Prevalence And Severity Of Fibropapillomatosis In Juvenile Green Turtles (chelonia Mydas) In Three Habitats On Florida's Eas

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PREVALENCE AND SEVERITY OF FIBROPAPILLOMATOSIS IN JUVENILE GREEN TURTLES (*CHELONIA MYDAS*) IN THREE HABITATS ON FLORIDA'S EAST COAST

by

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ABSTRACT

Fibropapillomatosis (FP) is a tumor-forming disease mainly found in juvenile green turtles (*Chelonia mydas*) inhabiting Florida's east coast. Despite increased research on the herpes virus that putatively causes it, long-term assessment is still needed of the distribution and severity of FP. Using the decades-long database compiled by the University of Central Florida Marine Turtle Research Group, I determined FP severity and distribution at three different sites: Indian River Lagoon (IRL), Sabellariid Worm Reef (SWR) and Trident Submarine Basin (TSB). Fibropapillomatosis occurred in >50% of IRL turtles, 18% of SWR turtles and <1% of TSB turtles. Regression of FP tumors was correlated with its prevalence, i.e. when and where FP was common, tumor regression was common. The probability of a turtle being non-afflicted or mildly afflicted increased with both increasing straight-line carapace length (SCL) and increasing relative body condition (residuals of log body mass versus log SCL). Mean annual growth rates of IRL and SWR turtles did not vary with FP severity; however, mean annual growth rates in IRL (1.10 cm/y) were significantly higher than in SWR (1.05 cm/y) and TSB (1.04 cm/y). Annual apparent survival estimates for IRL and TSB turtles were 0.72 and 0.73, respectively, and were constant over time. Even with increased prevalence of FP, annual apparent survival estimates were constant and similar to survival estimates of juvenile green turtles in areas without FP. In IRL, survival rates among FP Categories 0, 1 and 2 were similar (0.74, 0.74 and 0.81 respectively) and lower only for FP Category 3 (0.63). Thus, while FP occurred in >50% of turtles in some Florida east coast populations, their annual apparent survival only declined in advanced cases (FP Category 3). These data suggest 1) FP afflicts smaller or

younger turtles, 2) larger juveniles, sub-adults and adults are either non-afflicted or possibly recover from this disease, and 3) annual apparent survival rates of green turtle populations are independent of FP prevalence except when tumor growth is extreme.

For all of the maté, corona, and turtle talks, this one's for you.
Boyd Lyon 1969-2006

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I extend a special thank you to the over 300 past and present UCF Marine Turtle Research Group members. Without their hard work in the wind, rain, heat and sun throughout the years, there would not be such an incredible long-term database.

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LIST OF ABBREVIATIONS

ACNWR	Archie Carr National Wildlife Refuge
ANOVA	Analysis of variance
B	Burnham model
$\hat{c}$	Variance inflation factor
CC	Catch-curve analysis
CCL	Curved carapace length
χ^2	Chi-squared statistic
CI	Confidence interval
CJS	Cormack-Jolly-Seber
CPUE	Catch per unit effort
FP	Fibropapillomatosis
GoF	Goodness of Fit
IRL	Indian River Lagoon
N	Sample size
NMFS	National Marine Fisheries Service
QAICc	Quasi-Akaike Information Criterion coefficient
SCL	Straight-line carapace length
SD	Standard deviation
SE	Standard error
sGRB	Southern Great Barrier Reef
SJRWMD	St. Johns River Water Management District

SWR	Sabellariid Worm Reef
TSB	Trident Submarine Basin
TSM	Time since marking
TWEG	Turtle Expert Working Group
UCARE	Unified Capture Recapture
UCFMTRG	University of Central Florida Marine Turtle Research Group
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service

CHAPTER 1: INTRODUCTION

The green turtle (*Chelonia mydas*) is listed as endangered in the 2007 International Union for the Conservation of Nature and Natural Resources Red List of Threatened Species (Seminoff 2004), and is federally listed as endangered in Florida and Mexico's Pacific Coast, and threatened in all other areas (National Marine Fisheries Service and U.S. Fish and Wildlife Service 1991, 2005). All life stages of this marine turtle are found along Florida's east coast, including within and surrounding Archie Carr National Wildlife Refuge (ACNWR). The ACNWR is the primary green turtle nesting beach in the continental United States, with a record number of nests laid in 2007 (3,963 green turtle nests; Bagley et al. 2008). Large populations of juvenile green turtles are found within three habitats surrounding ACNWR: Indian River Lagoon (IRL), Sabellariid Worm Reef (SWR), and Trident Submarine Basin (TSB) in Indian River and Brevard Counties (Figure 1). These three habitats differ mainly in water movement, potential exposure of turtles to anthropogenic stressors (McGarrity 2005, Fauth et al. in prep) and incidence of the disease fibropapillomatosis (FP), which ranges from near zero at TSB to >50% at IRL (Hirama 2001, Hirama and Ehrhart 2007).

Fibropapillomatosis is a tumor-forming disease found in all marine turtle species, but it is most prevalent in green turtles (Jacobson et al. 1991, Herbst 1994, Lackovich et al. 1999, Huerta et al. 2002). Tumors range from less than one millimeter to over 25 cm diameter and can grow on skin, scales, scutes, oral cavities, viscera, eyes and surrounding tissues (Balazs 1991, Work and Balazs 1998). Tumor growth, particularly around the eyes, can compromise a turtle's ability to forage and escape from predators, and turtles with FP are more likely to become entangled in monofilament line or other debris (Witherington and Ehrhart 1989, Balazs et. al. 1997). Tumors also can grow internally, affecting organ function, digestion, buoyancy, cardiac function and respiration (Herbst 1994, Work and Balazs 1999). Turtles with advanced FP are chronically stressed, anemic and nutritionally imbalanced (Aguirre and Balazs 2000, Hirama 2001, Hirama and Ehrhart 2007).

Substantial research on FP was not conducted until 1985, approximately 47 years after diseased turtles were first documented in waters south of Key West (Smith and Coats 1938) and off Cape Sable, Florida (Lucke 1938). Most FP research has been performed in Hawaii and Florida, with more limited research in Indonesia (Adnyana et al. 1997). The cause of FP is still unknown, and possible etiologies, including viruses, parasites, pollutants, environmental factors and genetic predisposition, have been or are being tested (Aguirre 1991, Aguirre et al. 1994, Aguirre et al. 1998, Dailey and Morris 1995, Landsberg et al. 1999, Herbst et al. 1998, Quackenbush et al. 1998, McGarrity 2005).

Because FP is not encountered often in nesting (adult) green turtles, it once was considered a terminal disease (Balazs 1991). However, the first documented case of FP regression was among IRL turtles briefly held in captivity (Ehrhart et al. 1986). Short-term studies showed ~7% of the 56 IRL juvenile green turtles recaptured from 1982 to 1991, and ~5% of the 19 Hawaiian juvenile green turtles recaptured from 1988 to 1996 showed evidence of external tumor regression (Ehrhart et al. 1986, Bennett et. al. 2000). More recently, 88% of 25 IRL juvenile green turtles recaptured from 1998-1999 showed evidence of regression, with 21 turtles showing a 50% reduction in tumor number (Hirama and Ehrhart 2007). However, there are no longer-term studies of the disease and its consequences in juvenile green turtle populations. The University of Central Florida Marine Turtle Research Group (UCFMTRG), under the supervision of Dr. L. M. Ehrhart, has studied juvenile green turtle populations in three Florida sites and developed an extensive database of turtle capture histories. Using this database, I determined the prevalence and severity of FP and annual FP regression rates within three populations. I used Program MARK (White and Burnham 1999) to determine apparent survival estimates and recapture probabilities for each of the three study sites. The goal of my thesis research was to assess the possible long-term consequences of FP on these Florida green turtle populations by estimating population parameters. This information is invaluable for population viability analysis used to manage this endangered species.

CHAPTER 2: METHODS

Study Sites

Indian River Lagoon

The Indian River Lagoon (IRL) study site was located approximately 60 km south of Cape Canaveral and 3 km south of Sebastian Inlet in Indian River County, Florida, USA (Figure 1; 27°49’57” N, 80°26’18” W; see also Coberley et al. 2001). The netting location used by UCFMTRG since 1982 was a wide extension of IRL with limited water movement. Dominant vegetation was drift algae in the open bay area and sea grass beds in areas ≤1 m deep. Construction and development surrounding IRL degraded the estuary and altered its historic characteristics. Drainage projects increased freshwater flow to the lagoon and altered its salinity (U.S. Army Corps of Engineers and St. Johns River Water Management District 2003). Increased nutrients (specifically phosphorus and nitrogen), metals, pesticides, suspended solids and organic matter from developed areas in the basin caused muck to accumulate (Sigua et al. 2000). Increased freshwater and muck reduced water clarity and salinity, resulting in loss of more than 90% of seagrass habitat in some areas (USACE and SJRWMD 2003).

Sabellariid Worm Reef

The nearshore worm rock reef, known as the Sabellariid Worm Reef (SWR), has been a UCFMTRG study site since 1989. It was located at approximately the same latitude as IRL, but was in open ocean on the east side of the barrier island (27°47’38” N, 80°24’34” W; see Coberley et. al 2001). The reef ran north and south, and extended eastward >500 m, with depths from 0-20 m (Coastal Science Associates 2000). Water movement in the reef area was caused by ocean tides and was substantially greater than within IRL. Rocks that comprised the reef were formed by polychaete tube worms (*Phragmatopoma lapidosa*, Family Sabellariidae), whose colonies grow into mounding reefs that shelter many invertebrates, vertebrates and algae (Zale and Merrifield 1989, Nelson and Demetriades 1992). Juvenile green turtles used the reef for shelter and foraged on algae as a main food source (Holloway-Adkins 2001). Twenty-six genera and eight species of algae (e.g., *Hypnea*, *Bryothamnion seaforthi*, *Dictyota*, *Dictyopteris*, *Padina* and *Dictyosphaeria*) grew on the reef, attracting juvenile green turtles (Gilbert 2005).

Trident Submarine Basin

The Trident Submarine Basin (TSB) study site was adjacent to the mouth of Port Canaveral Ship Channel (28°24'38"N, 80°35'20"W), Brevard County, Florida, USA and was studied by UCFMTRG since 1993. It was a 0.8 km^2 artificial embayment lined with granite boulder rip-rap and had a concrete wharf approximately 600 m wide and 1200 m long (Redfoot 1997). Water movement in the basin was affected by the ebb and flow of ocean tides. The dominant marine vegetation consisted of algae growing on boulders along the basin perimeter.

Turtle Capture and Data Collection

To capture juvenile turtles, UCFMTRG used a small boat to deploy mesh tangle nets with a polypropylene top line and a lead bottom line. Bullet floats attached to the top line kept nets afloat and anchors attached to the ends of the top line secured the nets. On IRL, two 227 m, large-mesh nets (40 cm stretch mesh size) created one long continuous net. Large buoy floats attached at the ends of the net, and dive flags attached at intervals along the net, alerted boaters of its location. One 227 m, small-mesh net (30 cm stretch mesh size) was used at SWR, and separate 227 m, large-mesh and small-mesh nets at TSB. In both IRL and TSB, UCFMTRG continuously monitored nets from two boats, while 5-7 snorkelers tended nets on SWR. When a turtle became entangled in the net, a dip net was used to pull the turtle into the boat. In TSB, UCFMTRG also used long-handled dip nets to capture turtles feeding on rocks along the basin perimeter.

