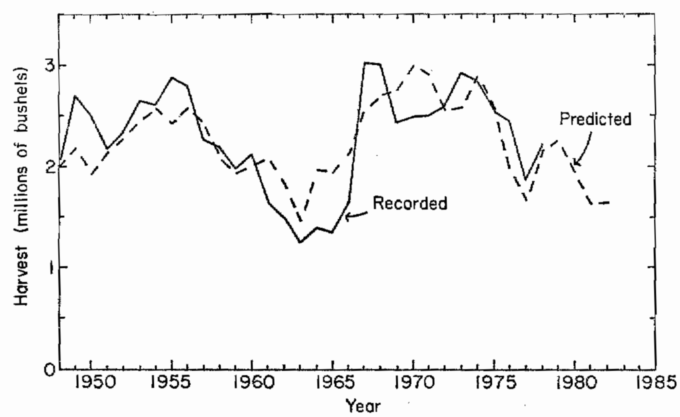

Figure 3. Recorded oyster harvest (————) and that predicted by correlation with spat set and seeding effort (— — — — —).

Prediction from management repletion efforts

Perusal of all the fisheries and environmental variables revealed only one trend which might suffice to explain the excess of actual harvest over that predicted. The late 1960's was a period of accelerated management effort throughout Maryland. The numbers of bushels of seed oysters moved reached an annual high of 1·4 million bushels in 1966. If this effort had been effective, it should show up in higher returns of oysters harvested during the 1970's relative to the previous return on spat from earlier years.

It became clear that the spat production should be weighted by the management effort expended in seeding. When spat density was multiplied by seeding effort, the logarithms of the products for years 4, 5, 6 and 9 in the past were able to explain 56% of the variation in harvest according to the equation.

$$H_t = 260\,357 \log S_4 + 287\,539 \log S_5 + 139\,321 \log S_6 + 365\,750 \log S_9 - 5\,261\,809$$

where H_t is the harvest in year t and S_n represents one plus the product of the number of bushels of seed oysters set out in year $t-n$ with the observed density of spat in year $t-n$. The F-value of the regression is 8·341 with 26 degrees of freedom in the residual sum of squares and 4 degrees of freedom in the regression sum of squares ($a < 0{\cdot}05$).

A comparison of reported and predicted harvest is shown in Figure 3. Since an estimate for harvest in any 1 year only requires data 4 years or more in the past, it becomes possible to forecast harvests 4 years into the future once the spat density and seed plantings for the present year are known.

Summary and discussion

The dominant factors affecting spat production in the Maryland reach of the Chesapeake and tributaries appear to be sustained high salinity and harvest activity. Sustained high salinities contribute to greater spat production. In contrast, harvest tends to depress the number of surviving spat.

Efforts to predict oyster harvest by using a 'wild' fisheries model were unsuccessful. Although production in decades past could be reasonably treated with such models, more recent harvests appear to be augmented by management practices such as seeding. The obverse of this conclusion implies that management repletion effort is necessary to maintain present levels of harvest. These remarks come as no surprise to the Chesapeake oyster biologists, who have been aware that the decrease in oyster density on natural bars has occasioned a shift in harvest effort to the more concentrated populations present in the planted areas.

Knowing the records of spat density and seeding effort for the past 9 years, it becomes possible to estimate harvest levels 4 years into the future. Five-year old oysters appear to dominate the catch if contribution to the regression is taken as a convenient yardstick. Conditions 9 years in the past contribute significantly to the regression. A peak in the cross-correlation between spat and harvest also appears at a 9-year lag, indicating a possible natural cycle of oyster populations or a cycle induced by environmental driving forces yet to be determined.

It is in the nature of multivariate analyses that the investigator is usually far from certain that he has made the best choice of independent variables. Any given series of data can, after all, be transformed in an infinite variety of ways. Although we do not claim that our search has been exhaustive, we do feel confident that the qualitative relations discovered should be seriously discussed by those concerned with the oyster fishery. The quantitative agreement between predicted and observed harvest is probably as good as is warranted by the quality of the input data and should be of some help to the fishermen, packers, managers, and marketers associated with the industry.

