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Growth and Survival of Kemp's Ridley Sea Turtle, Lepidochelys kempi, in captivity

By

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ABSTRACT

Six year-classes (1978-1983) of Kemp's ridley sea turtle, Lepidochelys kempi, were reared at the National Marine Fisheries Service, Southeast Fisheries Center, Galveston Laboratory in Galveston, Texas. This paper describes the growth in weight per individual, the increase in biomass, and the survival of aggregates of turtles during their first year of life in captivity. It also lays a statistical foundation for future experiments on factors affecting growth and survival of Kemp's ridley in captivity.

The exponential phases of first-year growth in weight per individual (for all year-classes, 1978-1983) and increase in biomass (only for year-classes 1981-1983) of aggregates of turtles were transformed to straight-line relationships represented by the rectilinear regressions of the natural logarithm of weight or biomass on the square root of age or square root of lapsed time (when age was unknown). The slopes of the straight lines, as indices of the rates of increase in weight (growth rate) and biomass, were used to detect differences among year-classes or sub-divisions (e.g., "imprint-groups" and clutches) within year-classes. The most rapid growth was exhibited by the 1980 year-class and the slowest growth by the 1983 year-class.

Within the 1981-1983 year-classes, there were significant differences among clutches in growth rate and rate of increase in biomass, but these differences were confounded with other sources of variation. There was greater similarity in growth rates than in rates of biomass increase among year-classes and among clutches within year-classes. There was a curved relationship (concave downward) between the indices of biomass increase and of growth. At lower levels of both indices, the growth rate index exceeded the index of biomass increase. The two indices converged (became more alike) as they increased. Survival and growth rate index increased up to point, then survival declined with further increase in the growth rate index. Such results suggest that carrying capacity of the raceways for turtle biomass is a limiting factor and that compensatory mortality occurs as the size of the turtles increases.

A minimum sample size of 25 turtles per clutch is adequate for detecting differences between means of logarithmically-transformed weights, either for comparisons among different clutches at the same time or for comparisons within the same clutch at different times. Growth in weight with carapace length followed the "cube law." Carapace width and length were linearly related, with the former being only slightly shorter than the latter.

Growth in weight of ten turtles from the 1978 year-class, held in captivity for 5 years at Sea-Arama Marineworld in Galveston after having been reared at the Galveston Laboratory, followed a sigmoid pattern described by a fitted Gompertz growth function. The upper asymptotic weight was 29.2 kg, much smaller than the size (39-49 kg) recorded for nesting adults.

BACKGROUND

The only known nesting colony of Kemp's ridley sea turtle, Lepidochelys kempi, estimated to contain more than 40,000 nesters in 1947 (Hildebrand, 1963), has dwindled to fewer than 600 (Jack Woody, U.S. Fish and Wildlife Service, Albuquerque, NM, personal communication, June 1986). The nesting beach is located near the village of Rancho Nuevo, Tamaulipas State, on Mexico's upper coast bordering the Gulf of Mexico (Carr, 1963; Casas-Andreu, 1978; Chavez et al., 1968; Hildebrand, 1963; Pritchard and Marquez, 1973). The most likely cause of the pronounced decline in nesters is excessive exploitation of the turtles and eggs by man, but predation and other natural causes have not been eliminated as contributing factors (Caillouet, 1984).

In 1966, the Mexican government initiated biological investigations and beach patrols to prevent Kemp's ridley, the most endangered of the sea turtle species, from becoming extinct (Chavez et al., 1968). In 1978, the U.S. Fish and Wildlife Service (FWS), the National Park Service (NPS), the National Marine Fisheries Service (NMFS), and the Texas Parks and Wildlife Department (TPWD) joined with Mexico's Instituto Nacional de la Pesca (INP) in a cooperative program directed toward enhancement of the Kemp's ridley population (Klima and McVey, 1981). The program's objectives now include: (1) prohibitions on the possession and sale of the eggs, turtles and various turtle products for which the demand is substantial; (2) protection of the nesting turtles, their nests and eggs by Mexican military personnel and international teams of biologists through beach patrols during the nesting and hatching season from April through August; (3) translocation of clutches of eggs to protected corrals at Rancho Nuevo; (4) promotion of the use of specialized gear (turtle excluder device or trawling efficiency device) to allow escapement of turtles caught incidentally in shrimp trawls; (5) "head starting" Kemp's ridley with a view toward establishment of a new nesting colony at the Padre Island National Seashore near Corpus Christi, Texas, and (6) captive propagation.

Head starting involves the incubation and hatching of eggs and

the rearing of hatchlings in captivity so as to enhance their survival (Mrosovsky, 1983). In the wild, the eggs and hatchlings of Kemp's ridley are vulnerable to a variety of natural predators (Hildebrand, 1963), and little is known about the turtles during their first year at sea (Carr, 1980).

At the NMFS Southeast Fisheries Center's (SEFC) Galveston Laboratory in Texas, eight year-classes, 1978-1985, of Kemp's ridley have been head started by rearing them in captivity for one year or less. Out of 15,260 hatchlings received alive, 10,792 (71%) have been reared, tagged and released into the Gulf of Mexico in hopes that some will mature and return to nest on the beaches at Padre Island or Rancho Nuevo to which they were exposed as hatchlings (Caillouet et al., MS; Fontaine and Caillouet, 1985; Klima and McVey, 1981; Owens et al., 1982).

An additional 264 captive-reared Kemp's ridleys were tagged and distributed among Bass Pro Shops (Springfield, MO; 5 turtles of the 1984 year-class), the Cayman Turtle Farm (Grand Cayman Island, British West Indies; 96 turtles of the 1979 year-class; 5 turtles of the 1982 year-class; 15 turtles of the 1984 year-class), Clearwater Marine Science Center (Clearwater, FL; 5 turtles of the 1982 year class), Dallas Aquarium (Dallas, TX; 5 turtles of the 1984 year-class), Gulfarium (Fort Walton Beach, FL; 5 turtles of the 1982 year-class), Marineland, Inc. (St. Augustine, FL; 5 turtles of the 1984 year-class), Marine Life Park, Inc. (Gulfport, MS; 5 turtles of the 1982 year-class), Miami Seaquarium (Miami, FL; 29 turtles of the 1978 year-class; 50 turtles of the 1979 year-class), New England Aquarium (Boston, MA; 4 turtles of the 1984 year-class), North Carolina Marine Resources Center (Kure Beach, NC; 3 turtles of the 1984 year-class), Pan American University (South Padre Island, TX; 2 turtles of the 1984 year-class), Sea-Arama Marineworld (Galveston, TX; 10 turtles of the 1978 year-class; 3 turtles of the 1984 year-class), Sea World of FLorida (Orlando, FL; 5 turtles of the 1984 year-class), and Theater of the Sea (Islamorado, FL; 5 turtles of the 1982 year-class), for extended head starting or captive propagation. In September 1986, 111 (42%) of these, ranging in age from 2 1/4 to 8 1/4 years, remained

alive. A few head started turtles that exhibited abnormalities or were incurably sick or permanently handicapped by injuries were either transferred to other investigators or disposed of humanely (Fontaine et al., 1985).

In May 1984, two 5-year-old female Kemp's ridleys that had been reared from hatchlings at Galveston then transferred to the Cayman Turtle Farm in February 1980 laid eggs at the farm (Wood and Wood, 1984). Three of the eggs hatched, indicating that they had been fertilized by the captive-reared males, but the hatchlings did not survive. There was no reported reproductive activity in this captive stock in 1985. In spring 1986, several nestings occurred and viable hatchlings were produced. These events represent major breakthroughs by documenting the earliest age for copulation and nesting in the species as well as proving feasibility of captive propagation as a "safety net" for the species (Caillouet, 1984).

Growth of captive-reared sea turtles other than Kemp's ridley has been examined by a number of investigators (Bacon et al., 1983; Frazer and Schwartz, 1982; Hirth, 1982; LeBrun, 1975; Nuitja and Uchida, 1982; Rajagopalan, 1984; Stickney et al., 1973; Uchida, 1967; Witham and Futch, 1977; Witzell, 1980; Wood and Wood, 1981). Growth of Kemp's ridley in captivity has been depicted by Caillouet and Koi (1985), Caldwell (1962), Fontaine et al. (1985), Klima and McVey (1981), Marquez (1972), McVey and Wibbels (1984), McVey et al. (MS), and Pritchard and Marquez (1973).

OBJECTIVES

The main objective of this paper is to examine and summarize data on growth, increase in biomass and survival of the first six year-classes, 1978-1983, of Kemp's ridleys head started by the Galveston Laboratory. We describe first-year exponential growth in weight per individual and increase in biomass of aggregates of Kemp's ridley, as well as their survival in captivity from the time the hatchlings were received to their release as "yearlings" into the Gulf of Mexico, or their transfer to other organizations. A second objective is to describe the growth in weight of ten Kemp's ridleys (eight remained alive in December 1986) that were transferred to Sea-Arama Marineworld

after having been reared from hatchlings at the laboratory.

New empirical relationships (equations) were developed to describe the exponential phases of increase in weight per individual and increase in biomass of aggregates of Kemp's ridley with age or lapsed time (when age was unknown) during their first year of life. The equations were derived by fitting rectilinear regressions of the natural logarithm of weight (g) or the natural logarithm of biomass (kg) on the square root of age (days) or the square root of lapsed time (days) when age was unknown. The slopes of the rectilinear regression equations are indices of rates of increase in weight and in biomass with age or lapsed time, and they were used to compare year-classes and subdivisions (e.g., "imprint"-groups and clutches) within year-classes. Variability in weight among individuals, clutches, and larger aggregates of turtles was examined, and the sample size required for detecting differences between means of logarithmically-transformed weights, both between and within clutches, was determined. Weight-length and width-length relationships were derived.

MATERIALS AND METHODS

Source of Hatchlings

Each spring, beginning in 1978, INP and FWS personnel and collaborators collected clutches of Kemp's ridley eggs as they were being laid at the beach near Rancho Nuevo (Caillouet, 1984; Fontaine and Caillouet, 1985; Fontaine et al., 1985; Klima and McVey, 1981; McVey et al., MS). Most of the eggs were collected in plastic bags to prevent their contact with and possible imprinting on Rancho Nuevo beach sand (Table 1). At Rancho Nuevo, the eggs were placed in polystyrene foam boxes containing beach sand from the Padre Island National Seashore, and the boxes were transported by aircraft to the Padre Island National Seashore where they were tended by NPS personnel during incubation. Within the first three year-classes (1978-1980), a few clutches were incubated in Rancho Nuevo beach sand (Table 1). Within the second three year-classes (1981-1983), so few eggs were incubated in Rancho Nuevo sand that the turtles that hatched were excluded from our analyses.

As the hatchlings emerged (either at the Padre Island National Seashore or at Rancho Nuevo) they were taken to the beach and allowed to crawl into the surf where they were scooped up in nets (Caillouet, 1984; Fontaine and Caillouet, 1985; Fontaine et al., 1985; Klima and McVey, 1981; McVey et al., MS). The "imprinted" hatchlings (Table 1) were placed in boxes and transported by aircraft to the Galveston Laboratory where they were reared in captivity. It is hoped that exposure to beach sand and seawater imprinted the hatchlings (Grassman et al., 1984) so that some of those reared in captivity then tagged and released into the Gulf of Mexico will mature and return to nest at the beach to which they were exposed (Owens et al., 1982).

Rearing Containers

The containers used to rear the 1978-1983 year-classes of Kemp's ridley have been described by Fontaine et al. (1985) and McVey et al. (MS). They included fiberglass raceways, concrete tanks, and fiberglass basins. However, the primary rearing containers were 15 rectangular raceways, each filled with approximately 3,140 liter of seawater. The raceways were housed within two metal-framed quonset huts covered with white polyethylene sheathing which allowed penetration of sunlight. The 2 x 8 m raceways were placed side by side (with a walk-space between them) in an east-west row inside the quonset huts. As clutches were received, they were distributed more or less sequentially among the rearing containers; i.e., no attempt was made at randomization.