After a turtle was captured, UCFMTRG took standard body measurements, including straight-line carapace length (SCL) and body mass. Straight-line carapace length was measured from the nuchal scute to the last marginal scute using calipers. Body mass was obtained using a spring scale and net support to cradle the turtle. UCFMTRG photographed dorsal and ventral views of each turtle, examining them for FP tumors. When available, digital photos were taken of any tumor, using a soft measuring tape in the same plane as the tumor for reference. Prior to digital photography, a “pap map” was created for each diseased tumor showing the exact location and size of each tumor, along with a description of its color and texture. For my study, I assigned each turtle a severity score (Balazs 1991) determined by the size and number of tumors:

0 = non-diseased, 1 = mildly afflicted, 2 = moderately afflicted and 3 = severely afflicted (Figure 2).

Data Analysis

I determined the number of green turtles in each FP Category at each site for each year using digital photos or "pap maps." I determined if there was a significant temporal trend in the proportion of afflicted green turtles at each location using linear regression techniques (Rice 1988). I also standardized the data set by dividing the number of turtles per FP Category by km-hours for each year to compare the number of turtles captured among years, as an index of their abundance. I also determined the number of turtles with regressed tumors at each location and year. I identified regressed tumors by their gray and smooth appearance, or by comparing photos of recaptured animals (Hirama and Ehrhart 2007). If a recaptured turtle's tumors decreased in size, disappeared or were gray and smooth in appearance, I scored it as regressed. I tested for first-order temporal autocorrelation using the Durbin-Watson (D) statistic (H_o = no autocorrelation) and used the Cochrane-Orcutt procedure to remove it if present. After adding one to each count to eliminate zeros, I determined if there was a significant temporal trend in the number of afflicted green turtles at each location using regression techniques.

H_o = There was no temporal trend in the number or percentage of green turtles per FP Category or with regressed tumors.

H_{a1} = The number or percentage of green turtles per FP Category or with regressed tumors increased with time.

H_{a2} = The number or percentage of green turtles per FP Category or with regressed tumors decreased with time.

I used multinomial logistic regression to examine the relationship between each FP Category and SCL or relative body condition (Kleinbaum 1994). I determined if FP severity changes with SCL or relative body condition by testing the hypotheses:

H_o = FP severity did not vary with SCL or relative body condition.

H_{a1} = FP severity increased with increasing SCL or relative body condition.

H_{a2} = FP severity decreased with increasing SCL or relative body condition.

I quantified growth rates as the geometric mean of the SCL ratio between captures corrected for time interval in years: $(SCL_{i+1}/ SCL_i)^{1/t}$ where i = initial and t = time interval in years. Using ANCOVA with initial SCL as a covariate, I tested whether growth rates of juvenile green turtles varied with FP Category and among sites.

H_o = Growth rates did not differ among FP categories or among sites.

H_a = Growth rates differed among FP categories or among sites.

I used Program MARK (White and Burnham 1999) to estimate population parameters from the capture history of individual animals. I used the Cormack-Jolly-Seber (CJS) approach (Lebreton et al. 1992) to determine the probability that a turtle remained alive (apparent survival, φ) and was available for recapture (recapture probability, ρ) for each study site (Figure 3). The following four CJS assumptions were met prior to continuing with estimations (Lebreton et al 1992):

a) Every marked animal present in populations at time (*i*) had the same probability of recapture (ρ_i).
b) Every marked animal in the population immediately after time (*i*) had the same probability of surviving to time ($i + 1$).
c) Marks were not lost or missed.
d) All samples were instantaneous, relative to the interval between occasion (*i*) and ($i + 1$), and each release was made immediately after the sample.

Consistent use of PIT tags, which are inserted internally and therefore cannot be lost, began in IRL and SWR in 1999, so only encounter histories of turtles captured from 1999-2006 were used. In TSB, PIT tags were used throughout the study period; therefore, I analyzed the entire 13-year dataset. After assumptions were met, goodness of fit (GoF) was evaluated in a series of tests. I tested the full parameter CJS model using the Unified Capture-Recapture (UCARE) program (Choquest et al. 2001) to evaluate assumptions that marked turtles had the same recapture and survival probabilities (TEST2+3). Recapture heterogeneity (TEST2.Ct) evaluated the possibility of "trap happiness": elevated recapture probabilities of previously captured turtles due to the trap or capture method (Pradel 1993). I selected the best model based on the Quasi-likelihood corrected form of the Akaike Information Criterion coefficient (QAICc) (Burnham et al. 1995, Anderson et al. 1998) and assessed GoF using parametric bootstrap methods in Program MARK (Pradel et al. 1997). Details of this program with specific application to probability estimation of sea turtle survival are provided in Chaloupka et al. (1999), Chaloupka (2000) and Chaloupka & Limpus (2002, 2005).

CHAPTER 3: RESULTS

Indian River Lagoon

Temporal Trend in Prevalence of Fibropapillomatosis

A total of 2,452 individual juvenile green turtles was captured in 1983-2006. All but 18 turtles (99.27%) were categorized by FP status using photos or "pap maps." Of the 2,434 unique individuals remaining, 1135 were FP Category 0 (46.63%), 836 were FP Category 1 (34.35%), 331 were FP Category 2 (13.60%), and 132 were FP Category 3 (5.42%), giving an overall FP incidence of 52.98%. The number of turtles in each FP Category per km-hour varied over time, but spiked in 1996 (Figure 4). Using exponential regression analyses after correcting for auto-correlation within Category 3, the number of turtles captured in all FP categories increased significantly over time (Table 1). The 4% annual increase for FP Categories 0 and 1 were at least double that of FP Categories 2 and 3 (2% and 1% annual increase, respectively). Despite the overall increase in number of turtles per FP Category, there were no significant changes in the percentage of turtles per FP Category (Figure 5; Table 2). Across this 23-year period 49.25 ± 2.31% (27.78-72.09%) of turtles captured lacked FP, 32.12 ± 1.52% (13.33-43.64%) were FP Category 1, 13.25 ± 1.44% (4.35-29.87%) were FP Category 2 and 5.38 ± 0.80% (0.00-14.71%) were FP Category 3.

A total of 236 unique green turtles captured in IRL was classified as regressed including seventy-two recaptured turtles. Of those turtles recaptured, 29 turtles (40.28%) showed no signs of FP at the second capture. Exponential regression showed a 2% annual increase in the number of captured turtles with regressed tumors over time (Figure 6, Table 1), while linear regression showed a 1% annual increase in the percentage of turtles with regressed tumors over time (Figure 7, Table 2). Of the total 112 recaptured turtles, 42 turtles showed regression of the disease compared to the 16 turtles that showed disease progression (Figure 8). No turtle was recaptured showing disease progression after being initially classified as regressing.

Table 1. Exponential regression analysis of the number of *Chelonia mydas* captured per km-hour in Indian River Lagoon per fibropapillomatosis category. df1 = numerator degrees of freedom; df2 = denominator degrees of freedom; R^2 = coefficient of determination; F = F-ratio; p = significance of the F statistic; DW = Durbin-Watson autocorrelation statistic; Regression Equation = equation of regression line.

	df1, df2	R^2	F	p	DW	Regression Equation
Category 0	1, 22	0.734	60.75	**<0.001**	2.26	$Y = 1.17*e^{0.04X}$
Category 1	1, 22	0.675	45.75	**<0.001**	1.66	$Y = 0.99*e^{0.04X}$
Category 2	1, 22	0.517	23.56	**<0.001**	1.47	$Y = 0.97*e^{0.02X}$
Category 3*	1, 22	0.257	7.59	**0.012**	1.94	$Y = 1.02*e^{0.01X}$
Regressed	1, 22	0.619	35.80	**<0.001**	1.16	$Y = 0.90*e^{0.02X}$

*after correcting for autocorrelation using Cochrane-Orcutt procedure

Table 2. Linear regression analysis of the percentage of *Chelonia mydas* captured in Indian River Lagoon per fibropapillomatosis category. df1 = numerator degrees of freedom; df2 = denominator degrees of freedom; R^2 = coefficient of determination; F = F-ratio; p = significance of the F statistic; DW = Durbin-Watson autocorrelation statistic; Regression Equation = equation of regression line.

	df1, df2	R^2	F	p	DW	Regression Equation
Category 0	1, 22	0.142	3.63	0.070	2.28	Y = 0.57 - 0.01X
Category 1	1, 22	0.141	3.62	0.070	2.18	Y = 0.27 + 0.01X
Category 2	1, 22	0.048	1.12	0.302	2.27	Y = 0.10 + 0.01X
Category 3	1, 22	0.001	0.01	0.925	2.21	Y = 0.06 - 0.01X
Regressed	1, 22	0.439	17.22	**<0.001**	1.18	Y = 0.99 + 0.01X

Size, Condition and Growth Rates

Mean SCL of juvenile green turtles in IRL was 43.8 ± 9.99 cm and ranged from 24.3 cm to 83.6 cm. Non-afflicted turtles (Category 0) had a mean SCL of 46.1 ± 11.59 cm (N=1133), Category 1 turtles were 42.4 ± 8.22 cm (N=837), Category 2 turtles 40.5 ± 6.71 cm (N=331) and Category 3 turtles 40.9 ± 7.16 cm (N=132). No significant relationships were found between the probabilities of FP Category 1, 2 or 3 and relative body condition; therefore all afflicted turtles were combined and simple logistic regression was performed. FP severity decreased significantly with increasing SCL, i.e. larger turtles were more likely to be non-afflicted or mildly afflicted with FP (χ^2 = 111.89, df = 1, p = <0.001; Figure 9).

Fibropapillomatosis varied with relative body condition of juvenile green turtles in IRL (Figure 10). Again, no significant relationships were found between the probabilities of FP Category 1, 2 or 3 turtle and relative body condition; therefore all afflicted turtles were combined and simple logistic regression was performed. The probability of a non-afflicted turtle captured in IRL increased with increased relative body condition, whereas turtles with diminished relative body condition were more likely to be afflicted with FP (χ^2 = 17.82, df = 1, p = <0.001).

One-hundred and ninety juvenile green turtles were recaptured at least once over the 23 years of the IRL study, which permitted analysis of growth rates. I excluded 74 turtles recaptured within the same year; 3 recaptured turtles' information were incomplete and also were not included. Geometric mean growth rates did not differ significantly among initial FP Categories (N = 113; Table 3). After testing for equality of error variances ($F_{3,109}$ = 2.45, p = 0.067) and lack of fit ($F_{8,100}$ = 2.19, p = 0.117), there was no effect of initial FP Category on growth rates after adjusting for initial SCL ($F_{3,108}$ = 1.54, p = 0.208; Figure 11).

Table 3. Mean growth rates per initial fibropapillomatosis category for juvenile green turtles in Indian River Lagoon; N = sample size, SD = standard deviation.