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References

Dow, R. L. 1977 Effects of climatic cycles on the relative abundance and availability of commercial marine and estuarine species. *Journal du Conservation international et Exploration de la Mer* **37**, 274–280.

Driver, P. A. 1976 Prediction of fluctuations in the landings of brown shrimp (*Crangon crangon*) in the Lancashire and Western Sea Fisheries District. *Estuarine and Coastal Marine Science* **4**, 537–567.

Jensen, A. L. 1976 Time series analysis and forecasting of Atlantic Menhaden catch. *Chesapeake Science* **17**, 305–307.

Koganezawa, A. 1972 Ecological studies at a seed oyster production area. II. Studies on the spawning condition of the Pacific oyster in Matsushima Bay. *Bulletin of the Japanese Society of Scientific Fisheries* **38**, 1315–1324.

Meritt, D. W. 1977 Oyster spat set on natural cultch in the Maryland portion of the Chesapeake Bay (1939–1975). UMCEES Special Report No. 7, Cambridge, Maryland.

Sutcliffe, W. H., Jr 1972 Some relations of land drainage, nutrients, particulate material, and fish catch in two eastern Canadian bays. *Journal of the Fisheries Research Board of Canada* **29**, 357–362.

Ulanowicz, R. E., Caplins, W. C. & Dunnington, E. A. 1978 Improved prediction of oyster harvest, including historical analysis and development of predictor models. UMCEES Ref. No. 78-12CBL, Solomons, Maryland.

Watt, K. E. F. 1956 The choice and solution of mathematical models for predicting and maximizing the yield of a fishery. *Journal of the Fisheries Research Board of Canada* **13**, 613–645.

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TABLE 2. Annual environmental conditions near Solomons, Md, 1938–76

Year	Yearly average				Cumulative excesses			
	Salinity (‰)	Water temperature (°C)	Air temperature (°C)	Precipitation (cm d^{-1})	Salinity (‰-days)	Water temperature (°C-days)	Air temperature (°C-days)	Precipitation (cm-days)
1938	13·19	15·33	15·22	0·33	9	46	133	10
1939	13·24	15·26	14·98	0·31	45	41	132	13
1940	14·28	13·44	13·19	0·28	149	25	111	6
1941	15·71	15·36	14·97	0·25	290	29	179	12
1942	14·69	15·26	14·82	0·27	169	65	126	7
1943	12·50	14·41	14·70	0·24	99	70	232	14
1944	15·06	14·67	14·65	0·26	208	25	169	5
1945	11·75	14·95	14·78	0·37	40	16	96	21
1946	12·21	15·32	15·36	0·30	17	5	52	17
1947	13·79	14·73	14·51	0·27	39	32	86	9
1948	13·61	14·68	14·61	0·39	36	31	105	24
1949	13·21	15·72	15·66	0·34	144	72	109	25
1950	13·54	14·98	14·40	0·30	30	11	54	16
1951	12·44	14·98	14·65	0·28	35	61	81	16
1952	11·96	15·26	14·93	0·31	6	68	143	8
1953	11·98	15·99	15·69	0·29	27	51	150	10
1954	15·37	15·30	15·03	0·23	240	9	117	2
1955	14·06	15·01	14·71	0·25	13	78	112	18
1956	12·34	14·71	14·48	0·33	1	23	78	18
1957	14·38	15·22	14·72	0·31	191	18	117	8
1958	12·28	14·14	13·54	0·39	2	17	99	20
1959	14·07	15·32	15·25	0·27	27	64	129	19
1960	12·24	15·03	14·19	0·32	0	32	52	19
1961	13·01	14·95	14·48	0·27	80	65	122	4
1962	14·23	14·70	13·97	0·30	49	5	76	10
1963	15·59	14·41	14·11	0·23	270	31	114	8
1964	14·60	15·02	14·65	0·25	240	14	103	5
1965	15·90	15·24	14·19	0·23	298	35	64	8
1966	16·14	14·69	13·57	0·27	360	56	118	16
1967	13·75	14·49	14·16	0·25	182	26	33	5
1968	13·56	14·99	14·55	0·21	43	86	144	8
1969	15·46	14·84	14·00	0·38	144	51	91	51
1970	13·45	15·11	14·37	0·24	23	54	117	8
1971	12·59	15·51	14·72	0·23	0	24	123	9
1972	10·00	14·77	14·05	0·33	13	24	71	16
1973	11·44	15·44	14·97	0·24	0	53	128	13
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1957	14·38	15·22	14·72	0·31	191	18	117	8
1958	12·28	14·14	13·54	0·39	2	17	99	20
1959	14·07	15·32	15·25	0·27	27	64	129	19
1960	12·24	15·03	14·19	0·32	0	32	52	19
1961	13·01	14·95	14·48	0·27	80	65	122	4
1962	14·23	14·70	13·97	0·30	49	5	76	10
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1970	13·45	15·11	14·37	0·24	23	54	117	8
1971	12·59	15·51	14·72	0·23	0	24	123	9
1972	10·00	14·77	14·05	0·33	13	24	71	16
1973	11·44	15·44	14·97	0·24	0	53	128	13
1974	12·44	15·11	14·73	0·26	109	3	69	17
1975	11·01	15·19	14·85	0·35	7	36	91	16
1976	10·29	14·18	14·27	0·21	0	0	82	5