Rearing of the 1978 year-class began by intermingling the hatchlings within the containers, but the turtles bit and injured each other which led to mortality (Klima and McVey 1981; McVey et al., MS). Therefore, beginning in January 1979, the turtles were reared in isolation. Most were placed as individuals in separate plastic buckets containing about 10 liter of seawater when suspended within the raceways. The raceways each held 108 buckets (6 columns x 18 rows) perforated by holes (2.5 cm in diameter) in their bottoms to allow circulation of seawater and liberation of turtle excrement and uneaten food (Fontaine et al., 1985). The fiberglass basins, of 26-liter capacity, also were used intermittently as rearing containers for individual turtles. Also some turtles outgrew their buckets near the

end of each rearing period and had to be transferred to basins for a short time before release.

Rearing containers were drained, flushed by hosing, and refilled with clean seawater about thrice each week, except in rearing the 1978 year-class during which these were daily practices (Fontaine et al., 1985; McVey et al., MS). Once each week, all containers were scrubbed with brushes to remove attached algae and waste materials.

The 10 Kemp's ridleys (all "imprinted" at the Padre Island National Seashore) transferred to Sea-Arama Marineworld were maintained there in a concrete tank holding about 1,760 liter of seawater and partitioned into 10 compartments (each 120 cm x 106 cm x 68 cm deep) by plywood dividers, with one turtle per compartment. Seawater was exchanged by flow-through at a rate approximating 23 liter per min.

Sampling for Weight, Length and Width

Weights, carapace lengths (total carapace length as defined by Bjorndal and Balazs, 1983) and carapace widths were taken on all hatchlings, then on random samples of turtles at approximately monthly intervals during head starting (McVey et al., MS; Fontaine et al., 1985). Wet weighings were made to the nearest 0.1 g on an O'haus triple-beam balance. The balance pan was dried and the balance re-zeroed after consecutive weighings of three turtles. Length and width measurements were made to the nearest 0.1 cm by the straight-line method. Until the turtles were 4-5 months old, lengths and widths were taken with a ruler. Thereafter, calipers were used.

For year-classes 1978-1980, McVey et al. (MS) recorded the weights and measurements only by "imprint"-group within year-class (Table 1); one group "imprinted" at the Padre Island National Seashore and the other at Rancho Nuevo. Clutch identity was neither kept track of nor recorded. At approximately monthly intervals, it took two or more consecutive days to weigh and measure the large samples of sea turtles which were then considered to be representative of the two "imprint" groups. In analyzing the data recorded by McVey et al. (MS), we treated each day's weights and measurements as coming from independent samples from the particular "imprint"-group sampled. Because these samples represented aggregates of clutches, they included turtles of

ages differing by days or weeks. Clutches were received from NPS shortly after they hatched (Table 1), but all clutches did not hatch simultaneously, because they came from nestings over a period of time. Also, all hatchlings from a given clutch did not emerge on the same day, some taking longer than others to hatch. Therefore, individuals in the same clutch could have varied in age by a few days, and clutches could have varied in age by several weeks. About one month from the end of each head starting period, all healthy survivors to be tagged and released were weighed and measured.

For year-classes 1981-1983, most of the hatchlings were "imprinted" at the Padre Island National Seashore (Table 1), and observations on these were taken and recorded by clutch (Fontaine et al., 1985). For year-classes 1981 and 1983, random samples of not more than 25 turtles from each clutch (some clutches contained fewer than 25 turtles) were weighed and measured at approximately monthly intervals. Exceptions were that all hatchlings of a year-class were weighed and measured before head starting, and all healthy survivors in each clutch were weighed and measured at the time they were tagged, about one month before their release. Thus the first and last samples contained more than 25 turtles, if the clutch initially contained more than 25 hatchlings or subsequently contained more than 25 survivors. If the clutch contained fewer than 25 hatchlings or survivors, all were weighed and measured each time samples were taken. For the 1982 year-class, monthly random sample size was not more than 30 per clutch with comparable exceptions concerning the first and final samples of weights and measurements. Though weights and measurements were taken on turtles from all clutches of the 1983 year-classes (Table 1), only clutches 1-3 were included in our analyses for that year-class because the other clutches contained too few turtles.

Each combination of year-class and "imprint"group, or year-class and clutch, provided at least one sample of turtle weights, carapace lengths and carapace widths at approximately monthly intervals (Fontaine et al., 1985; McVey et al., MS). An exception was the 1983 year-class for which sampling intervals were wider due to the disruption and damage caused by hurricane Alicia which crossed Galveston

Island on 18 August 1983. The number of times in which a given combination was sampled during head starting was designated m (Table 2). This number varied somewhat depending on how long the turtles were held in captivity and upon variation in the interval between samplings. In the 1978-1980 year-classes, m was inflated by the sampling procedure which spread the monthly sampling of turtles within "imprint"-groups over a number of consecutive days. In these cases, each day was considered to provide a separate sample for our analyses. For the 1981-1983 year-classes, fewer turtles were weighed and measured on any given occasion, and m was the number of samples taken from a given clutch over the period of head starting.

The 10 Kemp's ridley transferred to Sea-Arama Marineworld were weighed and measured approximately monthly during the first few years, then less frequently thereafter.

Survival

For year-classes 1981-1983, the number of survivors in each year-class-clutch combination was determined each time samples were taken for weighing and measuring, and at the end of the head starting period (Fontaine et al., 1985). For year-classes 1978-1980, only final survival was determined by year-class (ibid.; McVey et al., MS). Included as survivors were any animals that were "cropped" for tagging and release or for transfer to the Cayman Turtle Farm or to marine aquaria before the head starting period was complete, and any abnormal, sick or handicapped (by injuries) turtles still alive at the time of the last weighing and measuring.

Foods, Feeding and Health Care

The foods and feeding methods used in head starting Kemp's ridley have been elaborated in detail (Fontaine et al., 1985; McVey et al., MS). The primary food was a dry, floating, pelleted diet (Table 3) manufactured by Central Soya and Subsidiaries, Fort Wayne, Indiana Feeding methods evolved both through small-scale experimentation and by trial-and-error. The 1978 year-class was fed three times per day, and the 1979-1983 year-classes two times per day.

McVey et al. (MS) offered the turtles of the 1978-1980 year-classes daily amounts of food that were slightly more than the amount eaten (Fontaine et al., 1985). Starting with the 1981 year-class, we fed the hatchlings at a rate roughly 5% of average body weight per day, with the amount of food divided into two portions for two feedings, one in the morning and the other in the afternoon. As the turtles grew larger, the daily ration was gradually changed to reach roughly 1.5% of average body weight per day by the end of the head starting period. The total quantity of food for each day was based on the biomass of all the turtles (estimated by multiplying the grand arithmetic average weight of turtles from the most recently weighed samples by the total number of survivors held in captivity). Once the total amount of food was calculated, the food was distributed among the turtles in each raceway by hand, with the larger turtles given move than the smaller ones. This feeding technique, while admittedly highly subjective, was used to assure adequate feeding while avoiding excessive waste of food. However, if during the interval between weighings, the turtles appeared to require more food than the calculated amount, additional food was provided. If the turtles showed signs of bloating or if water quality deteriorated too rapidly from decomposition of uneaten food, either the amount of food was decreased or the feeding stopped until conditions improved.

Foods and feeding were not controlled in such a manner that their effects could be evaluated statistically, but they provided acceptable levels of survival and growth. However, the faster-growing turtles received more food than their slower-growing counterparts under the feeding regimen used, and the differences in amounts of food may have further enhanced the differences in growth among turtles of different sizes.

The Kemp's ridleys maintained at Sea-Arama Marineworld were fed a diet of smelt (Osmeridae), mackerel (Scombridae), squid (Cephalopoda) and live blue crabs (Callinectidae), supplemented by encapsulated vitamins A, D and E and a vitamin-mineral tablet (SEATAB, Pacific Research Laboratory, Inc., El Cajon, CA). They were fed three times per week and received, at each feeding, 0.45 kg of fish or squid, 3

medium-sized crabs, ½ of a SEATAB tablet, and two veterinary-grade vitamin capsules (one containing 10,000 IU of vitamin A and 400 IU of vitamin D, and the other containing 400 IU of vitamin E).

Health care for the turtles consisted of prophylactic and therapeutic measures associated with research in turtle pathology (Clary and Leong 1984; Leong et al., MS).

Environmental Variables

During the rearing operations, salinity, pH and 24-hr maximum and minimum water temperatures were monitored intermittently in selected raceways, and served as general guides to environmental conditions (Fontaine et al., 1985; McVey et al., MS). Temperature ranged from a low of 20°C (with occasionally lower temperatures in September-February) to 30°C (with occasionally higher temperatures in July-September), on an annual cycle. During winter, despite the heating of the air in the quonset huts with forced-air heaters and the incoming seawater by immersion heaters, the temperature in the raceways dropped. Levels of pH were slightly above 7.0 during most of the year, except in late summer and fall when they increased to levels near 7.5. Occasionally this range was extended by somewhat lower and higher pH, respectively. For the most part, salinity was near 26 ppt, rising above 30 ppt in July-September and dropping below 20 ppt in May-June. A more precise assessment of environmental conditions was not possible due to limitations on quantity and quality of the available data.

Rectilinear Regression Analyses

Rectilinear regressions of the form $Y = a + bX$ are used a number of times in this paper to fit straight lines to various groups of data. Therefore, the dependent variable, "Y", the independent variable, "X", and parameters a and b represent different quantities when representing different data sets.

Rationale for Logarithmic Transformation of Weights

The range in weight among individuals increased with age or time, indicating that variance in weight was heterogeneous (Caillouet and

Koi, 1985). The method of Taylor (1961), based on the relationship between sample variances and arithmetic means, was used to determine the type of transformation of the weight data required for fitting growth curves and for comparing means. The variances (s^2) and arithmetic means ($\bar{W}$) of weight (W, in g) were calculated for each of the 52 time-series (Table 2) of samples of turtles (by "imprint"-group and clutch). The slopes of rectilinear regressions of $\ln s^2$ on $\ln \bar{W}$ (for each time-series) ranged from 1.88 to 3.66. We considered them to be close enough to 2 to justify logarithmic transformation of all sample weights. The logarithmic transformation reduced the heterogeneity of variance substantially, and had the added practicality of helping transform the exponential phase of growth in the turtles into a straight line.

Rectilinear Regression of Transformed Weight on Transformed Age or Lapsed Time

The time unit T (days), used to assess growth in clutches from the 1981-1983 year-classes, was actual age (within a day or two). The age from the day of hatching was known for each clutch, and all observations for each random sample of turtles from a given clutch usually were taken within the same day. Rarely did this extend to three consecutive days. When measurements of a clutch spanned more than 1 day, a weighted, arithmetic average age of the lumped samples was calculated.

Using the procedure of Box and Tidwell (1962), we determined that a square root transformation of the time scale (abscissa) also was necessary to obtain a straight line relationship. The straight line relationship was obtained by fitting a rectilinear regression to the data representing natural logarithm of weight and the square root of age for clutches within year-classes 1981-1983:

$$\widehat{\ln W} = \ln a + bT^{1/2} + \ln d \qquad (1)$$

where W is weight in g, T is age in days, lna is the intercept, b is the slope and an index of growth rate, and lnd is the deviation or

residual from regression. This represents the following exponential relationship between weight and age for a given clutch:

$$\hat{W} = (ae^{bT^{1/2}})d \qquad (2)$$

For the 1978-1980 year classes, extraneous variation in size resulting from the sampling procedure and differences in age among the turtles made it necessary to use the time unit T' (days) to assess growth. T' represented the time lapsed from the earliest date on which weights and measurements were taken on hatchlings of a given year-class. For the growth analysis applied to data from the two "imprint"-groups in each of the 1978-1980 year-classes, lapsed time was substituted for age (which was not known) as follows:

$$\widehat{\ln W} = \ln a' + bT'^{1/2} + \ln d' \qquad (3)$$

where T' is the time lapse in days following the earliest weighings of hatchlings from a given year-class. Parameters lna' and b' and residual lnd' are not strictly comparable to corresponding parameters in equation (1). Equation 3 can be expressed in exponential form relating weight to lapsed time for a given "imprint"-group within a year-class as follows:

$$\hat{W} = (a'e^{b'T'^{1/2}})d' \qquad (4)$$

Rectilinear Regression of Transformed Biomass on Transformed Age

For each clutch of the 1981-1983 year-classes, size and survival data were available upon which to calculate biomass at a given age. Biomass was determined by multiplying the geometric mean weight ($\bar{W}'$) of each random sample of turtles from each clutch by the number of surviving turtles within the clutch. The geometric mean weight was calculated as:

$$\bar{W}' = \text{Antilog}\left[\left(\sum_{i=1}^{n} \ln W_i\right)/n\right]$$

where $\bar{W}'$ is the sample geometric mean weight, W_i is the weight (in kg) of the ith turtle in the sample, n is the number of turtles in the sample, and i is 1, 2, ..., n. The relationship between biomass and age was transformed to the straight-line relationship:

$$\widehat{\ln B} = \ln a + bT^{1/2} + \ln d \qquad (5)$$

where B is the biomass in kg, T is the age in days, lna is the intercept, b is the slope, and lnd is the deviation or residual from regression. Expressed in exponential form, the relationship is as follows:

$$\widehat{B} = (ae^{bT^{1/2}})d \qquad (6)$$

It was not possible to calculate biomass at intervals during rearing of the 1978-1980 year-classes, because survival was not recorded by McVey et al. (MS) at intervals during head starting.