Initial FP Category	N	Mean Growth Rate ± SD (cm/y)
0	47	1.09 ± 0.035
1	45	1.11 ± 0.043
2	15	1.10 ± 0.068
3	6	1.11 ± 0.040

Apparent Survival and Recapture Probabilities

Using UCARE, the full parameter model passed TEST2+3 ($\chi2 = 25.49$, df = 46, p = 0.07). Therefore, there was no evidence that previously marked turtles had different recapture and survival probabilities compared to unmarked turtles. The model also passed UCARE TEST2.Ct (trap-dependence statistic = -0.35, p = 0.73), showing no evidence of heterogeneity of recapture probability. Thus, previously captured turtles did not have a higher recapture probability. Modeling parameters indicated that the model with both constant survival and recapture probabilities was the best fit. Bootstrap methods using 1000 simulations yielded a GoF p-value of 0.07 and a variance inflation factor ($\hat{c}$) value of 1.996 (SE = 0.02, 95% CI interval 1.96-2.03), indicating overdispersion in the data. After correcting for overdispersion, the constant survival and recapture probabilities model was the best fit by 10.35 times (QAICc weight of model 1/QAICc weight of model 2). Table 4 shows the QAICc values, QAICc weights, number of parameters and deviations.

Using the constant survival and recapture model, the estimate of annual apparent survival in IRL during the 7-year study was 0.75 ± 0.06 with 95% CI of 0.62-0.84, and estimated annual recapture probability was 0.04 ± 0.01 with 95% CI of 0.03-0.06.

Table 4. Cormack-Jolly-Seber modeling summary for Indian River Lagoon population based on a 7-year capture-recapture study. Best model selected indicated by bold QAICc. Φ = survival probability; ρ = recapture probability; QAICc = quasi-likelihood corrected form of Akaike information criterion; NP = number of parameters; Dev = relative deviance; time = time-dependent.

Φ	ρ	QAICc	QAICc Weights	NP	Dev
constant	constant	**785.5985**	0.81129	2	147.5409
time	constant	790.2728	0.07837	8	140.0928
category	constant	790.4956	0.07011	5	146.3936
category	time	792.0677	0.03195	11	135.7757
time	time	794.7696	0.00827	13	134.3841
category*time	constant	812.0444	0.00000	29	118.3531
category*time	time	817.5834	0.00000	34	113.2766

However, to determine survival rates per FP category I used the model with survival per category and constant recapture rates. Survival rates of non-afflicted turtles were similar to rates of mild and moderately afflicted turtles, but survival rates of severely afflicted turtles were lower but still indistinguishable statistically (Table 5).

Table 5. Apparent survival estimates for juvenile green turtle in Indian River Lagoon per FP category using Cormack-Jolly-Seber model. S.E. = standard error; C.I. = confidence interval.

	Estimate	SE	95% CI
FP Category 0	0.74	0.07	0.59 – 0.85
FP Category 1	0.74	0.07	0.57 – 0.85
FP Category 2	0.81	0.09	0.57 – 0.93
FP Category 3	0.63	0.18	0.28 – 0.88

In summary, juvenile green turtles in IRL had a high prevalence of FP during the 23-year study period. Larger IRL turtles were more likely to be non-afflicted or mildly afflicted, but FP Category did not affect growth rates. From 1999-2006, annual apparent survival for IRL turtles was 0.75 and annual recapture probability was 0.04, with FP Categories 0, 1 and 2 having similar survival rates. Juvenile turtles in FP Category 3, however, had a more variable survival, which tended to be lower than less-afflicted turtles.

Sabellariid Worm Reef

Temporal Trend in Prevalence of Fibropapillomatosis

A total of 941 individual juvenile green turtles was captured in 1989-2006. All turtles were categorized using photos or pap maps. Of the 941 unique individuals captured, 801 were FP Category 0 (85.12%), 128 were Category 1 (13.60%), and 12 were Category 2 (1.28%), giving an overall FP incidence of 13.82%. No Category 3, or severely afflicted turtle, was captured in SWR. Figure 12 showed that FP was not found on SWR until 1997, eight years after the start of the project. Using exponential regression, after correcting for autocorrelation within categories 0 and 1, there were no significant changes in the number of non-afflicted turtles captured within the 17-year SWR study or in the number of afflicted turtles captured since the disease was found in 1997 (Table 6). However, the proportion of non-afflicted turtles declined about 2% per year because no afflicted turtles were captured before 1997 (Figure 13; Table 7).

A total of 21 unique green turtles captured in SWR was classified as regressed by their gray, smooth tumor appearance. Nine more recaptured turtles were classified as regressed using their photos or pap-maps. Six of the nine recaptured turtles (66.67%) showed no signs of FP. Both the number and percentage of juvenile green turtles with regressed tumors did not change significantly over time (Figure 14; Table 6; Figure 15; Table 7).

Table 6. Exponential regression of the number of *Chelonia mydas* captured in Sabellariid Worm Reef within the 17-year study period for Fibropapillomatosis Category 0 turtles and within the 9-year study period for afflicted (Category 1-3) and regressed turtles. df1 = numerator degrees of freedom; df2 = denominator degrees of freedom; R^2 = coefficient of determination; F = F-ratio; p = significance of the F statistic; DW = Durbin-Watson autocorrelation statistic; Regression Equation = equation of regression line.

	df1, df2	R^2	F	p	DW	Regression Equation
Category 0*	1, 16	0.046	0.77	0.393	1.75	$Y = 6.70*e^{0.03X}$
Category 1*	1, 8	0.197	1.96	0.199	2.14	$Y = 4.79*e^{-0.06X}$
Category 2	1, 8	0.003	0.02	0.888	2.30	$Y = 1.15*e^{0.01X}$
Category 3	-	-	-	-	-	-
Regressed	1, 8	0.222	2.28	0.170	2.31	$Y = 1.70*e^{-0.04X}$

*after correcting for autocorrelation using Cochrane-Orcutt procedure

Table 7. Linear regression of the percentage of *Chelonia mydas* captured in Sabellariid Worm Reef within the 17-year study period for Fibropapillomatosis Category 0 turtles and within the 9-year study period for afflicted (Category 1-3) and regressed turtles. df = degrees of freedom; R^2 = coefficient of determination; F = F-ratio; p = significance of the F statistic; DW = Durbin-Watson autocorrelation statistic; Regression Equation = equation of regression line.

	df	R^2	F	p	DW	Regression Equation
Category 0*	16	0.726	42.41	**<0.001**	2.41	Y = 0.99 – 0.02X
Category 1*	8	0.346	4.23	0.074	2.36	Y = 0.02 + 1.10X
Category 2	8	0.012	0.10	0.763	2.54	Y = 0.01 + 1.01X
Category 3	-	-	-	-	-	-
Regressed	8	0.099	0.88	0.375	1.46	Y = 1.02 + 0.01X

Size, Condition and Growth Rates

Mean SCL of juvenile green turtles in SWR was 41.7 ± 10.21 cm and ranged from 20.0 cm to 72.3 cm (N = 941). Mean SCL of non-afflicted turtles (Category 0) was 41.2 ± 10.25 cm

(N=799), Category 1 turtles were 44.5 ± 9.71 cm (N=130) and Category 2 turtles 42.2 ± 7.82 cm (N=12). No significant relationships were found between the probabilities of FP Category 1 or 2 and body size; therefore all afflicted turtles were combined and simple logistic regression was performed. FP severity decreased significantly with increasing SCL, i.e. larger turtles were more likely to be non-afflicted or mildly afflicted with FP (χ^2 = 10.64, df = 1, p = 0.001; Figure 16).

Fibropapillomatosis varied with relative body condition of juvenile green turtles in SWR (Figure 17). Again, no significant relationships were found between the probabilities of FP Category 1 or 2 turtle and relative body condition; therefore all afflicted turtles were combined and simple logistic regression was performed. The probability of a non-afflicted turtle captured in SWR increased with increased relative body condition, whereas turtles with diminished relative body condition were more likely to be afflicted with FP (χ^2 = 10.12, df = 1, p = 0.002).

Fifty-one juvenile green turtles were recaptured at least once over the 18 years of the SWR study. Geometric mean growth rates did not differ significantly among initial FP categories (Table 8). After testing for equality of error variances ($F_{1,49}$ = 0.229, p = 0.229) and lack of fit ($F_{1,44}$ = 1.959, p = 0.272), there was no significant effect of initial FP Category on growth rates, even after adjusting for initial SCL ($F_{2,44}$ = 0.100, p = 0.753; Figure 18).

Table 8. Mean growth rates per initial fibropapillomatosis category for Sabellariid Worm Reef; N = sample size, SD = standard deviation.

Initial FP Category	N	Mean Growth Rate ± SD (cm/y)
0	42	1.05 ± 0.021
1	9	1.05 ± 0.011

Apparent Survival and Recapture Probabilities

Using UCARE, the full model passed TEST2+3 ($\chi 2$ = 11.07, df = 16, p = 0.81) and UCARE TEST2.Ct (trap-dependence statistic = 0.30042, p = 0.76385). Therefore, there was no evidence of age-dependence, transience or heterogeneity of recapture probability. Modeling parameters indicated that the model with time-dependent survival and constant recapture probabilities was the best fit. Bootstrapping with 1000 simulations yielded a GoF p-value of 0.045 and a ĉ value of 2.32 (SE = 0.03, 95% CI interval 2.27-2.37), indicating overdispersion in the data. After correcting for overdispersion, the time-dependent survival and constant recapture model was still the best fit by 12.90 times (QAICc weight of model 1/QAICc weight of model 2). Table 9 shows the QAICc values, QAICc weights, number of parameters, and deviation.

Table 9. Cormack-Jolly-Seber modeling summary for the Sabellariid Worm Reef population of juvenile green turtles based on a 7-year capture-recapture study. Best model selected indicated by bold QAICc. Φ = survival probability; ρ = recapture probability; QAICc = quasi-likelihood corrected form of Akaike information criterion; NP = number of parameters; Dev = relative deviance; time = time-dependent.

Φ	ρ	QAICc	QAICc Weights	NP	Dev
time	constant	**252.9553**	0.82913	4	21.2178
constant	constant	258.0691	0.06429	2	30.3768
time	time	258.1190	0.06271	9	16.1537
constant	time	258.8340	0.04386	8	18.9276

Using the time-dependent survival and constant recapture model, the estimate of apparent survival range per year was 0.28 to 0.79 (geometric mean = 0.44; Table 10). Unfortunately, three time intervals did not have enough captures and recaptures, resulting in a SE of 0.00 and

95% CI of 1.00. The wide range of values for the remaining intervals indicated insufficient data for the SWR dataset. The estimate of annual recapture probability was 0.04 ± 0.01 with 95% CI of 0.03-0.06.

Table 10. Estimates for apparent survival (Φ) and recapture probabilities (ρ) for Sabellariid Worm Reef from a time-dependent (t) survival and constant (.) recapture Cormack-Jolly-Seber model (Table 9). SE = standard error; CI = confidence interval.

Parameter	Estimate	SE	95% CI	Comments
Φ(t1)	0.38	0.12	0.18 – 0.63	
Φ(t2)	1.00	0.00	0.00 – 1.00	
Φ(t3)	0.79	0.21	0.24 – 0.98	
Φ(t4)	1.00	0.00	1.00 – 1.00	Invalid
Φ(t5)	1.00	0.00	1.00 – 1.00	Invalid
Φ(t6)	0.28	0.10	0.12 – 0.51	
Φ(t7)	1.00	0.00	1.00 – 1.00	Invalid
ρ(.)	0.04	0.01	0.03 – 0.06	

In summary, green turtles captured at SWR had a low prevalence of FP (13.82%) during the 17-year study period. Similar to juvenile green turtles at IRL, larger SWR turtles were more likely to be non-afflicted, but FP Category did not affect growth rates. From 1999-2006, mean annual apparent survival for SWR turtles (0.44) was lower compared to the annual apparent survival for IRL (0.78), but annual recapture probability as similar (0.04).