	Cumulative deficits			Extreme values						
Year	Salinity (‰-days)	Water temperature (°C-days)	Air temperature (°C-days)	Max. salinity (‰)	Min. salinity (‰)	Max. water temperature (°C)	Min. water temperature (°C)	Max. air temperature (°C)	Min. air temperature (°C)	Max precipitation (cm d^{-1})
1938	6	15	164	17·60	9·40	29·10	2·50	36·10	—9·40	5·30
1939	114	25	115	17·40	6·40	28·70	1·50	35·00	—8·30	7·60
1940	104	205	356	19·20	6·60	29·70	—0·50	39·40	—13·90	4·50
1941	3	118	219	20·40	9·60	28·70	—0·50	36·70	—7·20	7·60
1942	7	77	250	20·20	3·70	30·00	1·70	37·20	—15·60	5·90
1943	165	112	238	18·70	5·40	28·80	0·80	37·20	—13·30	11·10
1944	36	90	185	18·70	7·00	29·60	1·10	26·70	—6·70	5·50
1945	133	178	232	17·90	6·80	28·50	—0·50	37·20	—10·60	11·90
1946	132	58	133	17·10	6·40	28·00	1·50	35·00	—9·40	8·80
1947	33	75	207	17·70	7·30	28·80	0·70	35·00	—12·80	9·00
1948	48	167	251	17·60	6·70	30·20	—0·80	36·70	—12·20	11·50
1949	41	0	68	19·00	7·00	29·90	4·00	36·10	—5·00	11·90
1950	28	18	170	17·80	7·70	28·00	1·80	35·00	—9·40	13·60
1951	141	68	187	17·90	7·00	30·00	0·40	33·90	—10·60	10·20
1952	162	12	81	16·70	6·00	31·00	2·70	37·20	—8·90	6·60
1953	227	0	58	17·40	7·20	29·60	4·10	36·70	—6·70	9·00
1954	8	47	149	19·10	9·30	27·60	1·90	37·20	—7·80	4·70
1955	0	101	244	17·30	10·50	29·40	0·80	36·70	—11·70	13·90
1956	45	85	127	16·50	8·20	29·00	0·90	35·60	—7·80	12·10
1957	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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1944	36	90	185	18·70	7·00	29·60	1·10	26·70	—6·70	5·50
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1948	48	167	251	17·60	6·70	30·20	—0·80	36·70	—12·20	11·50
1949	41	0	68	19·00	7·00	29·90	4·00	36·10	—5·00	11·90
1950	28	18	170	17·80	7·70	28·00	1·80	35·00	—9·40	13·60
1951	141	68	187	17·90	7·00	30·00	0·40	33·90	—10·60	10·20
1952	162	12	81	16·70	6·00	31·00	2·70	37·20	—8·90	6·60
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1956	45	85	127	16·50	8·20	29·00	0·90	35·60	—7·80	12·10
1957	34	36	133	19·40	7·20	29·60	1·30	36·70	—11·10	7·40
1958	213	148	297	16·50	5·90	28·20	—0·60	35·00	—13·30	10·50
1959	14	111	186	17·40	7·30	28·70	—0·30	37·20	—10·60	9·40
1960	98	93	264	16·30	7·50	28·50	—0·30	33·90	—11·10	11·30
1961	102	113	213	18·00	8·20	29·30	—0·50	34·40	—13·30	4·30
1962	31	109	245	17·70	8·40	29·10	0·30	35·00	—12·20	5·00
1963	4	212	303	19·90	8·50	28·40	—0·60	35·60	—13·30	7·30
1964	58	86	162	19·40	7·20	29·00	0·50	36·10	—14·40	5·10
1965	0	44	207	19·50	10·80	29·00	1·20	34·40	—11·10	7·20
1966	0	115	259	20·90	11·30	31·00	—1·00	36·10	—11·70	9·50
1967	12	33	194	20·00	8·60	29·00	1·80	32·70	—10·60	5·20
1968	2	160	357	17·80	9·90	29·90	—0·30	35·60	—14·40	7·00
1969	1	142	193	18·50	12·00	29·00	0·80	36·10	—9·40	30·10
1970	42	165	286	17·70	7·60	28·60	—0·80	35·00	—13·90	6·30
1971	48	106	249	16·30	8·80	30·00	—0·70	35·60	—12·80	7·20
1972	544	15	192	14·90	2·50	29·50	2·50	35·00	—12·60	6·90
1973	117	44	229	16·00	7·90	28·60	2·00	35·00	—11·10	10·90
1974	121	3	116	20·00	6·60	27·20	2·90	35·60	—8·30	10·00
1975	203	10	126	16·90	5·50	28·50	2·90	35·60	—8·30	8·60
1976	326	103	282	14·40	5·10	26·90	0·00	35·60	—11·70	6·60