Sample Size

Until our analyses were completed, it was not known what sample size would be adequate for detecting differences in average weight between groups of Kemp's ridleys reared in captivity, or in assessing their growth in weight. A pooled variance ($s_p^2 = 0.0403$) of the logarithmically transformed weights of turtles from clutches of the 1981-1983 year-classes was used to determine sample size (n) required to detect differences ($\bar{D}$) between sample means of logarithmically transformed weights of turtles. This sample size applies to samples taken at different times from a given clutch or to samples from different clutches taken at the same time. In comparing two such samples, designated 1 and 2 for example, the mean difference, $\bar{D}$, is $(\ln\bar{W}')_1 - (\ln\bar{W}')_2$. Figure 1 shows relationships between the critical level of $\bar{D}$ and n for the 80%, 90% and 95% probabilities of detecting real differences (i.e., the power of the test) of magnitude $\bar{D}$ at the 5% level of significance (i.e., probability of type I error - rejecting the null hypothesis of no difference when it is true). It is clear that a minimum sample size of 25 is adequate, because the critical level of $\bar{D}$ increases rapidly as sample size decreases below 25.

Samples taken from aggregates of turtles made up of more than one clutch, as was the case for "imprint"-groups of the 1978-1980 year-classes, contained possible clutch differences that would be expected to inflate the variability in weight among individuals. Therefore, a sample size larger than 25 would be required to detect mean differences between samples containing mixed clutches. We would recommend against lumping clutches in samples, because it is easy enough to keep track of clutch identities during head starting. Also, for turtles kept in a captive breeding stock, the measurement of their growth, as related to their parentage, may be an important criterion in selective breeding.

RESULTS

Weight-Length and Width-Length Relationships

Relationships between weight and carapace length and between carapace width and carapace length were calculated for each "imprint"-group of the 1978-1980 year-classes and for each clutch of the 1981-1983 year-classes. The differences among the groups and clutches appeared negligible, so the relationships were determined for data lumped by year-classes (Tables 4 and 5). The exponent of the exponential weight-length relationship was near 3 (Table 4) as expected from the "cube law" of growth in weight with length. The carapace of Kemp's ridley is almost as wide as it is long (Carr, 1967), as confirmed by the observed slopes, slightly less than 1, for the rectilinear width-length relationships (Table 5).

Growth Pattern and Variability in Weight

The range in weight increased as the animals grew larger and there was a slowing of growth about the middle of the growth period (Caillouet and Koi, 1985). As expected, variability in weight among individuals at any given time during head starting was greater in the 1978-1980 year-classes than in the 1981-1983 year-classes (ibid.). The two different forms of sampling, by "imprint"-group within the 1978-1980 year-classes (which included variation among clutches) and

by clutch within the 1981-1983 year-classes, contributed to the differences in levels of variability among year-classes. In the 1978 and 1979 year-classes, another source of variation in size of individuals was the intermittent "cropping" of the largest of the turtles for tagging and release or transfer to marine aquaria (McVey et al., MS). These removals no doubt affected the ranges and average sizes of subsequent samples from those two year-classes.

Growth Comparisons

Table 6 gives the slopes and other statistics for the rectilinear regressions (equation 1) of transformed weight on transformed age of Kemp's ridleys by clutch for year-classes 1981-1983. These slopes are indices of the rate of growth in weight of the turtles, and we refer to them as weight increase indices or growth rate indices. Analysis of covariance (Table 7) detected significant (used here and henceforth in this paper to refer to the 5% level of significance) differences among these indices. Figure 2 is a plot of the indices (slopes) for each clutch of the 1981-1983 year-classes, along with three horizontal lines representing the "average" indices, one for each year-class, derived as the common regression for all clutches combined within a year-class (Table 6). Clearly, the 1982 year-class exhibited the most rapid rate of growth in weight, followed by the 1981 year-class and the 1983 year-class, in descending order (Fig. 2). Detransformed growth curves for year-classes 1981-1983 are shown in Figure 3.

Table 8 gives the slopes and other statistics for the rectilinear regressions (equation 3) of transformed weight on transformed lapsed time for Kemp's ridleys by "imprint"-group for year-classes 1978-1980. These slopes are indices of growth in weight with lapsed time, and we refer to them as weight increase indices or growth rate indices. However, they are not strictly comparable to those for the 1981-1983 year-classes. Analysis of covariance (Table 9) detected significant differences among the slopes for "imprint"-groups. Also, the "average" (common) weight increase indices for each of the three year-classes were different (Table 8). The 1980 year-class clearly showed the most rapid growth rate, followed by the 1979 year-class and the

1978 year-class in descending order. The Padre Island National Seashore "imprint"-groups of the 1978 and 1980 year-classes grew faster than the corresponding Rancho Nuevo "imprint"-groups. The opposite was true for the two "imprint"-groups of the 1979 yearclass.

Detransformed growth curves for year-classes 1978-1980 are shown in Figure 3. While these curves are not strictly comparable to those of year-classes 1981-1983, due to differences in the time variable used on the abscissa as well as different levels of sampling variation, one can get an impression from Figure 3 of the differences in growth among all of the year-classes. Year-class 1980 stands out as the best-growing year-class, and 1983 as the poorest.

Biomass Increase Comparisons

The slope of the straight-line relationship represented by equation 5 was an index of the rate of increase in biomass with age for year-classes 1981-1983 (Table 10). In Figure 4, the indices for each clutch within year-classes 1981-1983 are plotted along with horizontal lines representing the "average" (common) biomass increase indices for each year-class. Three features of these plots are worth noting as compared to Fig. 2. First, the rank order of the two indices (weight increase and biomass increase) by year-class is the same. Second, for each year-class, the common index (horizontal line) for biomass increase (Fig. 4) was lower than that for the comparable weight increase index (Fig. 2), indicating that the rate of increase in individual weight was faster than the rate of increase in biomass. Third, the common index for biomass increase varied more among year-classes than the common index for growth in weight. In other words, year-classes and clutches showed greater similarity in growth rate than they did in rate of biomass increase, the difference reflecting variability in survival among clutches and year-classes. Analysis of covariance (Table 11) detected significant differences among the slopes of the regressions (equation 5) applied to clutches within the 1981-1983 year-classes (Table 10), indicating significant differences among biomass increase indices within year-classes.

Biomass Increase Index, Weight Increase Index, and Survival

Figure 5 shows the relationship between the biomass increase index and weight increase index for clutches of the 1981-1983 year-classes. A curved trend (concave downward) is evident with only one apparent outlier represented by clutch 3 of the 1983 year-class. Clutch 3 was sampled the fewest times of all clutches during head starting (Table 2), so it is not surprising that it was aberrant. Though 46 different clutches representing three different year-classes were represented, most of the points followed a rather tight pattern. Also, the two indices converged (became more alike) as they increased.

Within the 1978-1980 year-classes, highest survival (95%) was exhibited by year-class 1980, intermediate (83%) by year-class 1979, and lowest (68%) by year-class 1978. Slowest growth was associated with lowest survival and vice versa. Survival rates for the 1978-1980 year-classes treated as survivors not only the healthy turtles tagged and released after the head start period, but also those transferred to the Cayman Turtle Farm (year-class 1979) and marine aquaria (year-classes 1978 and 1979), those tagged and released before the end of the head start period (year-class 1978), and those that were abnormal, sick or permanently handicapped by injuries at the end of the head start period and therefore were not tagged and released.

Survival in 39 of the 46 clutches of the 1981-1983 year-classes was above 80%. Among the clutches exhibiting less than 80% survival over the head start period were 1, 13, and 21 of the 1981 year-class, 1 and 5 of the 1982 year-class, and 1 and 3 of the 1983 year-class. Survival rates for the 1981-1983 year-classes included not only the healthy turtles tagged and released after head starting, but also those transferred to marine aquaria (year-class 1982), and those that were abnormal, sick or handicapped at the end of the head start period and therefore were not tagged and released.

A scatter plot of final survival (in %) against the weight increase index (Fig. 6) for clutches of the 1981-1983 year-classes showed wider variability than the plot in Figure 5. Survival and growth rate increased concommitantly up to a point, then survival appeared to decline with further increase in growth rate.

Growth of Kemp's Ridleys at Sea-Arama Marineworld

The weight of the 10 turtles (9 remained alive after 9 June and 8 after 11 June 1984) maintained at Sea-Arama Marineworld followed an asymmetric sigmoid trend, so a Gompertz growth function (Ricker, 1975, p. 232) was fitted to the data (Table 12; Fig. 7). Hatchlings in the Padre Island National Seashore "imprint-group" of the 1978 year-class were received from 6 July to 3 August 1978 (Table 1). The date 23 July was chosen as day zero for lapsed time T' on the abscissa. The data for first-year's growth of the 1978 year-class (Fig. 3) were not included in the fit for two reasons: (1) the animals chosen for transfer to Sea-Arama Marineworld had been among the largest available from the year-class, and therefore were not representative of the year-class as a whole, and (2) variability in weight of individual turtles was heterogeneous among the samples within the first year of life (Caillouet and Koi, 1985), but appeared to be homogeneous from sample to sample thereafter (Fig. 7). The upper and lower asymptotes of the fitted Gompertz growth curve were 29.2 kg and 0.25 kg, respectively. The sigmoid curve was fitted without forcing it through the origin. The lower asymptote, 0.25 kg, of the fitted growth curve was 15–17 times higher than the average weight of hatchlings (15–17 g), in part probably an artifact of curve fitting and selection of large animals from the 1978 year-class for transfer to Sea-Arama Marineworld.

DISCUSSION

While the head starting activities produced the data upon which the statistical analyses in this paper are based, they did so incidental to the primary objective of culturing the animals for tagging and release into the wild. The rearing methods used were chosen to assure adequate safety, health, survival and growth of the turtles, as well as for convenience, within the constraints of available resources (Fontaine et al., 1985; McVey et al., MS). No attempts were made by McVey et al. (MS) or Fontaine et al. (1985) to conduct large-scale, carefully planned and executed experiments; e.g., to test effects of different foods, feeding rates or feeding frequency on growth and

biomass. There was no randomization of clutches among the rearing containers nor allocation of clutches according to an experimental design for the purpose of segregating possible clutch (i.e., genetic) effects from locational (among rearing containers) or microenvironmental effects. Rather, the data for this paper were fortuitous outgrowths of higher-priority husbandry. The data came from "mensurative experiments" which are experiments that involve the taking of measurements at one or more points in space or time (Hurlbert, 1984). As a result, it cannot be determined whether the observed differences in growth rates among clutches, "imprint"-groups, and year-classes reflect genetic effects, sex ratio differences, climatic effects, locational or microenvironmental effects, or other influences, because such effects were confounded. Evaluators of the results presented herein should consider that the methods of collecting the data reflected secondary and lower-priority purposes as compared to that of head starting the turtles.

If there are differences between male and female Kemp's ridley in growth and survival, they could have contributed to the observed differences in variability within aggregates of turtles in our analyses. As far as we know, Kemp's ridley does not exhibit secondary sexual characteristics during its first year of life. Because this species is seriously endangered, sacrificing healthy animals to determine their sex is prohibited. The gonads of most of the turtles that died during head starting were excised and preserved for sex determination by histological methods (Leong et al., MS). They were transferred to Robert King, NPS, Corpus Christi, TX, and thence to David Owens, Texas A&M University, College Station, TX, for sex determination. Wibbels et al. (1986) have determined that there was a male bias in the sex ratios of captive-reared Kemp's ridleys of year-classes 1981-1983.