Trident Submarine Basin

Temporal Trend in Prevalence of Fibropapillomatosis

A total of 1,220 juvenile green turtles was captured in TSB in 1993-2006. Two hundred and eight turtles were recaptured, including 81 within the same year. Of the 1,139 individual turtles captured, only three turtles had FP tumors (0.26%; Figure 19). The first FP capture was a Category 2 turtle recorded on 16 March 2005. The second FP turtle also was a Category 2 turtle captured on 11 July 2006. This turtle was captured 23 times during a nine year period beginning on 30 March 1997 and showed no evidence of FP during any previous capture. The third FP turtle was captured on 15 December 2006 and classified as Category 1 with regressed tumors.

The number of non-afflicted turtles per net soak hours during the 13-year study period increased significantly ($Y = 0.75*e^{0.05X}$; $F_{1,13} = 7.87$, $p = 0.016$). With only three afflicted turtles captured, statistical analysis could not be performed on temporal changes in the number or percentage of turtles with FP.

Size, Condition and Growth Rates

Mean SCL of juvenile green turtles in TSB was 32.4 ± 5.70 cm and ranged from 22.8 cm to 52.0 cm (N = 847). Over the 14 years of the TSB study, 125 juvenile green turtles were recaptured at least once. No statistical analyses of growth rates between FP Categories were performed due to the rarity of FP- afflicted turtles (N = 3). After adjusting for initial SCL, growth rates significantly differed among sites ($F_{1,2} = 33.76$, $p = <0.001$; Figure 20). Using

Tukey HSD for multiple comparisons, growth rates in IRL (1.11 ± 0.05 cm) were significantly higher than in SWR and TSB ($p < 0.01$). Growth rates for SWR and TSB did not differ significantly ($p = 0.25$), and combined averaged 1.05 ± 0.021 cm/yr.

Apparent Survival and Recapture Probabilities

Using UCARE, the full model failed TEST2+3 ($\chi 2 = 108.15$, df = 42, $p < 0.00$), but passed the TEST2 component ($\chi 2 = 4.65$, df = 8, p p=0.79), so there was no evidence of transience. The model also passed TEST3.Sm ($\chi 2 = 12.2421$, df = 11, p=0.34572), which indicated transience was not a problem, but failed TEST3.Sr ($\chi 2 = 6.8202$, df = 12, p = 0.000), so survival probabilities were age-dependent and an age-class model should be used. The model also failed UCARE TEST2.Ct (trap-dependence statistic = -2.8451, p = 0.0044), suggesting that previously captured turtles had a higher recapture probability or were "trap-happy". Trap dependence effects are hard to interpret (Pradel 1993), but the TSB data structure mimics "trap-happiness" because of the high recapture probabilities resulting from the shallow waters (Bjorndal et al. 2003). Certain turtles may have been less wary and therefore more prone to capture using active methods (i.e., dip netting from a boat). Results should be interpreted with caution as the survival estimate may be biased (Pradel 1993).

Because the model failed TEST3.Sr, an age-class model should be used. However, because turtle age was unknown, a more appropriate model was time since marking (TSM), which is used when individuals that will leave the population at a certain time are present in marked samples. Due to lack of larger turtles in TSB, turtles may leave it at a certain age or size. Modeling parameters indicate that the model with two age classes (2-M class) with constant survival and time-dependent recapture probabilities was the best fit. Bootstrapping using 100 simulations yielded a GoF p-value of 0.01 and a ĉ value of 4.58 (SE = 0.05, 95% CI interval 4.49-4.67), indicating overdispersion in the data. After correcting for overdispersion, the constant survival and recapture model was still the best fit by 16.95 times (QAICc weight of model 1/QAICc weight of model 2; Table 11).

Table 11. Cormack-Jolly-Seber modeling summary for the Trident Submarine Basin population of green turtles based on a 13-year capture-recapture study. Best model selected indicated by bold QAICc. Φ = survival probability; ρ = recapture probability; QAICc = quasi-likelihood corrected form of Akaike information criterion; NP = number of parameters; Dev = relative deviance; M2 = 2 tag-cohort-age classes; c = constant; time = time-dependent.

Φ	ρ	QAICc	QAICc Weights	NP	Dev
M2 (c/c)	time	**406.4138**	0.92008	15	107.7179
time	constant	412.0748	0.05900	13	117.5271
constant	time	413.7404	0.02360	14	117.1213
constant	constant	418.6466	0.00203	2	146.5441
time	time	427.7556	0.00002	25	107.9993

Using the time-dependent survival and constant recapture model, the estimate of survival of the first M-class (first year after marking) was 0.47 ± 0.03 SE with 95% CI of 0.40-0.54, which was negatively biased since the first M-class consists of residents and transients. The estimate of survival of subsequent M-classes (the years following the first year after marking; M2+) was 0.78 ± 0.02 SE with 95% CI of 0.73-0.82. This estimate was closer to the "true" parameter estimate of resident turtles in the TSB population. Estimates of recapture probabilities over time ranged from 0.27 to 0.79 (geometric mean = 0.42; Table 12).

Table 12. Estimates of apparent survival (Φ) and recapture probabilities (ρ) for Trident Submarine Basin from a 2 tag-cohort-age class (2M+) and time-dependent (t) recapture Cormack-Jolly-Seber model (Table 12). SE = standard error; CI = confidence interval.

Parameter	Estimate	SE	95% CI
Φ(M1)	0.47	0.04	0.40 – 0.54
Φ(M2+)	0.78	0.02	0.73 – 0.82
ρ(t1)	0.49	0.11	0.29 – 0.69
ρ(t2)	0.79	0.08	0.60 – 0.91
ρ(t3)	0.27	0.06	0.17 – 0.41
ρ(t4)	0.44	0.08	0.30 – 0.60
ρ(t5)	0.36	0.07	0.24 – 0.50
ρ(t6)	0.76	0.06	0.63 – 0.86
ρ(t7)	0.73	0.06	0.61 – 0.82
ρ(t8)	0.77	0.07	0.61 – 0.88
ρ(t9)	0.51	0.08	0.36 – 0.65
ρ(t10)	0.26	0.07	0.16 – 0.41
ρ(t11)	0.29	0.07	0.18 – 0.45
ρ(t12)	0.26	0.06	0.15 – 0.40
ρ(t13)	0.16	0.05	0.09 – 0.28

Comparisons among Sites

The number of juvenile green turtles captured at IRL and TSB increased significantly over time, while no trend was apparent at SWR. Prevalence of FP was significantly higher at IRL (52.98%) compared to SWR (13.82%) and TSB (0.26%). Annual apparent survival estimates at IRL and TSB were approximately equal and fell near the upper range of estimates for SWR (Table 13). Recapture probabilities for IRL and SWR were indistinguishable, and combined averaged 0.04 ± 0.01 with 95% CI of 0.03-0.06. The recapture probability range of TSB was at least six times higher than at IRL and SWR. Different sampling methods were used in the three sites; only tangle nets for IRL and SWR and both tangle and dip nets for TSB. An overall comparison of population statistics is shown in Table 13 and key population characteristics are summarized in Table 14.

Table 13. Summary of annual survival estimates (Φ) and recapture probabilities (ρ) for juvenile *Chelonia mydas* captured at three study sites on Florida's Atlantic coast. GM = geometric mean.

Study site	Φ	ρ
Indian River Lagoon (7-year)	0.75	0.04
Sabellariid Worm Reef (7-year)	0.28 – 0.79 (GM 0.44)	0.04
Trident Submarine Basin (13-year)	0.78	0.27-0.79 (GM 0.42)

Table 14. Summary of juvenile green turtle life histories in Indian River Lagoon (IRL), Sabellariid Worm Reef (SWR) and Trident Submarine Basin (TSB). NA = not applicable.

	Indian River Lagoon	Sabellariid Worm Reef	Trident Submarine Basin
Prevalence and temporal trend in fibropapillomatosis	No Significant Changes	No Significant Changes	NA
Prevalence and temporal trend in FP regression	Increased	No Significant Changes	NA
Probability of capturing a non-afflicted turtle as a function of increased SCL	Increased	Increased	NA
Probability of capturing a non-afflicted turtle as a function of increased relative body condition	Increased	Increased	NA
Growth rate	No differences among FP Categories; Significantly higher than SWR and TSB	No differences among FP Categories; Significantly lower than IRL	Significantly lower than IRL
Apparent survival estimate	Not different than TSB; higher than SWR	Lower than IRL and TSB	Not different than IRL; higher than SWR
Recapture probability	Not different than SWR; lower than TSB	Not different than IRL; lower than TSB	Higher than IRL and SWR

CHAPTER 4: DISCUSSION

Fibropapillomatosis is considered a threat to green turtle populations because of its prevalence and severity in major populations, and the limited research on FP tumor regression (NMFS and USFWS 1991). My study is the first to use a long-term database to determine the prevalence and severity of FP, annual FP regression rates, annual apparent survival estimates and recapture probabilities of juvenile green turtle populations. Differences among sites in FP prevalence allowed me to estimate the possible long-term impact of this disease on Florida juvenile green turtle populations.

The percentage of FP-afflicted turtles in IRL did not change significantly over the 23-year study period, despite the overall increase in catch per unit effort (CPUE). This suggests that the population is increasing in size because capture protocols were identical throughout the study (Ehrhart et al. 2007). However, FP prevalence spiked in 1996 and increased from 44.57% in the 1980s, to 52.35% in the 1990s and 54.64% this decade. Despite this increase, FP had no detectable effect on turtle growth rates, apparent survival or recapture probability within IRL.

The probability of an IRL turtle being non-afflicted increased with increasing SCL; larger individuals were more likely to be non-afflicted or mildly afflicted with FP. Overall, >50% of IRL juvenile green turtles had FP, compared to approximately 1.5% of adult nesting green turtles at nearby ACNWR (Ehrhart, pers. comm.). Differences in FP rates between juvenile and adult turtles suggest that the disease regresses as juveniles mature. Regression of FP is understudied, but important for understanding the potential impact of FP on turtle populations; this is the first study to estimate it using a long-term database. During the 23-year period I studied, 40.28% of

IRL recaptures afflicted with FP at initial capture had regressed tumors, while only 22.22% of total recaptures showed disease progression. Four FP Category 3 turtles were recaptured during the study period; one exhibited no change in FP status, one decreased to FP Category 2, one to Category 1, and one to Category 0 within a four year span. Furthermore, evidence of regressed tumors (characterized by their smooth texture and gray color) was found on 236 IRL turtles (9.70%) from 1983-2006. Additionally, no turtle was recaptured showing disease progression after being initially classified as regressing. This suggests that once a turtle recovers from the disease it may be immune to contracting FP again. Despite the high FP prevalence in IRL, annual apparent survival estimate was 0.75 and annual recapture probability was 0.04. Survival rates of FP Category 0, 1 and 2 turtles were similar; survival rate of turtles in FP Category 3 was slightly lower (0.63). These data suggest that FP afflicts smaller or younger turtles, and larger juveniles, sub-adults and adults either are not afflicted or possibly recover from this disease provided that it has not advanced to a severe state. Severely afflicted turtles are more likely to be emaciated or become entangled in monofilament line or other debris (Witherington and Ehrhart 1989, Balazs et al. 1997)

The probability of a captured turtle being non-afflicted increased with increased relative body condition for IRL turtles, but no significant relationships between FP Category 1, 2 or 3 and relative body condition were found. Relative body condition was a poor indicator of FP Category, which is defined by differences in tumor size and number. Tumor growth around the eyes can affect a turtle's ability to forage (Balazs et al. 1997) and in advanced stages tumors can grow internally, affecting digestion (Work and Balazs 1999), and thereby relative body condition. In addition, tumors are well-vascularized masses of heavily collagenized fibrous tissues that can weigh 100 g (Balazs 1991 and Harshbarger 1991) and thereby contribute to overall body mass. As FP increased in severity, the number and size of tumors increased, thus any negative change in normal body mass due to increased FP severity could be offset by the increase in tumor mass.