	Episodes							
	High salinity (days)	Low salinity (days)	High water temperature (days)	Low water temperature (days)	High air temperature (days)	Low air temperature (days)	High precipitation (days)	Low precipitation (days)

1955	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1956	45	85	127	16·50	8·20	29·00	[illegible]	[illegible]	[illegible]	[illegible]
1957	34	36	133	19·40	7·20	29·60	1·30	36·70	—11·10	7·40
1958	213	148	297	16·50	5·90	28·20	—0·60	35·00	—13·30	10·50
1959	14	111	186	17·40	7·30	28·70	—0·30	37·20	—10·60	9·40
1960	98	93	264	16·30	7·50	28·50	—0·30	33·90	—11·10	11·30
1961	102	113	213	18·00	8·20	29·30	—0·50	34·40	—13·30	4·30
1962	31	109	245	17·70	8·40	29·10	0·30	35·00	—12·20	5·00
1963	4	212	303	19·90	8·50	28·40	—0·60	35·60	—13·30	7·30
1964	58	86	162	19·40	7·20	29·00	0·50	36·10	—14·40	5·10
1965	0	44	207	19·50	10·80	29·00	1·20	34·40	—11·10	7·20
1966	0	115	259	20·90	11·30	31·00	—1·00	36·10	—11·70	9·50
1967	12	33	194	20·00	8·60	29·00	1·80	32·70	—10·60	5·20
1968	2	160	357	17·80	9·90	29·90	—0·30	35·60	—14·40	7·00
1969	1	142	193	18·50	12·00	29·00	0·80	36·10	—9·40	30·10
1970	42	165	286	17·70	7·60	28·60	—0·80	35·00	—13·90	6·30
1971	48	106	249	16·30	8·80	30·00	—0·70	35·60	—12·80	7·20
1972	544	15	192	14·90	2·50	29·50	2·50	35·00	—12·60	6·90
1973	117	44	229	16·00	7·90	28·60	2·00	35·00	—11·10	10·90
1974	121	3	116	20·00	6·60	27·20	2·90	35·60	—8·30	10·00
1975	203	10	126	16·90	5·50	28·50	2·90	35·60	—8·30	8·60
1976	326	103	282	14·40	5·10	26·90	0·00	35·60	—11·70	6·60