Variability among clutches within the two "imprint"-groups of the 1978-1980 year-classes could have contributed to variation between these two groups. Any differences observed between the two "imprint"-groups could have occurred because the groups were made up

of different clutches that hatched at different times. The "imprinting" per se was not expected to have had any effect on growth. The variability among individuals and the patterns of growth of aggregates of turtles of the 1978 and 1979 year-classes could have been influenced by the intermittent "cropping" of the largest animals.

The distribution of clutches among rearing containers was not random. Therefore, any differences in growth among clutches or between "imprint"-groups of turtles were confounded with locational or microenvironmental effects. Because clutches were received and distributed among the rearing containers over time, the clutch and "imprint"-group effects are, in part, sequential effects reflecting the different ages of the clutches as well as the order in which they were received and distributed. Also, clutches within year-classes did not all hatch at the same time, so they were not all reared over precisely the same time interval within each head starting year. Therefore, the survival and growth of different clutches could have been affected differently by seasonal effects, depending on the time-phasing of the rearing and sampling within the year, and this could have contributed to the observed variability among year-classes. Clutches were not distinguished in the 1978-1980 year-classes, so no information is available on clutch effects for these year-classes. Even though differences in patterns of survival, variability and growth among clutches, "imprint"-groups and year-classes can be depicted (Caillouet and Koi, 1985), the causes of these differences remain obscure.

Because the food and feeding regimen was more or less the same for most of the year-classes, the large differences in growth rate among year-classes suggest some other cause (perhaps temperature differences among years). Based on nationwide temperature data in Kerr (1985), the average winter (December, January, February) temperatures for the years of head starting can be ranked by year, from highest to lowest, in the following order: 1982-1983, 1980-1981, 1979-1980, 1981-1982, 1983-1984, and 1978-1979. The rank order of growth rates from highest to lowest did not correspond exactly with the rank order of average

winter temperatures, but the three year-classes (1979, 1980 and 1982) with the most rapid growth (Fig. 3) were associated with the years of highest average winter temperature, and those (1978, 1981 and 1983) with the slowest growth were associated with the lowest average winter temperatures.

Regardless of the causes of the observed differences in growth, biomass increase and survival within and among year-classes, it is obvious that our regression equations 1 and 5 provide sensitive tools for detecting differences among clutches and year-classes. With carefully designed and executed experiments, it should be possible to segregate clutch and year-class effects from treatment effects. Segregating sex effects, if any, from other influences on growth will require a simple, rapid and non-sacrificial method of determining the sex of juvenile turtles.

The observed relationship between growth rate and survival would be expected if growth were not density-dependent. According to Patrick Burchfield (Gladys Porter Zoo, Brownsville, TX, personal communication, October 1984), healthy and robust hatchlings of reptiles are characteristically predisposed to good survival and growth, and sickly or small hatchlings usually perform poorly. However, the size of hatchlings from the various year-classes (Tables 4 and 5) gave no clue as to causes of differences in the growth among the year-classes (Fig. 3). Only in the case of year-class 1983, which exhibited the slowest growth, does it seem clear that the hatchlings were predisposed to poor performance. We received only 250 hatchlings from the 1983 year-class. This was the year-class with the poorest hatch of the six (Table 1).

The observations that the biomass increase index became larger as the weight increase index became larger, and that the two indices converged as they increased (Fig. 5), are of significance. Such results would be expected if carrying capacity of the raceways for turtle biomass were a limiting factor and the turtles exhibited compensatory mortality as they grew larger. Variability in the rate of increase in biomass seems to have been influenced more by differences in survival than by differences in growth rate among clutches (Figs. 5 and 6).

In other words, growth under the particular conditions of head starting did not appear to be density-dependent, but survival may have been density-dependent. This lends support to the idea that the carrying capacity of the rearing containers for turtle biomass was a limiting factor. In the absence of specific tests of effects of stocking density on survival and growth of head started Kemp's ridley, such interpretations should be considered speculation.

The turtles were not stocked at high densities. For example, initial stocking density in raceways was not more than 108 hatchlings per raceway, or roughly 1 per 28 liter. On the other hand, if carrying capacity of the raceways for biomass of turtles were a limiting factor, such limitation would be approached as the turtles grew larger. The total amounts of turtle excrement and uneaten food increased as the turtles grew larger. This, coupled with only thrice-weekly replacement of seawater, probably led to a greater buildup of potentially harmful by-products of decomposition of wastes in the rearing containers when they contained larger turtles than when they contained smaller turtles. Compensatory mortality probably was the result. For example, ammonia was one by-product of decomposition that accumulated rapidly over the 1 to 2 days between seawater replacements (Fontaine et al., 1985).

As the turtles grew larger, the space available to them within the buckets decreased, and this probably limited their scope of activity, thereby enhancing their growth. Near the end of the head starting period, individuals that outgrew their buckets had to be transferred to larger quarters (e.g., hemispherical basins) for a short time before tagging and release. Fast growth under confinement may make the turtles physically less fit than their wild counterparts. Transfer of larger turtles to the basins allows them greater latitude for exercise (swimming), and may alleviate this problem. A study of fitness and stamina in Kemp's ridley as related to head starting methods is currently underway in this regard.

Further experiments will be required to determine and evaluate the relationships among growth, survival and maturity of Kemp's ridley in

captivity. Fast growth in captivity may lead to early maturity, assuming that the egg layings of 5-year-old and 7-year-old head started Kemp's ridleys at the Cayman Turtle Farm represent earlier maturation than would occur in the wild. If rapid growth in captivity leads to early maturation, then the growth of head started turtles may slow down (after maturity) at an earlier age as compared to wild turtles of similar size that do not reach maturity as quickly (David W. Owens, Department of Biology, Texas A&M University, College Station, TX, personal communication, November 1984). If true, captive rearing might produce smaller adults with lower egg-laying capacity than turtles that spend their entire lives in the wild. The 5-year-old Kemp's ridleys that nested at the Cayman farm had a weight near 20 kg (Wood and Wood, 1984), which is below the asymptotic weight of 29.2 kg estimated from the Gompertz equation describing growth in the head started Kemp's ridley at Sea-Arama Marineworld. Both of these weights are well below those (39-49 kg) of adult female Kemp's ridleys nesting at Rancho Nuevo (Chavez et al., 1968).

Our working hypothesis has been that larger yearlings have a better chance of surviving in the wild than smaller ones. So far, head starting of Kemp's ridleys has been directed toward maximizing their survival and growth so as to provide as large a number of large, healthy yearlings as possible for tagging and release. In this respect, the methods used have been successful. Through control of water temperature, the amount of food, and the frequency of feeding, growth rate of captive-reared Kemp's ridleys probably can be manipulated. Modifying the seawater management methods, stocking density, size of containers, amount of food, and frequency of feeding might increase survival and optimize growth while improving fitness of the turtles for survival and maturation in the wild and in captive breeding colonies. Achieving rapid growth in captivity, provided it does not reduce the general health, fitness, survival or reproductive efficiency of the turtles, may well be a good strategy for head starting. However, the optimum growth rate for Kemp's ridleys to be tagged and released or added to a captive brood stock remains to be determined. There is much left to be learned about the relationships among growth, survival and maturity in this species.

Our statistical analyses are more detailed and involve more animals than did previously published accounts of growth in Kemp's ridley. Pritchard and Marquez (1973) presented graphs of monthly increments in weight, carapace length and carapace width, based on investigations by Marquez (1972) of captive hatchlings and tagged adults. Their graphs indicated that the increment in weight during the first year was less than 0.5 kg. Extrapolation of our results (Tables 6 and 8; Fig. 3) to 365 days gave annual average increments of 0.6 kg for the slowest growing year-class (1983) and 1.6 kg for the fastest growing year-class (1980).

Klima and McVey (1981) presented a plot of the arithmetic average weight, over a 9-month period, for Kemp's ridleys of the 1978 year-class head started at the Galveston Laboratory. The plot compared two groups, one hatched and "imprinted" at Rancho Nuevo and the other at the Padre Island National Seashore. Klima and McVey (1981) concluded that there was no difference in average growth rate between groups "imprinted" at Rancho Nuevo and at the Padre Island National Seashore. Our results for the 1978-1980 year-classes suggest that those "imprinted" at the Padre Island National Seashore grew at significantly different rates from those "imprinted" at Rancho Nuevo. For the 1978 and 1979 year-classes, the difference between "imprint"-groups might have been even greater had the Padre Island "imprint"-group not been "cropped" by removal of larger animals. Our detection of significant differences as compared to the results of Klima and McVey (1981) reflects a difference in statistical treatment of the data, and emphasizes the sensitivity of our growth analyses (equation 3) in detecting differences. We do not believe that the differences between "imprint"-groups had anything to do with the "imprinting" per se, but to the choice of clutches and the timing of hatching of the eggs for the two "imprint"-groups, as well as other possible factors.

McVey et al. (MS) presented plots of arithmetic means and ranges in weight and carapace length versus months for the 1979 and 1980 year-classes of Kemp's ridleys head started for 10 months at the Galveston Laboratory. Their plots clearly exemplified the kind of heterogeneity of variance in weight discussed herein as well as

depicted graphically for the 1978-1983 year-classes by Caillouet and Koi (1985). McVey et al. (MS) also presented a relationship between weight (W, in grams) and carapace length (CL, in centimeters) for 5,064 Kemp's ridleys, from hatchlings to 20 kg in size ($\hat{W} = 0.2301CL^{2.882}$).

McVey and Wibbels (1984) plotted the weights of Kemp's ridleys against age, comparing groups maintained at Miami Seaquarium and Sea-Arama Marineworld with animals recaptured after being tagged and released. Growth was fastest at Miami Seaquarium, intermediate at Sea-Arama Marineworld and slowest in the wild. Fontaine et al. (1985) plotted the arithmetic mean weights of Kemp's ridley of the 1978-1983 year-classes over time, but no interpretation was given.

In our study we reanalyzed the same data upon which the graphs of Fontaine et al. (1985), Klima and McVey (1981), McVey et al. (MS), and McVey and Wibbels (1984) were based, but in much greater statistical detail. Caillouet and Koi (1985) graphed and we analyzed additional data collected since the previous studies were completed. Our statistical analyses of increase in weight (equations 1 and 3) and of increase in biomass (equation 5) provide sensitive methods for detecting differences among groups of turtles, whether the differences are genetically induced, related to sex, or related to the particular conditions of incubation, hatching and rearing.

Caldwell (1962) examined growth in two Kemp's ridleys in captivity, one 3.2 kg and the other 2.8 kg upon capture at Fort Walton Beach, FL. Such sizes were larger than those reached during the typical head starting period at Galveston, so the animals were probably more than a year old when collected. The larger of the two specimens grew to 4.8 kg in 316 days on a diet of "cut-fish," and the smaller to 4.2 kg in 330 days on the same diet (ibid.). In an additional year, the smaller turtle grew to 6.0 kg. Such sizes were reached at two years of age in the head started Kemp's ridleys maintained at Sea-Arama Marineworld. Caldwell (1962) also measured growth in one smaller Kemp's ridley caught in the surf near Fort Walton Beach and maintained at Gulfarium. Though it appeared normal and was an active swimmer, it did not feed regularly during the five months it was held in captivity before it

died. It lost 0.3 kg in weight during the interim, from the 1.4 kg it weighed upon capture. Caldwell suggested that its survival under such a long period of starvation was an example of the survival potential for the species.

Rajagopalan (1984) examined growth in the closely related olive ridley, L. olivacea, reared in captivity for 47 months following emergence as hatchlings. He fed the turtles a diet of clams and fish. The 1980 year-class (15 animals) weighed an average of 0.5, 4.4, 13.4 and 19.0 kg at the end of 12, 24, 36 and 44 months, respectively. At 47 months, 11 survivors averaged 19.5 kg. The 1981 year-class (19 animals) weighed an average of 1.1, 9.9 and 14.5 kg at the end of 12, 24 and 32 months, respectively. At 35 months, 17 survivors averaged 15.8 kg. Such growth in captive olive ridleys was approximately comparable to that of Kemp's ridleys reared for extended periods in captivity (Fig. 7; Marquez, 1972; Pritchard and Marquez, 1973).