Prevalence of FP in SWR green turtles also did not change significantly during my study and it had no detectable effect on their growth rates, apparent survival or recapture probability. During the 17-year study period at SWR, 14.88% of turtles had FP, which was not present there until 1997, one year after disease incidence spiked in IRL. Since 1997, FP prevalence and frequency varied among years, but each FP Category neither increased nor decreased consistently over time. Nine turtles categorized as FP Category 1 at initial capture had no signs of FP at recapture and 21 turtles showed evidence of regressed tumors. Only two turtles recapture at SWR showed progression of the disease, suggesting that SWR turtles afflicted with FP were more likely to recover from the disease.

Similar to IRL, the probability of capturing a non-afflicted SWR turtle increased with increasing SCL and relative body condition; thus, larger juvenile green turtles were more likely to be non-afflicted with FP. Growth rates were not affected by FP status. Mean annual apparent survival rate for SWR was lower than IRL (0.44), but varied from 0.28 to 0.79. However, SWR recapture probability was similar to IRL (0.04). Again, these data suggest that the disease regresses as juvenile green turtles mature, and larger juveniles, sub-adults and adults either recover or are not afflicted by the disease.

Fibropapillomatosis was rarely found at TSB. Only three afflicted TSB turtles were captured within the 13-year study period, all recently and in consecutive years (2005-2006).

Mean SCL of TSB turtles (32.4 ± 5.70) was significantly smaller compared to SWR (41.7 ± 10.21) and IRL (43.8 ± 9.99). Mean growth rate of TSB (1.06 ± 0.04) turtles was significantly lower than IRL (1.10 ± 0.04).

My three study sites varied in habitat condition, FP prevalence and severity. Indian River Lagoon was a large embayment just south of Sebastian Inlet and had little water movement. It also is south of major development and citrus crops where run-off or pesticides, herbicides and other chemicals accumulate. Prevalence of FP in IRL was the highest, with >50% of IRL turtles afflicted. Tidal flux via Sebastian Inlet allowed the more polluted IRL water to flow to SWR, resulting in a mix of heavily polluted and ocean water. From the Sebastian Inlet bridge a plume of darker, more polled IRL water can be seen mixing with the lighter, less polluted ocean water during the out-going tide (Ehrhart, pers. comm.). However, FP prevalence in SWR was relatively low (~15%), and compared during the same time period (1989-2006), FP prevalence in IRL was over three times three higher than in SWR (52.87% versus 15.41%). Although SWR was close to IRL, there was little turtle movement between them; no IRL turtle was recaptured in SWR and only seven SWR turtles were recaptured in IRL.

Unlike the limited water exchange at IRL and the influential flow of polluted water over SWR, TSB was flushed by ocean tides twice daily. Only three turtles with FP were captured at TSB over the 13-year study period. Thus, juvenile green turtles in the more stagnant, polluted water of IRL had the highest FP prevalence, those in the nearby inshore waters of SWR had intermediate levels and turtles in TSB had the lowest FP prevalence. This pattern is consistent with that reported from Hawaii, Indonesia and Australia, where turtle populations in degraded waters had high FP prevalence (Adnyana et al. 1997, Bennett et al. 2000, Chaloupka and Balazs 2005).

Fibropapillomatosis affects a large percentage of turtles on the east coast of Florida, but my results suggest that populations may not be negatively affected by the disease. Hirama (2001) showed mildly or moderately afflicted IRL turtles were as healthy as non-afflicted turtles; only FP Category 3 turtles were chronically stressed, anemic and nutritionally imbalanced. Severely afflicted turtles comprised less than 15% of the IRL population, and no FP Category 3 turtle was captured at SWR or TSB. Even with the high prevalence of FP, apparent survival in IRL (0.75) was similar to TSB (0.78) where FP was extremely rare. Survival estimates for IRL and TSB were slightly higher than two Bahamas populations and slightly lower than a southern Great Barrier Reef population with no documentation of FP (Table 14). This is additional evidence that FP minimally effects survivorship of juvenile green turtles.

Similar results were found in Hawaiian populations. Fibropapillomatosis was found in 42-65% of juvenile green turtles in Kaneohe Bay (Oahu, HI) with approximately 80% of afflicted turtles showing oral tumors (Balazs 1991, Balazs et al. 1997, Work and Balazs 1998). However, larger turtles were more likely to FP-afflicted, whereas smaller turtles were more likely to be tumor free. Mean SCL for Hawaiian turtles without tumors was significantly lower (SCL = 44.0 ± 1.1 cm) than turtles with FP tumors (SCL = 56.0 ± 2.1 cm; Aguirre et al. 1994). Severely afflicted turtles were chronically stressed and immunospressed, but there were no significant differences in baseline plasma biochemistry among FP Categories 0, 1 and 2 (Aguirre 1991). These data suggest that despite the high prevalence of FP in Florida and Hawaii, these populations were not negatively affected by the disease (Chaloupka and Balazs 2005, 2007 and Chaloupka et al. 2007).

During the thirteen plus years that I evaluated, FP was most prevalent in the more polluted IRL, less prevalent in SWR and rare in the frequently flushed TSB. Regression of FP occurred at the same magnitude as prevalence, i.e., FP regression was high when prevalence was high. Larger turtles were more likely to be non-afflicted or mildly afflicted, but turtle growth rates did not differ significantly among FP Categories. These data suggest that FP afflicts smaller or younger turtles, and larger juveniles, sub-adults and adults either are not afflicted or possibly recover from this disease. In addition, populations with high FP prevalence had apparent survival rates similar to those where FP was rare, suggesting that FP is not a major driver of juvenile green turtle survival rates. Long-term datasets are essential to understanding demography; they can be used to determine changes in population size and disease frequency, apparent survival and recapture estimates, and forecast possible changes in future generations (Tinkle et al. 1993, Congdon et al. 1994, Madsen and Shine 2001). Research is still needed to determine the causes of FP, but long-term studies similar to mine can help identify changes in juvenile green turtle populations with and without FP.

Table 15. Estimates of apparent survival probabilities (Φ) of wild populations of marine turtles. CCL = curved carapace length; sGBR = southern Great Barrier Reef; CJS = Cormack-Jolly-Seber model; B = Burnham model; CC = catch-curve analysis. Table adopted from Bjorndal et al. 2003.

Species	Location and Habitat	Φ	Method	Source
Green Turtle (*Chelonia mydas*)	IRL, Florida, neritic	0.749	CJS	Current study
Green Turtle	SWR, Florida, oceanic	Range = 0.27801 - 0.79490	CJS	Current study
Green Turtle	TSB, Florida, neritic	0.77647	CJS	Current study
Green Turtle (35-65 cm CCL)	sGBR, Australia, neritic	0.880 (0.835-0.927)	CJS	Chaloupka and Limpus (2003)
Green turtle (65-90 cm CCL)	sGBR, Australia, neritic	0.847 (0.790-0.908)	CJS	Chaloupka and Limpus (2003)
Adult Green Turtles	sGBR, Australia, neritic	0.9482 (0.92-0.98)	CJS	Chaloupka and Limpus (2005)
Green Turtle	Union Creek, Bahamas, neritic	Range = 0.510-0.814	B	Bjorndal et al. (2003)
Green Turtle	Conception Creek, Bahamas, neritic	0.680 (0.631-0.725)	CJS	Bjorndal et al. (2003)
Loggerhead (*Caretta caretta*)	North Atlantic, oceanic	0.720	CC	Bjornal et al. (2003)
Loggerhead	Southeast US, neritic	0.695	CC	Frazer (1987)
Loggerhead	Southeast US, neritic	0.893	CC	Epperly et al. (2001)
Loggerhead	sGBR, Australia, neritic	0.830	CJS	Heppell et al. (1996)
Loggerhead	sGBR, Australia, neritic	0.859 (0.828-0.855)	CJS	Chaloupka and Limpus (2002)
Loggerhead	sGRB, Australia, neritic	0.918 (0.88-0.96)	CJS	Chaloupka and Limpus (2002)
Kemp's Ridley (*Lepidochelys kempi*)	Southeast US, neritic	Mode = 0.5, Range = 0.3-0.8	CC	TWEG (2000)