Episodes

Year	High salinity (days)	Low salinity (days)	High water temperature (days)	Low water temperature (days)	High air temperature (days)	Low air temperature (days)	High precipitation (days)	Low precipitation (days)
1938	12	8	29	19	29	14	12	38
1939	58	88	32	22	31	15	6	35
1940	90	69	14	74	17	38	21	31
1941	72	8	19	68	18	26	18	41
1942	76	0	25	59	12	10	10	34
1943	50	67	44	67	39	15	11	30
1944	61	23	23	52	27	12	7	34
1945	35	41	11	60	8	21	19	17
1946	14	51	6	39	6	14	14	22
1947	54	27	31	39	13	37	7	14
1948	39	24	14	68	16	29	12	15
1949	0	28	29	0	27	6	9	20
1950	25	26	8	4	8	17	20	35
1951	56	72	48	31	11	14	6	35
1952	22	94	42	11	26	7	18	26
1953	64	105	21	0	20	4	15	26
1954	20	13	12	35	14	10	12	29
1955	27	0	53	47	23	27	14	33

Year	(days)	(days)	(days)	(days)	(days)	(days)	(days)	(days)
1938	12	8	29	19	29	14	12	38
1939	58	88	32	22	31	15	6	35
1940	90	69	14	74	17	38	21	31
1941	72	8	19	68	18	26	18	41
1942	76	0	25	59	12	10	10	34
1943	50	67	44	67	39	15	11	30
1944	61	23	23	52	27	12	7	34
1945	35	41	11	60	8	21	19	17
1946	14	51	6	39	6	14	14	22
1947	54	27	31	39	13	37	7	14
1948	39	24	14	68	16	29	12	15
1949	0	28	29	0	27	6	9	20
1950	25	26	8	4	8	17	20	35
1951	56	72	48	31	11	14	6	35
1952	22	94	42	11	26	7	18	26
1953	64	105	21	0	20	4	15	26
1954	20	13	12	35	14	10	12	29
1955	27	0	53	47	23	27	14	33
1956	0	63	9	44	13	18	17	14
1957	116	19	11	35	18	12	18	32
1958	14	123	19	76	15	24	17	24
1959	45	7	31	61	23	16	16	31
1960	0	82	16	37	8	16	10	48
1961	62	79	31	49	20	24	13	42
1962	59	19	3	62	8	17	12	30
1963	85	0	17	70	14	34	14	38
1964	30	34	11	63	13	9	10	38
1965	65	0	20	41	10	13	7	29
1966	45	0	23	48	25	31	10	40
1967	64	12	25	27	7	18	11	41
1968	45	4	45	68	22	30	5	90
1969	67	0	53	77	12	16	7	67
1970	25	47	33	68	11	22	4	58
1971	0	50	50	49	13	21	4	55
1972	0	180	17	24	13	16	7	42
1973	0	77	48	23	33	16	7	62
1974	38	76	8	9	13	10	9	58
1975	18	125	37	15	25	10	5	43
1976	0	182	3	44	10	22	5	53

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