The head starting of Kemp's ridley at the Galveston Laboratory has been successful in terms of good survival and growth. It has produced 10,792 healthy animals tagged and released into the Gulf of Mexico, plus 264 for distribution among a turtle farm and marine aquaria for extended head starting and captive propagation (Caillouet et al., MS). Preliminary results from 481 reported recoveries (as of September 1986) indicate good growth and survival as well as wide dispersal in the tagged animals in the wild (Fontaine and Caillouet, 1985; Fontaine et al., 1985; Sharon Manzella, NMFS SEFC Galveston Laboratory, Galveston, TX, personal communication, September 1986).

Adding to the success of head starting are the egg layings and successful hatches of Kemp's ridley at Cayman Turtle Farm (Wood and Wood, 1984; James Wood, Cayman Turtle Farm, Grand Cayman, BWI, personal communication, September 1986), events which may lead to successful captive propagation within a much shorter time than was previously believed possible. Our results point out the need and opportunity for examining the relationships among survival, growth and maturation of Kemp's ridley in captivity and in the wild, as adjuncts to head starting and captive propagation. Through NOAA Sea Grant projects, David Owens and his students at Texas A&M University, College

Station, TX, are studying the reproductive physiology and behavior of Kemp's ridley in collaboration with INP, FWS, NPS, NMFS, Cayman Turtle Farm, and various marine aquaria. Andre Landry and his students at Texas A&M University in Galveston, TX, are conducting morphometric studies of Kemp's ridley in hopes of distinguishing the sexes of juveniles reared in captivity and segregating new recruits from previous nesters at Rancho Nuevo. Ron Malone and his students at Louisiana State University in Baton Rouge, LA, are developing and testing recycled seawater systems for use in rearing Kemp's ridley.

There are many issues and questions that must be considered in captive rearing and propagation of an endangered species (Carr, 1980; Ehrenfeld, 1974; Holden, 1984; Soule and Wilcox, 1980). Nevertheless, head starting not only has provided a large number of Kemp's ridleys for release into the wild and retention in captivity, but also has led to the first indications that captive propagation is feasible.

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Table 1. Dates and numbers of Kemp's ridley hatchlings received alive for head starting at the SEFC Galveston Laboratory.

Clutch no.[1]	Imprint-group[2]	Year-class 1978 Date[3] From	To	No.	1979 Date From	To	No.	1980 Date From	To	No.	1981 Date From	To	No.	1982 Date From	To	No.	1983 Date From	To	No.
1	PINS							6/24		63	7/24		54	7/6		94	7/8	7/13	97
2								7/4		86	8/1		72	7/19		9	7/8		87
3								7/9	7/10	98	8/8	8/11	37	7/16		108	7/27		22
4								7/9	7/10	82	8/7		53	7/16	7/19	101			
5								7/9	7/10	111	8/7		70	7/19		106	7/27		10
6								7/12		82	8/7		59	7/19		80	7/27		1
7								7/9	7/10	88	8/6	8/7	105	7/26	7/28	72			
8	"	7/26		63				7/9	7/10	91	8/6	8/7	78	7/28	8/2	59			
9	"	7/26		107				7/9	7/10	73	8/7		90	7/26		94	8/8		2
10								7/12		95	8/6	8/7	104	7/26	7/28	71			
11								7/14		88	8/7		86	7/28	8/2	63			
12								7/17		40	8/6		87	7/26		118	8/8		2
13								7/12		74	8/6	8/7	77	8/2		36			
14	"	7/26		129				7/14		60	8/6		89	8/10	8/13	56	8/8		3
15	PINS	7/26		93				7/14		73	8/6	8/7	85	8/13		56			
16	"	7/26		63				7/14	7/17	87	8/6	8/7	117	8/13		74			

Table 1. continued

Clutch no.[1]	Imprint-group[2]	Year-class 1978 Date[3] From	To	No.	1979 Date From	To	No.	1980 Date From	To	No.	1981 Date From	To	No.	1982 Date From	To	No.	1983 Date From	To	No.
17	"	7/26		63				7/14	7/15	58	8/6		111	8/13	8/16	67	8/12		6
18								7/14		89	8/6		105	8/13		69			
19								7/17		84	8/11		61	8/10		114			
20								7/14		67	8/17		53	8/13	8/16	77			
21											8/19		102						
22											8/22		84						
23											8/22		85						
24																			
25																			
?[4]	"	7/6	8/3	1,266	7/7	7/23	1,656	?		19[5]									
?	RN	7/6	8/11	1,226	6/26		187	7/26		207							7/8		20
Combined		7/6	8/11	3,080	6/26	7/23	1,843	6/24	7/17	1,815	7/24	8/22	1,864	7/6	8/13	1,524	7/8	8/12	250

[1]Also used by National Park Service (NPS) at Padre Island National Seashore.

[2]PINS = Padre Island National Seashore; RN = Rancho Nuevo.

[3]Month/Day.

[4]? indicates that clutch numbers on other information were not known, and the data represent composites of clutches.

[5]Unaccounted for; these probably died before being distributed among raceways.

Table 2. Number of times (m) that samples of weights and measurements of Kemp's ridleys were taken, by yearclass, "imprint"--group, and clutch.

Yearclass	"Imprint"-group[1/]	Clutch	No. of times sampled, m
1978	PINS	NA[2/]	41
	RN	"	24
1979	PINS	"	39
	RN	"	15
1980	PINS	"	52
	RN	"	10
1981	PINS	1	11
		2	10
		3	10
		4	11
		5	11
		6	11
		7	11
		8	11
		9	10
		10	11
		11	10
		12	11
		13	11
		14	11
		15	11
		16	11
		17	11
		18	11
		19	10
		20	10
		21	11
		22	10
		23	10

Table 2. continued

Year-class	"Imprint"-group[1/]	Clutch	No. of times sampled, m
1982	PINS	1	11
		2	11
		3	11
		4	11
		5	11
		6	11
		7	11
		8	11
		9	11
		10	11
		11	11
		12	11
		13	11
		14	11
		15	11
		16	11
		17	11
		18	11
		19	11
		20	11
1983	PINS[3/]	1	6
		2	6
		3	5

[1/]PINS = Padre Island National Seashore;

RN = Rancho Nuevo.

[2/]NA = Not applicable; clutch identity was not maintained for the first three year-classes.

[3/]PINS-"imprinted" clutches 5, 6, 9, 12, 14 and 17 and the RN-"imprinted" turtles of the 1983 year-class were excluded from all analyses due to low numbers of turtles in these clutches (see Table 1).

Table 3. Composition[1/] of floating, pelleted diet used for head-starting Kemp's ridley.

Proximate composition (%)	
Crude protein (minimum)	45
Crude fat (minimum)	5
Crude fiber (maximum)	3
Other (undefined)	47

Ingredients	
Plant protein products	Animal protein products
Grain products	Processed grain by-products
Roughage products	Lecithin
Vitamin A supplement	Vitamin E supplement
Vitamin B_{12} supplement	Choline chloride
Niacin supplement	Calcium pantothenate
Folic acid	Riboflavin supplement
Menadione sodium bisulfite complex	D-activated animal sterol (source of vitamin D_3)
Ascorbic acid	Biotin
Pyridoxine hydrochloride	Thiamine hydrochloride
Inositol	Methionine supplement
Ground limestone	Calcium phosphate
Salt and traces of magnesium oxide	Magnesium oxide
Ferrous sulfate	Calcium iodate
Ferrous carbonate	Cobalt carbonate
Copper oxide	Copper sulfate
Zinc oxide	

[1/] Provided by Central Soya and Subsidiaries, Fort Wayne, IN.

Table 4. Rectilinear regressions of the natural logarithms of weights (lnW; W in g) on the natural logarithms of carapace lengths (lnCL; CL in cm) of Kemp's ridleys, by year-class.

		$\widehat{\ln W} = \ln a + b \ln CL$			Range	
Year-class	No. of paired observations[1/]	Intercept, lna	Slope, b	Coeff. of determination, r^2	W, g	CL, cm
1978	8,114	-1.44	2.88	0.984	12.6-2,392	1.3-25.5
1979	8,050	-1.43	2.87	0.985	10.0-1,844	0.8-22.9
1980	5,984	-1.67	2.98	0.995	12.6-1,920	4.1-22.2
1981	8,228	-1.63	2.98	0.990	11.2-1,110	3.8-18.6
1982	6,186	-1.48	2.91	0.993	12.3-1,482	3.6-20.7
1983[2/]	812	-1.33	2.85	0.995	13.0-664	3.6-15.8

[1/] Number of paired observations of W and CL taken over the entire head starting period. This is a combination of the number of turtles weighed and measured each time samples were taken and the number of times that turtles were sampled over the head start period (see Table 2). It is possible that individual turtles could have been drawn more than once through random sampling.

[2/] Includes only clutches 1, 2 and 3 (see Tables 1 and 2).

Table 5. Rectilinear regressions of carapace widths (CW; in cm) on carapace lengths (CL; in cm) of Kemp's ridleys, by year-class.1/

	$\widehat{CW} = a + bCL$			
Year-Class	Intercept, a	Slope, b	Coeff. of determination, r^2	Range in CW, cm
1978	-0.241	0.937	0.989	3.4-24.6
1979	-0.012	0.893	0.986	2.4-20.0
1980	-0.313	0.931	0.993	3.1-21.0
1981	-0.381	0.936	0.991	3.0-16.8
1982	-0.226	0.923	0.993	3.1-19.5
1983[2/]	-0.163	0.908	0.980	5.7-14.6

1/See Table 4 for the number of paired observations of CW and CL, and for ranges of CL. CW measurements were not taken on hatchlings of the 1983 year-class. This is the reason for the higher CW at the lower end of the range in CW in year-class 1983, as compared to other year-classes. The number of paired observations used to regress CW on CL for year-class 1983 was 605.

2/Includes only clutches 1, 2 and 3 (see Table 1).

Table 6. Rectilinear regressions (equation 1) of the natural logarithms of weights (lnW; W in g) on the square roots of ages ($T^{1/2}$; T in days) of Kemp's ridleys, by clutch in year-classes 1981-1983[1/].

Year-class	Clutch[1/]	Intercept, lna	Slope, b	Variance of deviations from regression, $s^2_{dev.}$	Coefficient of determination, r^2
1981	1	2.27	0.217	0.070	0.932
	2	2.18	0.254	0.046	0.964
	3	2.32	0.229	0.059	0.948
	4	2.44	0.228	0.055	0.949
	5	2.21	0.250	0.032	0.974
	6	2.34	0.240	0.025	0.978
	7	2.41	0.237	0.030	0.975
	8	2.38	0.240	0.024	0.980
	9	2.41	0.237	0.028	0.977
	10	2.27	0.242	0.040	0.967
	11	2.38	0.239	0.031	0.975
	12	2.38	0.232	0.031	0.972
	13	2.44	0.223	0.038	0.961
	14	2.36	0.243	0.032	0.974
	15	2.46	0.230	0.034	0.968
	16	2.35	0.247	0.022	0.983
	17	2.30	0.249	0.024	0.981
	18	2.41	0.234	0.033	0.971
	19	2.31	0.226	0.059	0.952
	20	2.38	0.230	0.041	0.967
	21	2.43	0.216	0.064	0.940
	22	2.35	0.242	0.051	0.964
	23	2.20	0.253	0.030	0.980
	Clutches combined	2.34	0.238	0.049	0.960
1982	1	2.33	0.216	0.017	0.860
	2	2.35	0.255	0.061	0.944
	3	2.28	0.267	0.053	0.967
	4	2.56	0.250	0.045	0.969
	5	2.55	0.249	0.031	0.978
	6	2.49	0.246	0.066	0.954
	7	2.12	0.274	0.029	0.982
	8	2.16	0.271	0.092	0.942
	9	2.32	0.264	0.023	0.985
	10	2.33	0.231	0.015	0.886
	11	2.41	0.247	0.011	0.921
	12	2.51	0.257	0.051	0.966
	13	2.20	0.267	0.062	0.959
	14	2.22	0.264	0.039	0.975
	15	2.20	0.260	0.041	0.974
	16	2.16	0.259	0.041	0.974
	17	2.33	0.254	0.047	0.970
	18	2.35	0.261	0.022	0.986
	19	2.22	0.257	0.042	0.974
	20	2.21	0.267	0.059	0.965
	Clutches combined	2.30	0.257	0.089	0.943

Table 6. continued

Year-class	Clutch[1/]	Intercept, lna	Slope, b	Variance of deviations from regression, $s^2_{dev.}$	Coefficient of determination, r^2
1983	1	1.99	0.225	0.066	0.956
	2	1.93	0.246	0.034	0.980
	3	2.20	0.226	0.058	0.968
	Clutches combined	1.99	0.234	0.064	0.961

[1/] See Table 4 for the number of paired observations of W and T taken over the head starting period. It is the same as the number of paired observations of W and CL.