APPENDIX 1: FIGURES

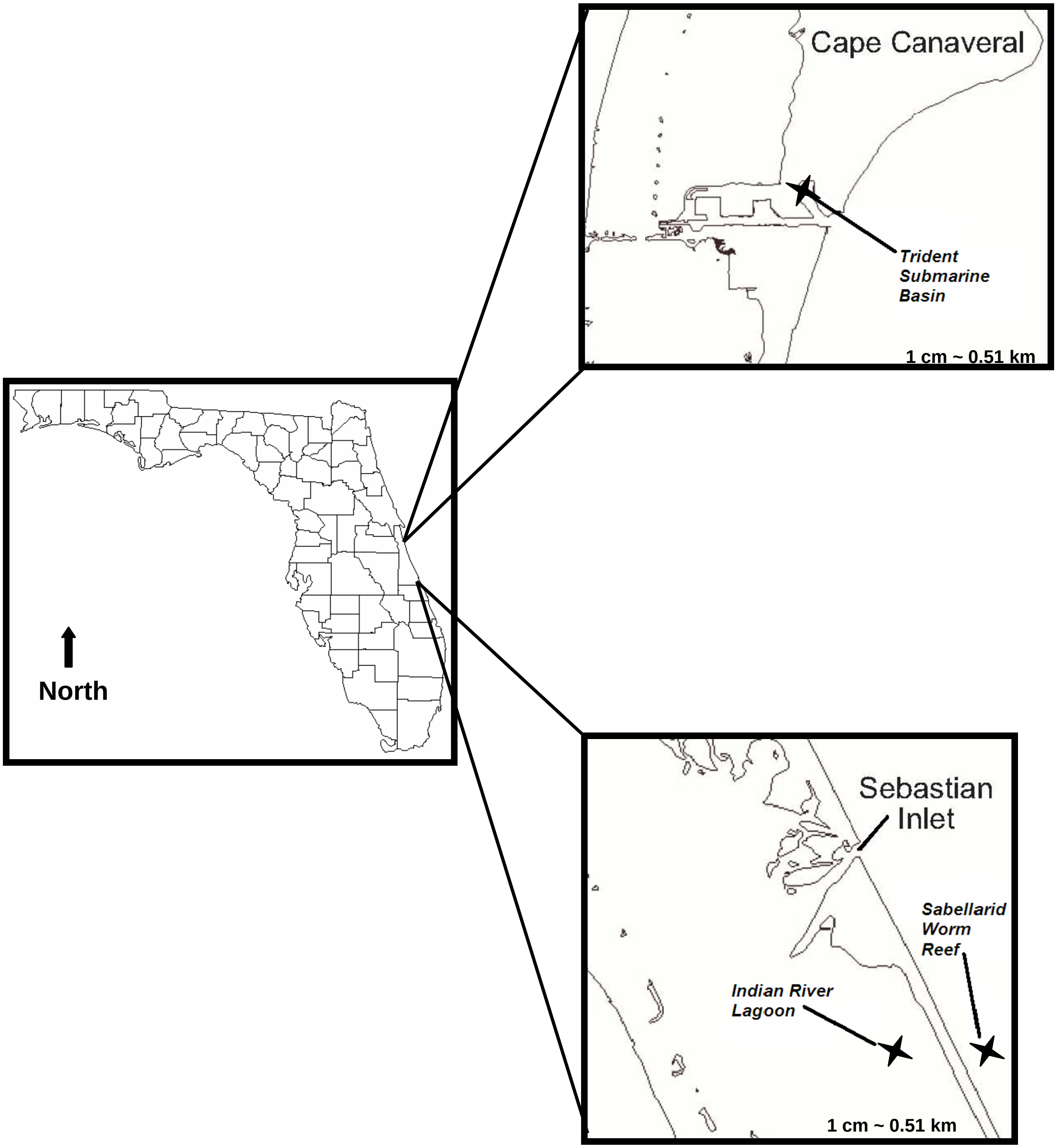

Figure 1. Location of three study sites on Florida's central Atlantic coast: Indian River Lagoon, Sabellariid Worm Reef and Trident Submarine Basin.

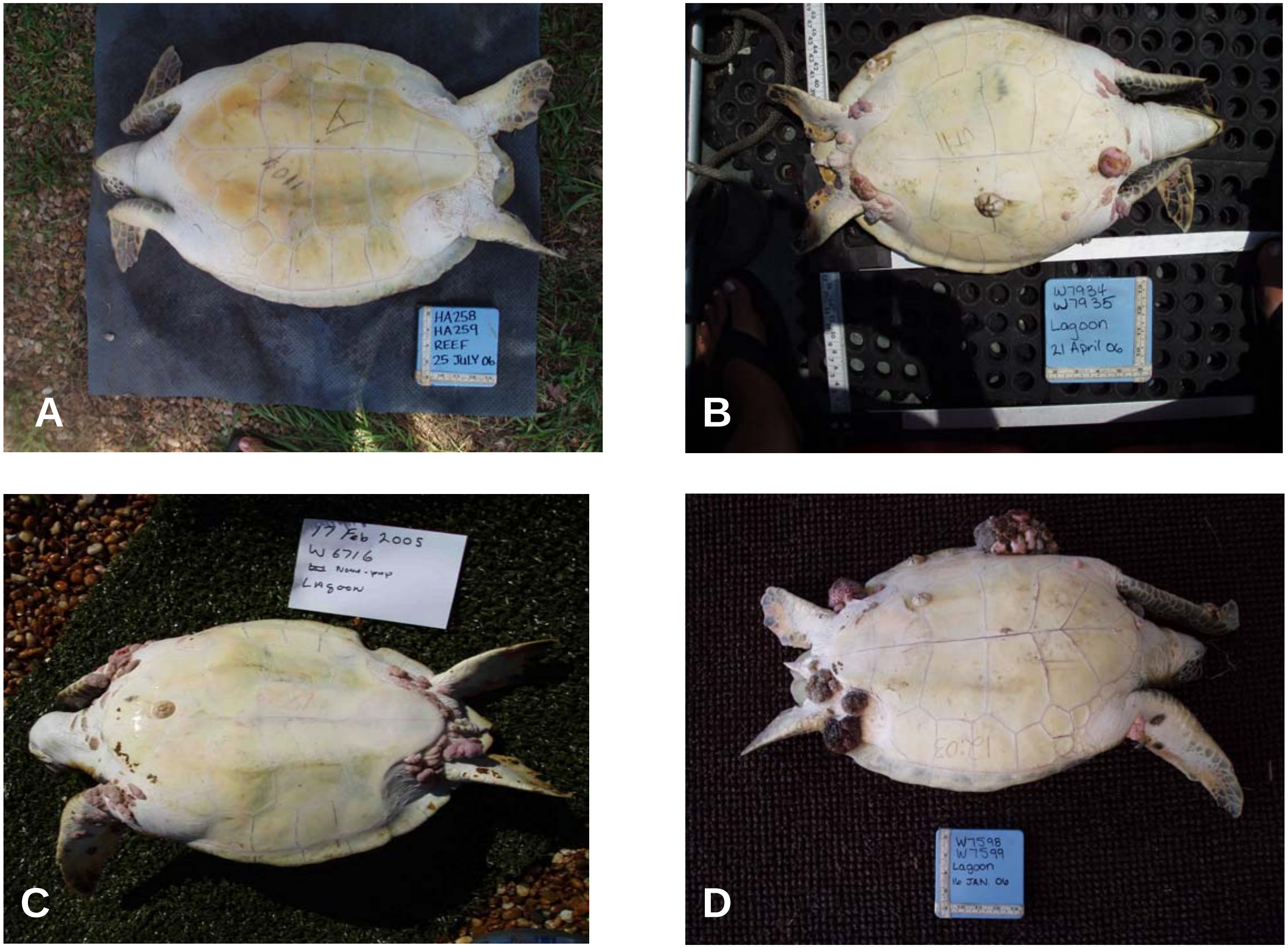

Figure 2. Examples of juvenile *Chelonia mydas* with various degrees of Fibropapillomatosis: Category 0 with no Fibropapillomatosis affliction (A), Category 1 with mild affliction (B), Category 2 with moderate affliction (C) and Category 3 with severe affliction (D).

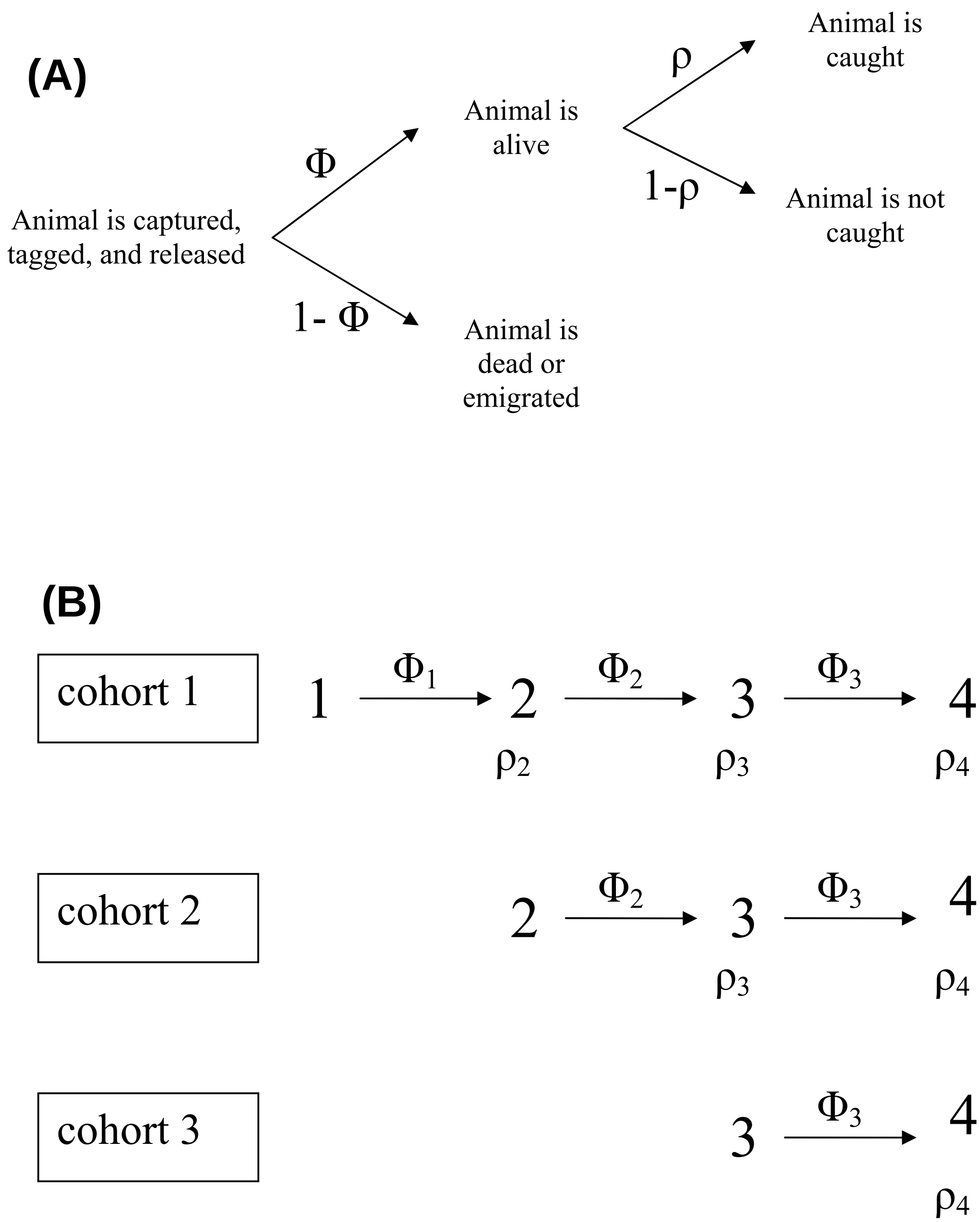

Figure 3. Schematic of apparent survival (φ) and recapture (ρ) probabilities for individual animals (A) and sampling cohorts (B) of a population.