Table 7. Analyses of covariance (test of slopes) based on rectilinear regression (equation 1) of transformed weight on transformed age for Kemp's ridley clutches in year-classes 1981-1983 (see Table 6).

1981 Year-class

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among clutches	22	17.371	0.790	20.79
Within clutches	8,182	313.903	0.038	

1982 Year-class

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among clutches	19	24.149	1.271	21.18
Within clutches	6,146	371.681	0.060	

1983 Year-class

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among clutches	2	2.471	1.236	24.24
Within clutches	806	41.251	0.051	

Table 8. Rectilinear regressions (equation 3) of the natural logarithms of weights (lnW; W in g) on the square roots of lapsed time[1/] ($T'^{1/2}$; T' in days) for Kemp's ridleys, by "imprint"-group in year-classes 1978-1980[2/].

Year-class	"Imprint"-group[3/]	Intercept, lna'	Slope, b'	Variance of deviations from regression, $s^2_{dev.}$	Coefficient of determination, r^2
1978	PINS	1.97	0.268	0.211	0.865
	RN	1.33	0.296	0.169	0.872
	Groups combined	1.87	0.269	0.219	0.853
1979	PINS	2.02	0.273	0.104	0.943
	RN	2.51	0.246	0.063	0.959
	Groups combined	2.08	0.270	0.105	0.942
1980	PINS	1.64	0.300	0.104	0.947
	RN	1.48	0.318	0.060	0.964
	Groups combined	1.63	0.301	0.100	0.948

[1/] From the date that measurements were first taken on a clutch of the year-class. These dates were 6 July 1978, 7 July 1979, and 24 June 1980, for the 1978, 1979 and 1980 year-classes, respectively.

[2/] See Table 4 for the number of paired observations of W and T' taken over the head starting period. It is the same as the number of paired observations of W and CL.

[3/] PINS = Padre Island National Seashore; RN = Rancho Nuevo.

Table 9. Analyses of covariance (test of slopes) based on rectilinear regression (equation 3) of transformed weight on transformed time lapse for Kemp's ridley "imprint"-groups in year-classes 1978-1980 (see Table 8).

1978 Year-class

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among groups	1	2.841	2.841	28.7
Within groups	5,980	593.036	0.099	

1979 Year-class

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among groups	1	11.951	11.951	119.5
Within groups	8,046	808.742	0.100	

1980 Year-class

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among groups	1	19.187	19.187	96.9
Within groups	8,110	1,604.530	0.198	

Table 10. Rectilinear regressions (equation 5) of the natural logarithms of biomass (lnB; B in kg) on the square roots of ages ($T^{1/2}$; T in days) of Kemp's ridleys, by clutch in year-classes 1981-1983[1/].

Year-class	Clutch	Intercept, lna	Slope, b	Variance of deviations from regression, $s^2_{dev.}$	Coefficient of determination, r^2
1981	1	-0.379	0.178	0.023	0.971
	2	-0.402	0.248	0.011	0.993
	3	-0.939	0.219	0.012	0.990
	4	-0.475	0.223	0.008	0.993
	5	-0.439	0.244	0.012	0.991
	6	-0.475	0.237	0.007	0.994
	7	0.227	0.228	0.008	0.993
	8	-0.118	0.230	0.010	0.992
	9	0.092	0.222	0.010	0.992
	10	0.057	0.235	0.008	0.994
	11	-0.030	0.233	0.015	0.989
	12	-0.017	0.220	0.007	0.994
	13	-0.141	0.203	0.008	0.991
	14	-0.008	0.234	0.004	0.996
	15	0.057	0.219	0.008	0.992
	16	0.220	0.245	0.006	0.996
	17	0.151	0.243	0.007	0.994
	18	0.214	0.227	0.010	0.992
	19	-0.351	0.209	0.016	0.987
	20	-0.552	0.222	0.009	0.993
	21	0.260	0.174	0.009	0.988
	22	-0.068	0.231	0.011	0.993
	23	-0.207	0.243	0.013	0.992
	Clutches combined	-0.134	0.224	0.153	0.866
1982	1	0.206	0.179	0.009	0.989
	2	-2.586	0.267	0.049	0.973
	3	-0.004	0.269	0.019	0.989
	4	0.217	0.254	0.019	0.988
	5	0.309	0.248	0.039	0.975
	6	-0.044	0.246	0.011	0.993
	7	-0.595	0.270	0.006	0.997
	8	-0.660	0.264	0.018	0.989
	9	-0.118	0.272	0.016	0.991
	10	-0.223	0.216	0.009	0.992
	11	-0.383	0.243	0.014	0.990
	12	0.295	0.265	0.029	0.983
	13	-1.147	0.267	0.007	0.996
	14	-0.719	0.260	0.005	0.997
	15	-0.657	0.257	0.005	0.997
	16	-0.444	0.257	0.007	0.996
	17	-0.370	0.254	0.010	0.994
	18	-0.363	0.263	0.017	0.991
	19	0.046	0.258	0.011	0.994
	20	-0.397	0.265	0.013	0.993
	Clutches combined	-0.378	0.253	0.384	0.775

Table 10. Continued

Year-class	Clutch	Intercept, lna	Slope, b	Variance of deviations from regression, $s^2_{dev.}$	Coefficient of determination, r^2
1983	1	-0.244	0.202	0.016	0.989
	2	-0.483	0.237	0.021	0.989
	3	-1.381	0.168	0.024	0.981
	Clutches combined	-0.807	0.217	0.692	0.653

1/See Table 2 for number of paired observations of B and T taken over the head starting period. It is the same as the number of times, m, the turtles were weighed over the head start period.

Table 11. Analyses of covariance (test of slopes) based on rectilinear regression (equation 5) of transformed biomass on transformed age for Kemp's ridley clutches in year-classes 1981-1983 (see Table 10).

1981 Year-class

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among clutches	22	1.727	0.078	7.8
Within clutches	199	1.993	0.010	

1982 Year-class

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among clutches	19	1.991	0.105	6.5
Within clutches	180	2.798	0.016	

1983 Year-class

Source of variation	Degrees of freedom	Sum of squares	Mean square	F
Among clutches	2	0.324	0.162	8.1
Within clutches	11	0.222	0.020	

Table 12. Parameter estimates for Gompertz growth function fitted to data[1/] on weight (W, in kg) versus lapsed time (T', in days) for 10 head started Kemp's ridleys of the 1978 year-class maintained at Sea-Arama Marine World, Galveston, Texas.

Parameter[2/]	Estimated value
W_0	0.2513 kg
W_∞	29.2 kg
G	4.756
g	0.001551

[1/]The number of paired observations of W and T' was 436.

[2/]$\hat{W} = W_0 e^{G(1-e^{-gT'})+d}$

where,

W is the weight in kg at lapsed time T' in days

W_0 is the weight at T' = 0.

G is the instantaneous growth rate at T' = 0.

g describes the rate of decrease in G.

d is the residual or deviation from regression.

$\hat{W}_\infty = W_0 e^G$

where,

W_∞ is the upper asymptotic weight in kg

The coefficient of determination, r^2, was 0.959, and the variance of deviations from regression, s^2, was 1.696.

See Ricker (1975, p. 232)

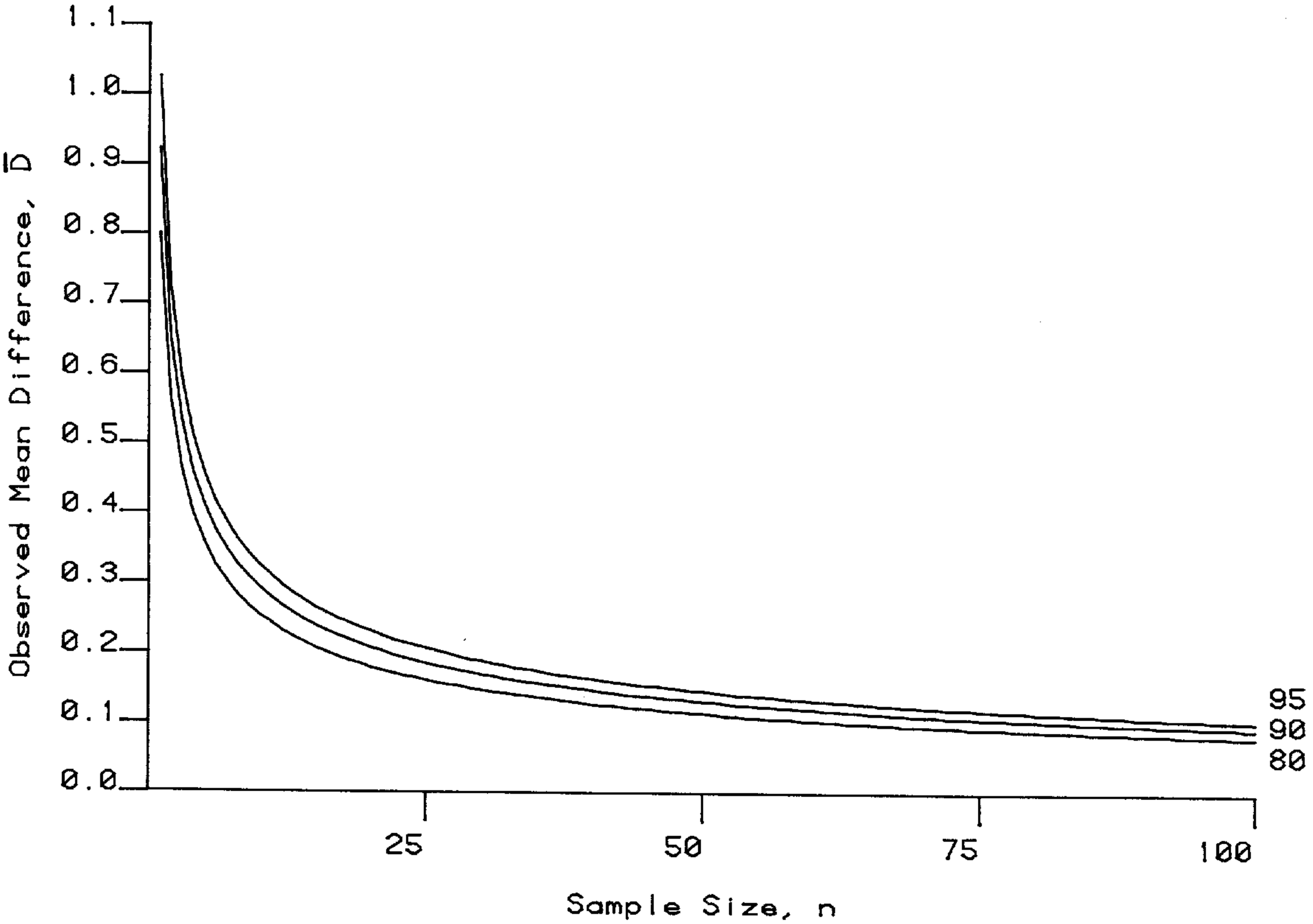

Figure 1. Relationships between the mean difference ($\bar{D}$) and sample size, n, for the natural logarithms of weights (lnW, W in g) of random samples from Kemp's ridley clutches. $\bar{D}$ represents the minimum detectable (or critical level) real difference between means ($\ln\bar{W}'$) of random samples of transformed weights of turtles from the same clutch at two different times, or from two different clutches at the same time. The three curves represent relationships at the 80%, 90% and 95% probabilities of detecting real differences (power of the test) of magnitude $\bar{D}$ at the 5% level of significance.

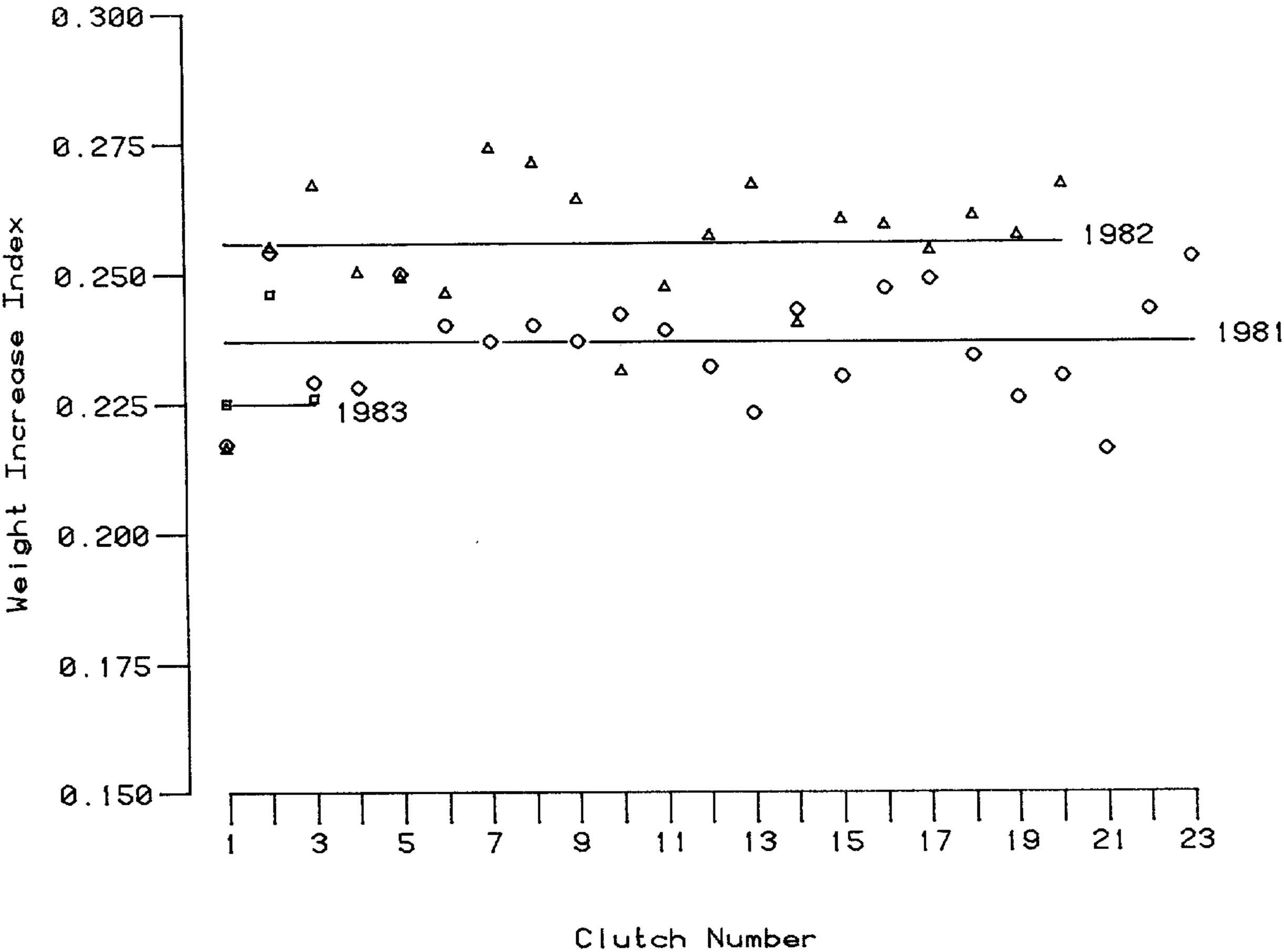

Figure 2. Weight increase indices for Kemp's ridley clutches of the 1981-1983 year-classes. These indices were calculated from rectilinear regression equation 1 (see Table 6). The horizontal lines represent the "average" weight increase index for each year-class based on the common regression for combined clutches of a year-class.

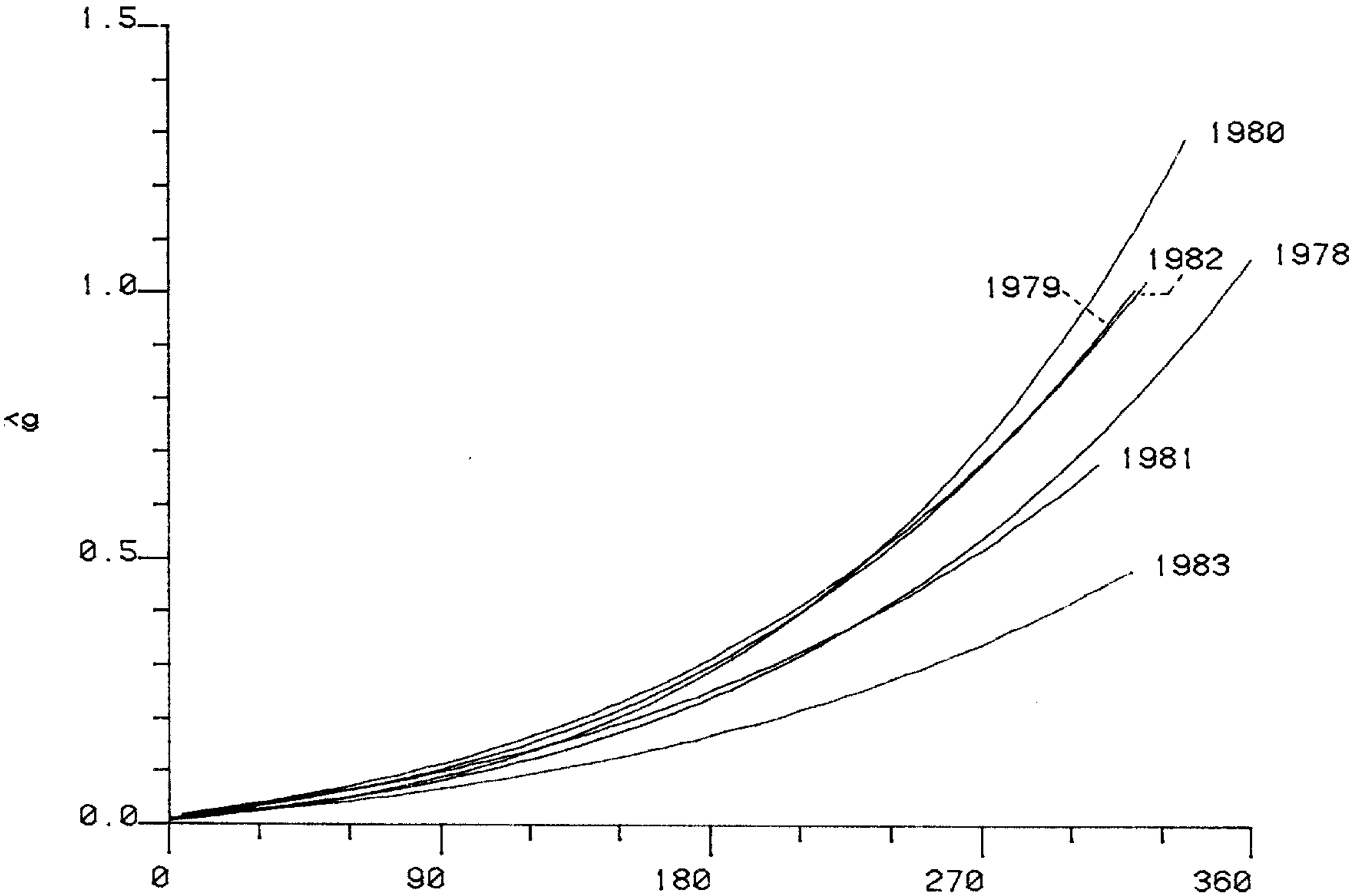

Figure 3. Fitted growth curves for Kemp's ridley year-classes 1978-1983. These curves represent the exponential form (i.e., equation 2) of rectilinear regression equation 1 applied to combined clutches of year-classes 1981-1983 (Table 6) and the exponential form (i.e., equation 4) of rectilinear regression equation 3 applied to combined "imprint"-groups of year-classes 1978-1980 (Table 8).

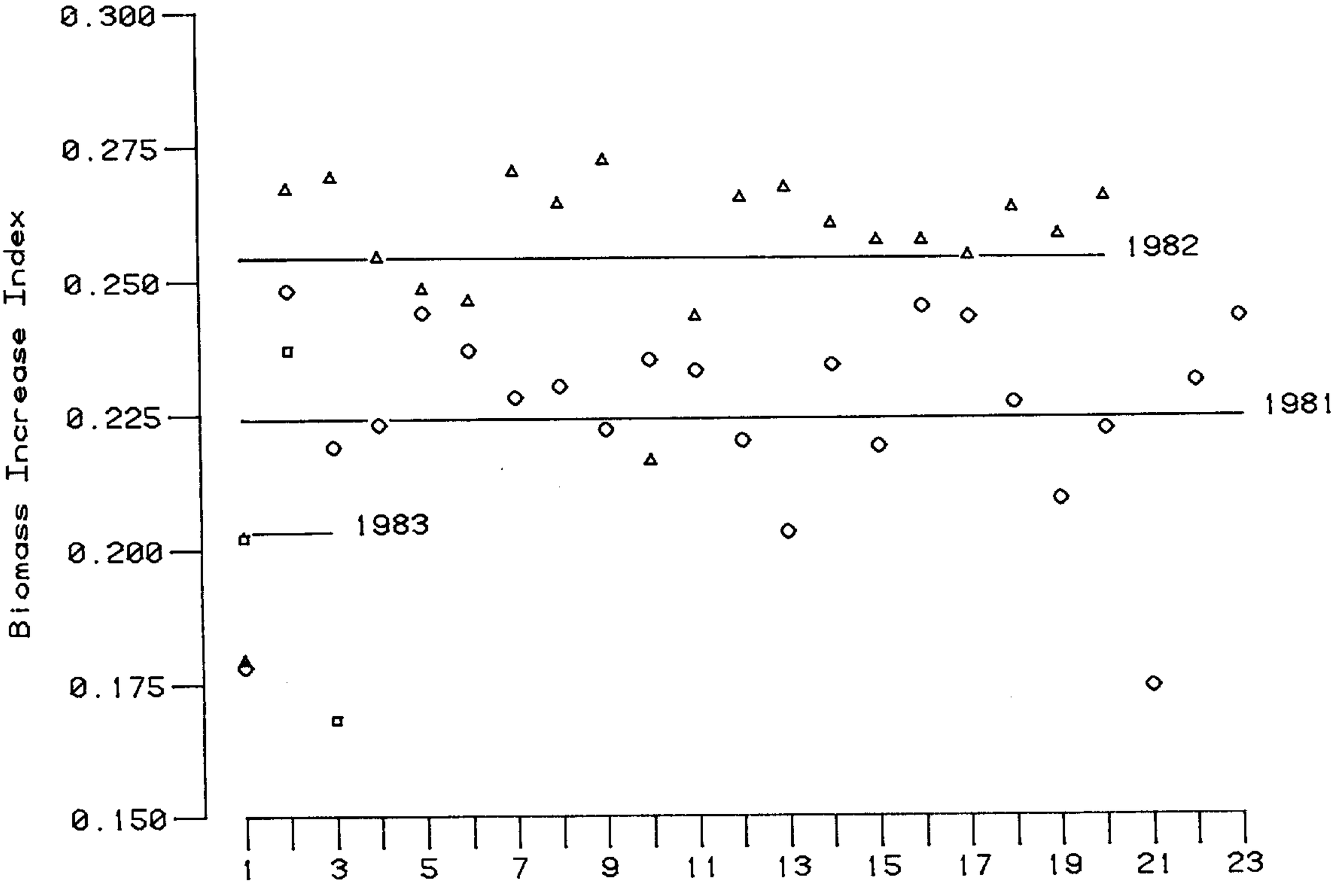

Figure 4. Biomass increase indices for Kemp's ridley clutches of the 1981-1983 year-classes. These indices were calculated from rectilinear regression equation 5 (see Table 10). The horizontal lines represent the "average" biomass increase index for each year-class based on the common regression for combined clutches of a year-class.