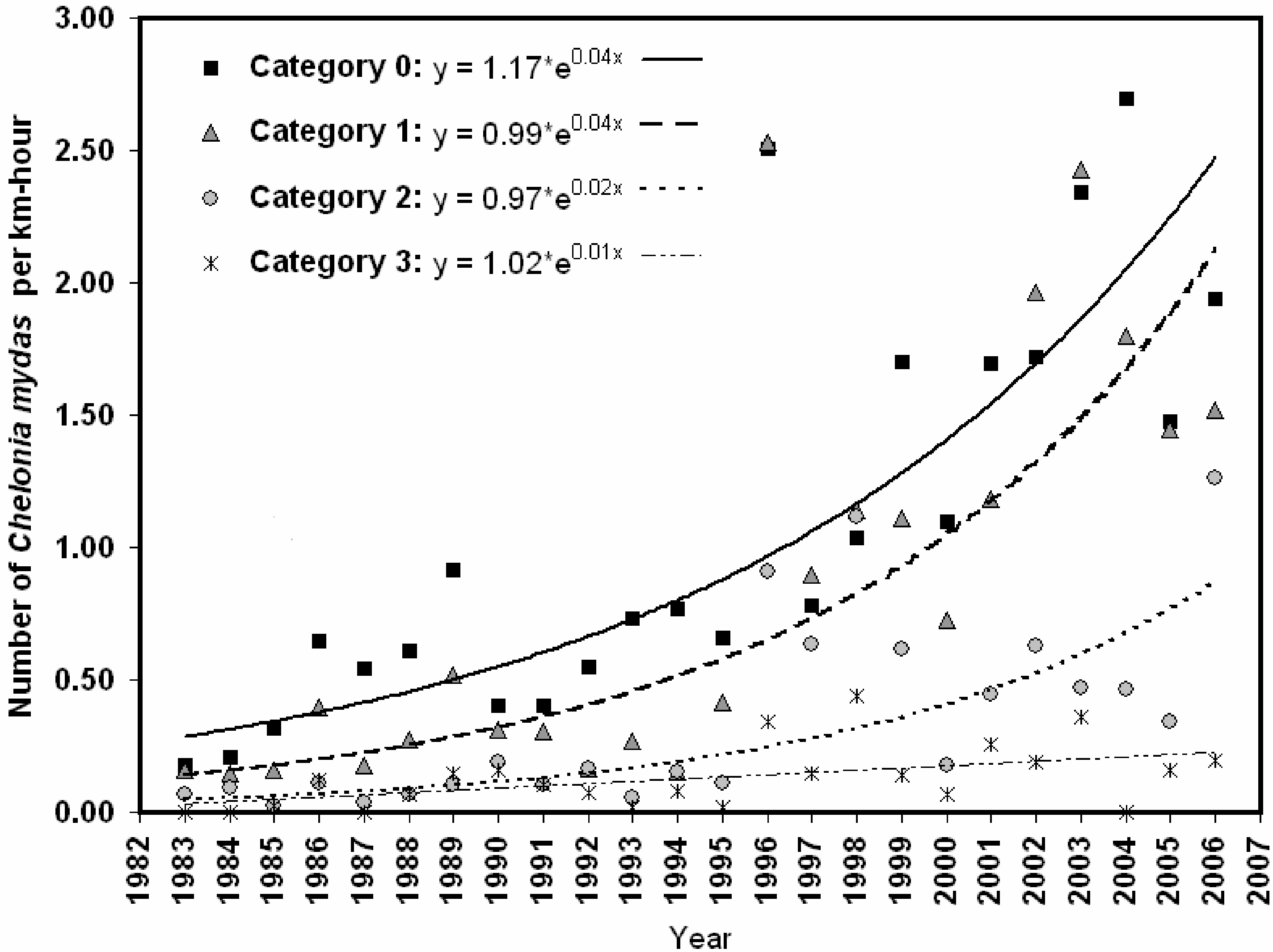

Figure 4. Number of Chelonia mydas in each fibropapillomatosis category captured per km-hour within Indian River Lagoon

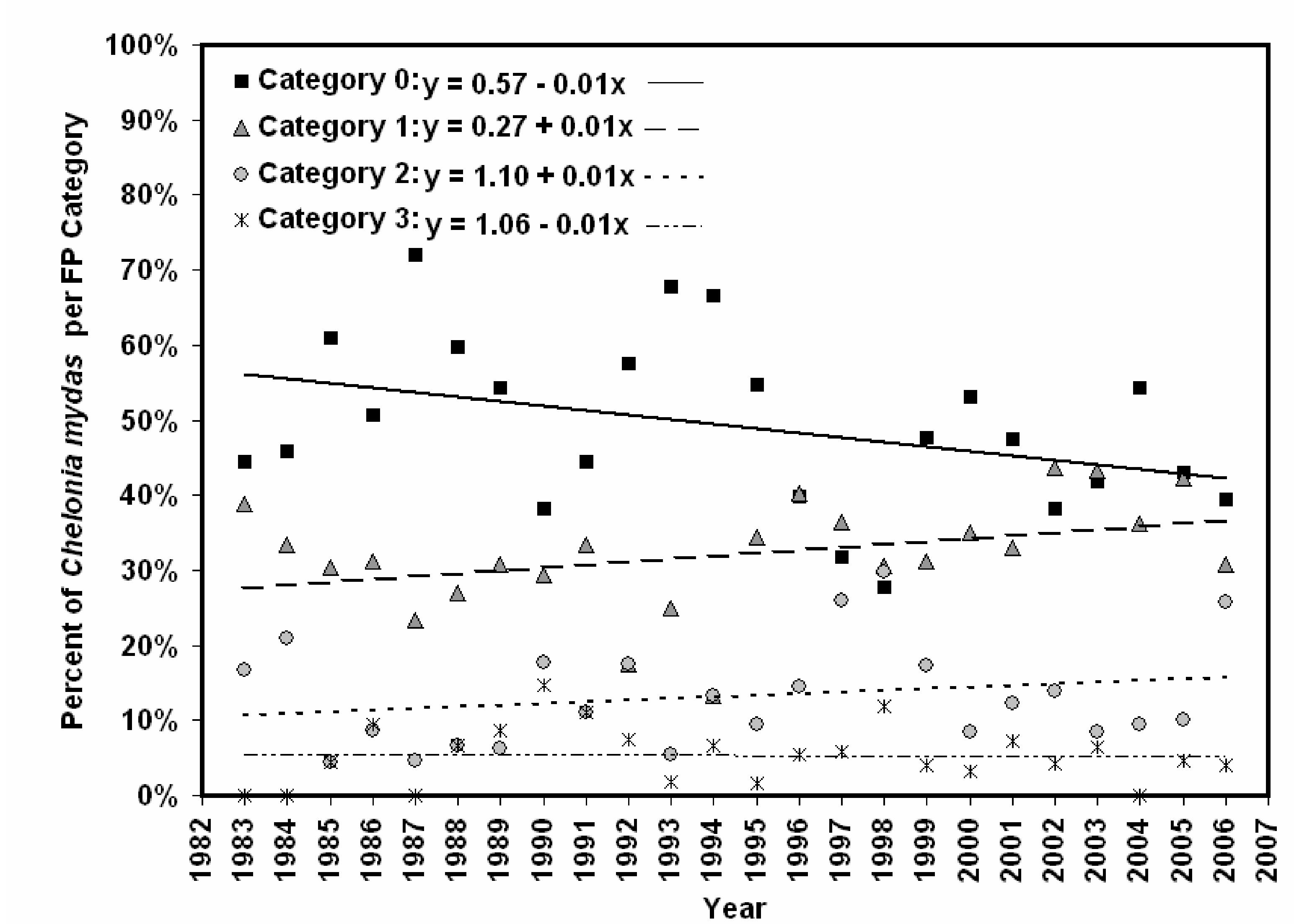

Figure 5. Percent of Chelonia mydas in each fibropapillomatosis category captured within Indian River Lagoon.

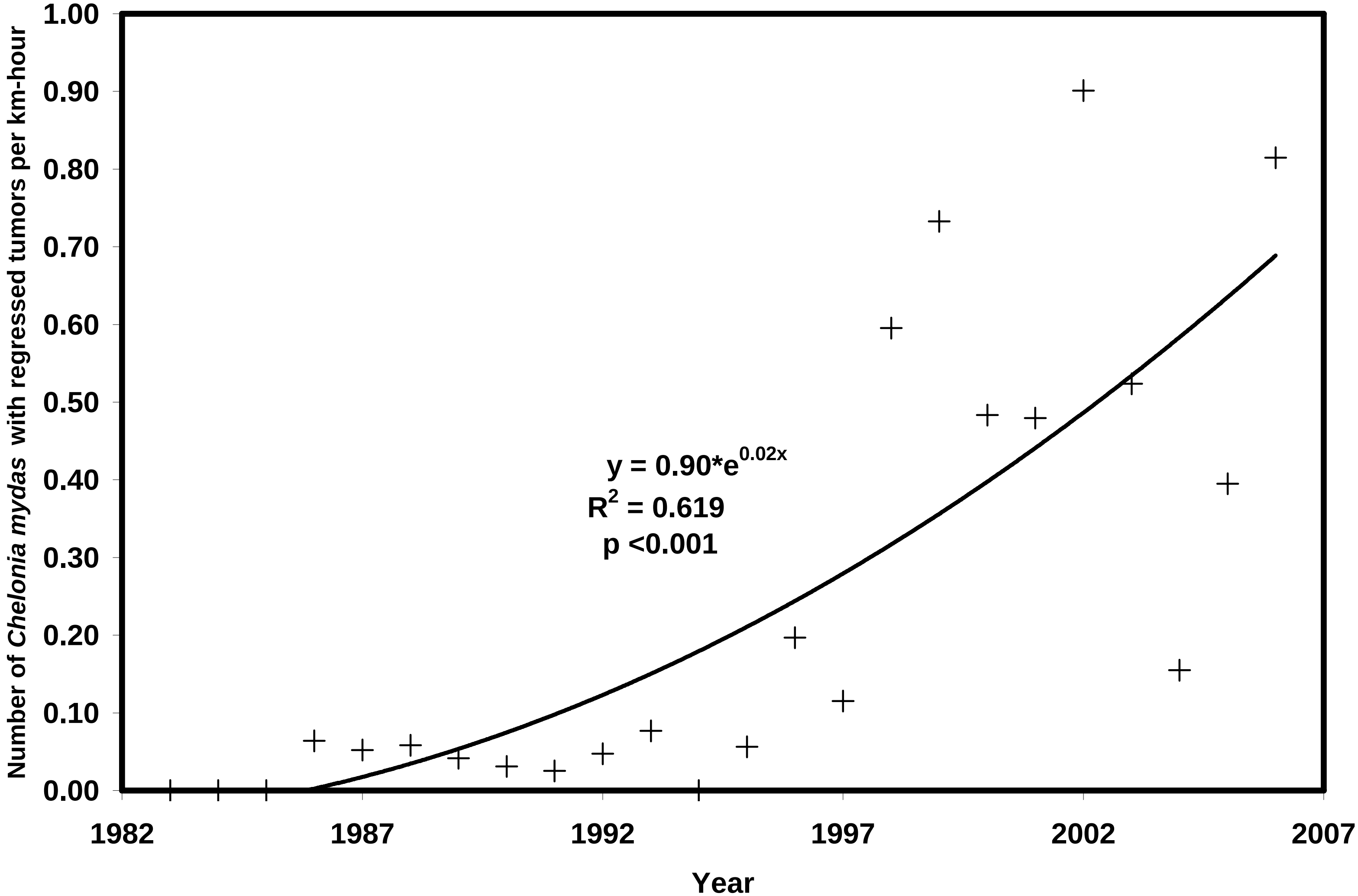

Figure 6. Number of Chelonia mydas captured per km-hour within Indian River Lagoon that had evidence of regressed tumors.