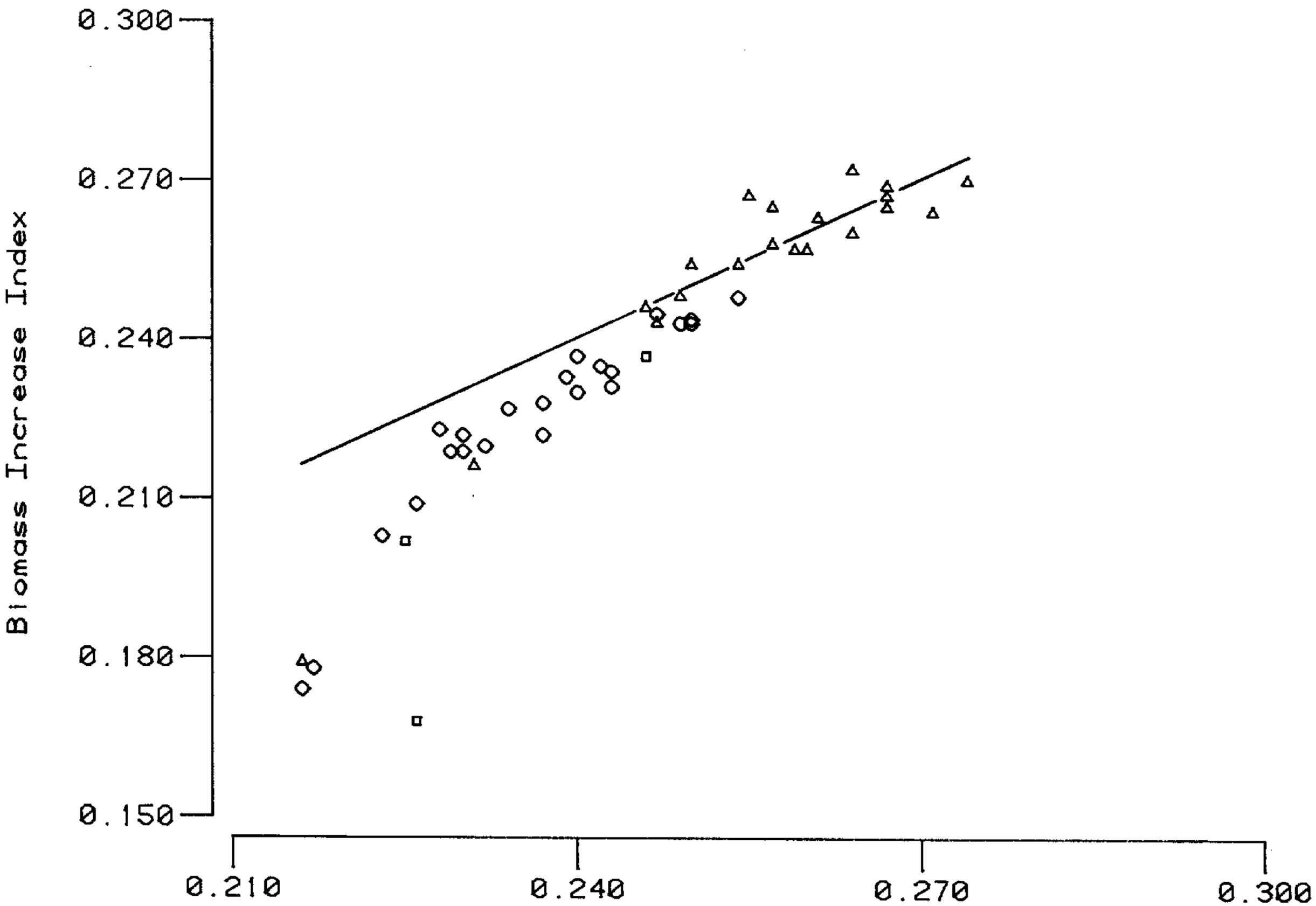

Figure 5. Relationship between the biomass increase index and the weight increase index for clutches of the 1981 (circles), 1982 (triangles) and 1983 (squares) year-classes of Kemp's ridley. The straight line is drawn to represent 1:1 correspondence.

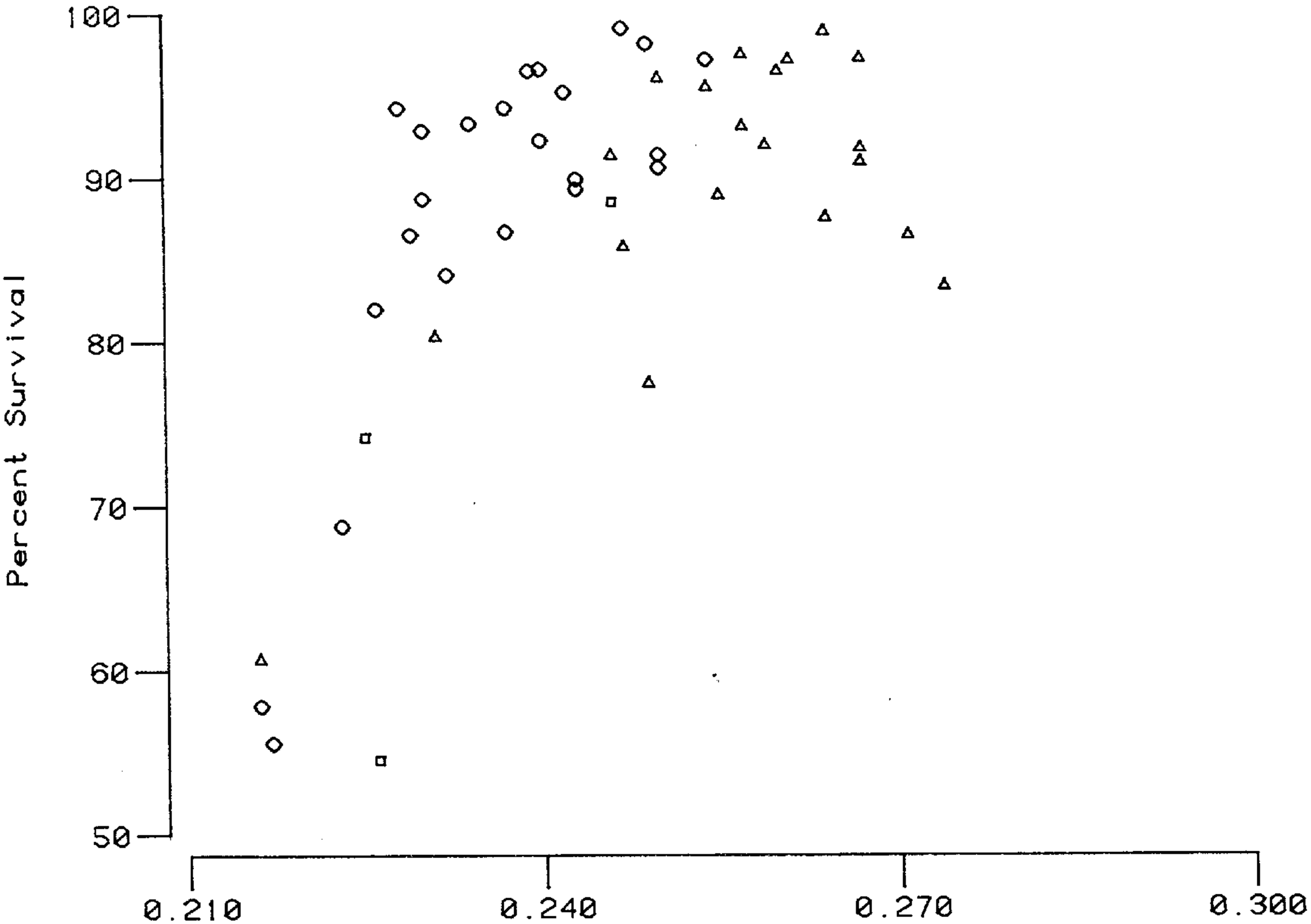

Figure 6. Relationship between percent survival (at the end of the head starting period) and the weight increase index for clutches of the 1981 (circles), 1982 (triangles) and 1983 (squares) year-classes of Kemp's ridley.

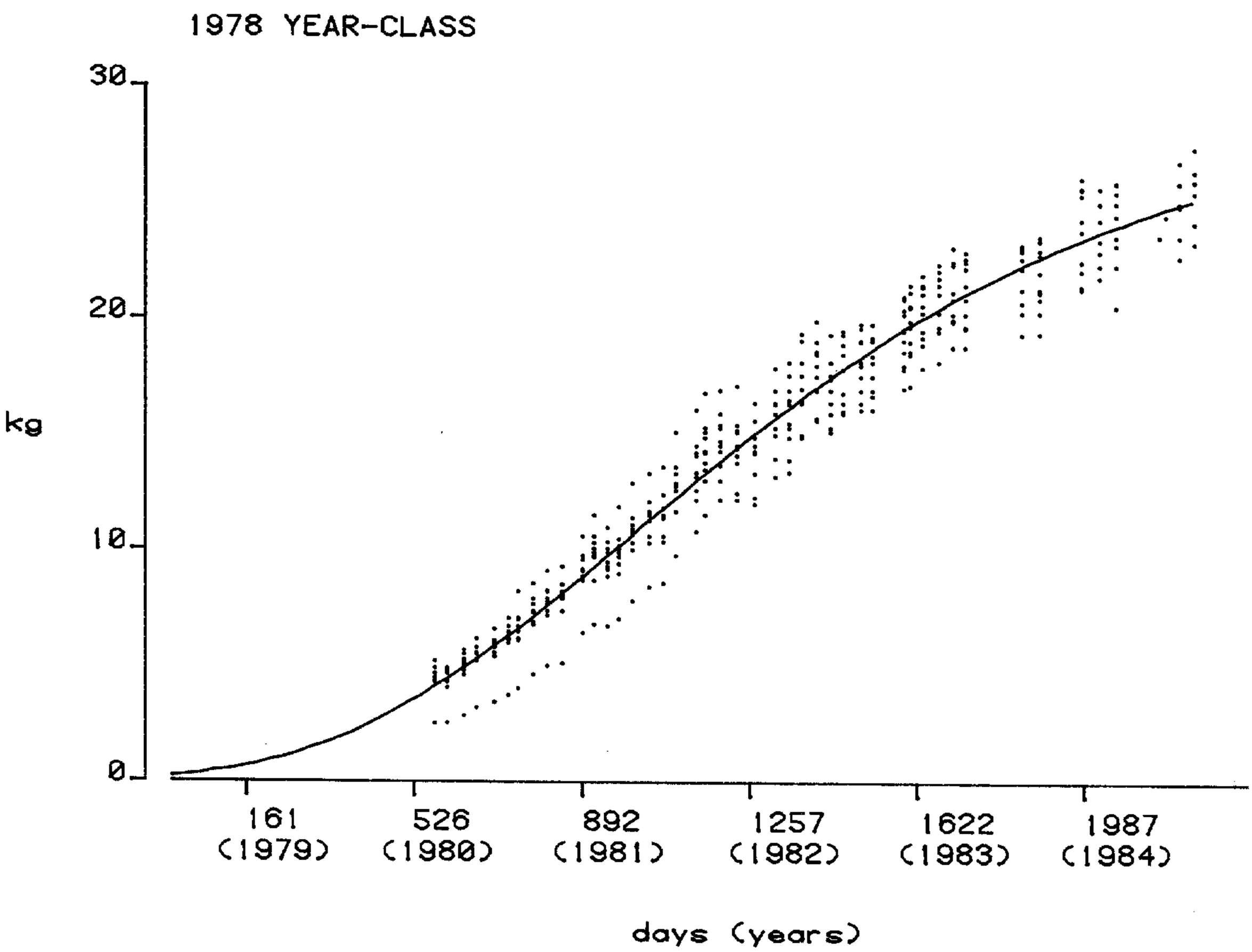

Figure 7. Growth in weight (kg) of 10 head started Kemp's ridleys of the 1978 year-class maintained at Sea-Arama Marineworld, Galveston, Texas. The solid line represents the fitted Gompertz growth function (see Table 12).