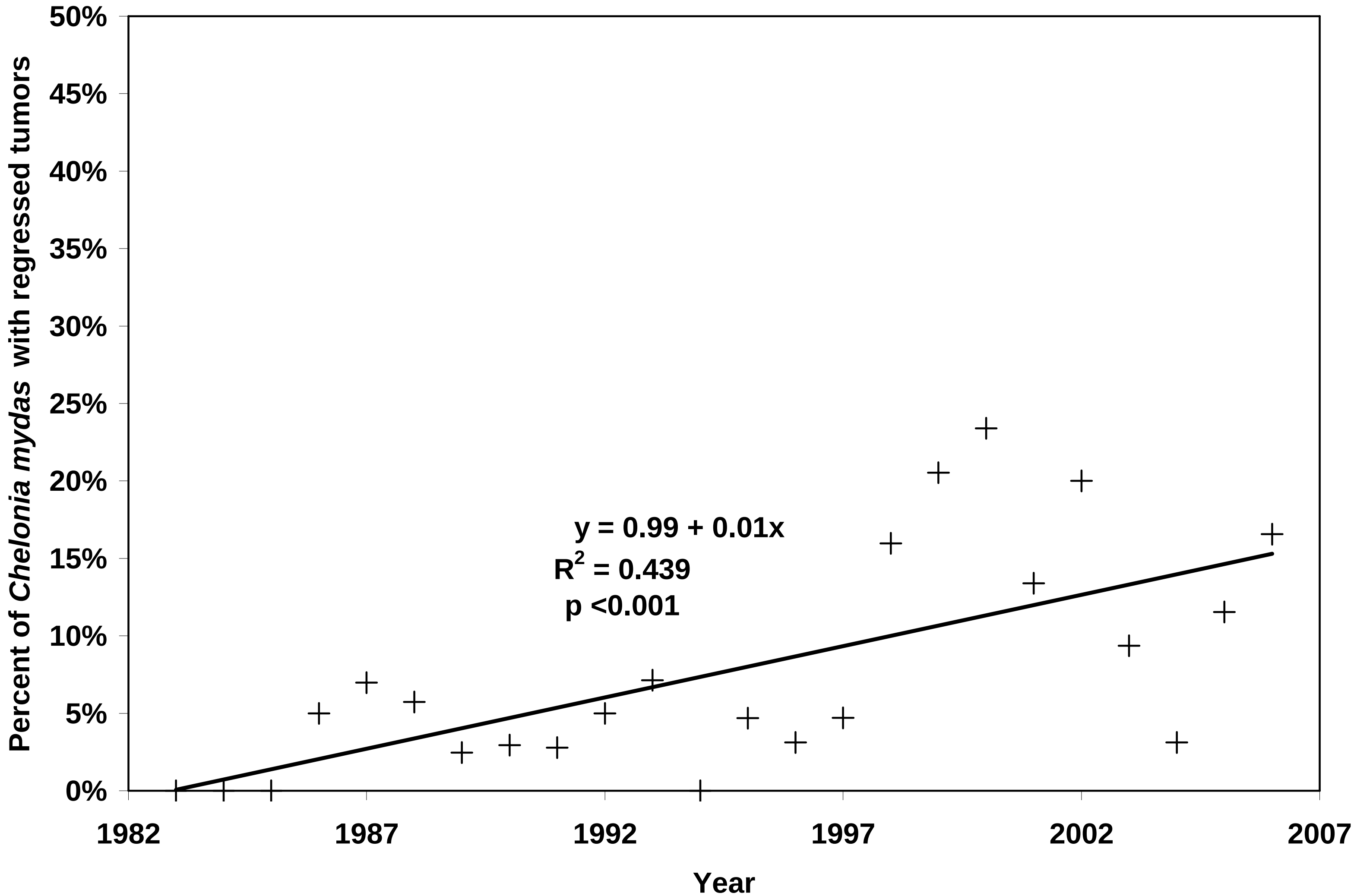

Figure 7. Percentage of Chelonia mydas captured within Indian River Lagoon that had evidence of regressed tumors.

Condition at first capture → / Initial condition ↓	FP Category 0	FP Category 1	FP Category 2	FP Category 3
FP Category 0	70.5% (31)	15.9% (7)	6.8% (3)	6.8% (3)
FP Category 1	50.0% (24)	43.8% (21)	4.2% (2)	2.1% (1)
FP Category 2	2.7% (4)	66.7% (10)	6.7% (1)	0.0% (0)
FP Category 3	20.0% (1)	60.0% (3)	0.0% (0)	20.0% (1)

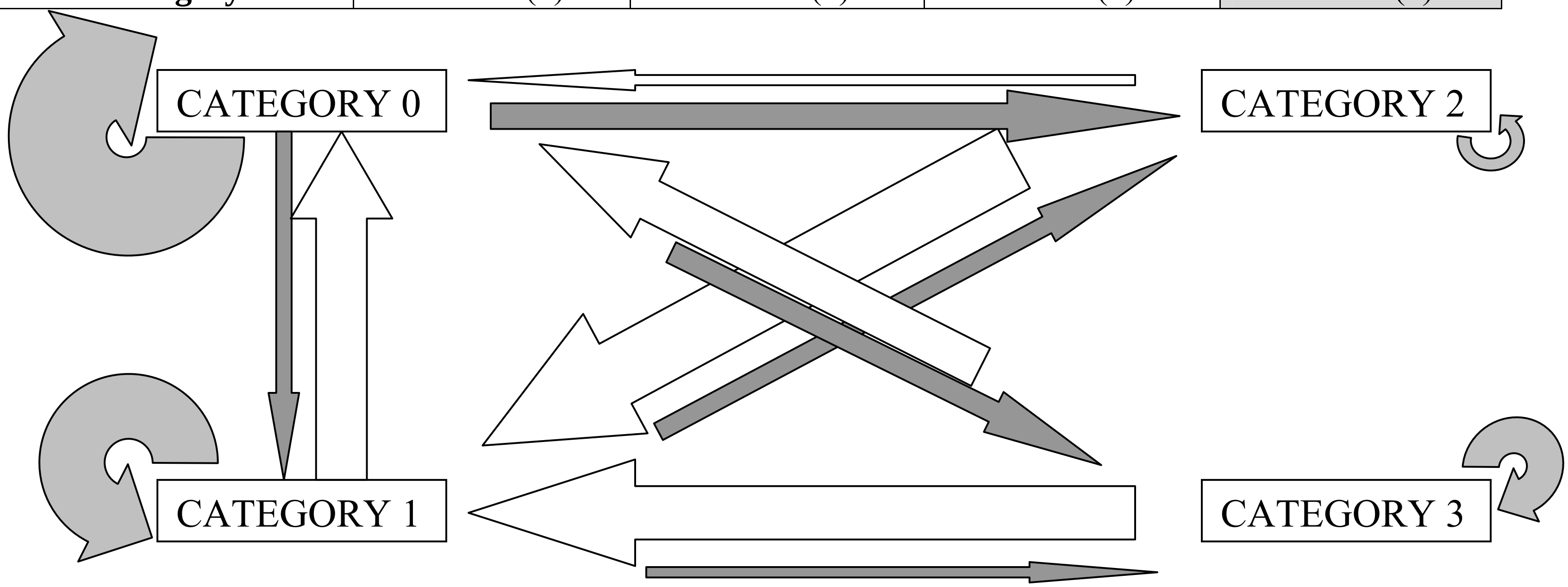

Figure 8. Matrix and flow chart of fibropapillomatosis changes in 112 recaptured turtles in IRL. Lightly shaded boxes represent no change in fibropapillomatosis status from initial to final capture, dark shaded boxes and arrows represent disease progression and white boxes and arrows represent disease regression. Arrow width correlates to the percentage of turtles.

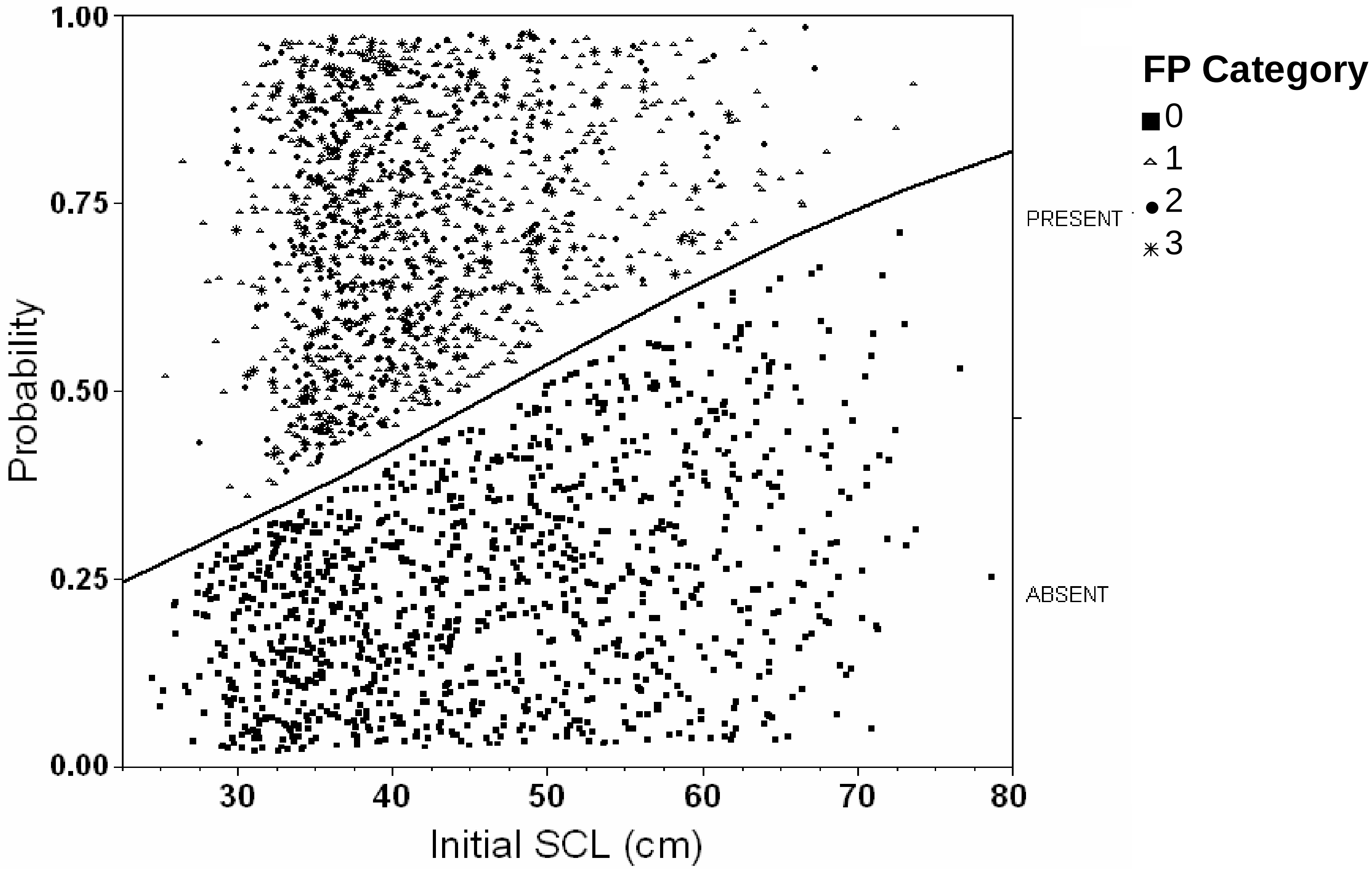

Figure 9. Cumulative logistic plot of the probability of a turtle captured in Indian River Lagoon being in Fibropapillomatosis Category 0, 1, 2 or 3 as a function of its initial straight-line carapace length (SCL). The logistic probability curve partitions the probability axis into absence of fibropapillomatosis in the lower right and present in the upper left. The probability of a captured turtle without fibropapillomatosis (absent) of a given initial SCL is given by the height of the probability curve.

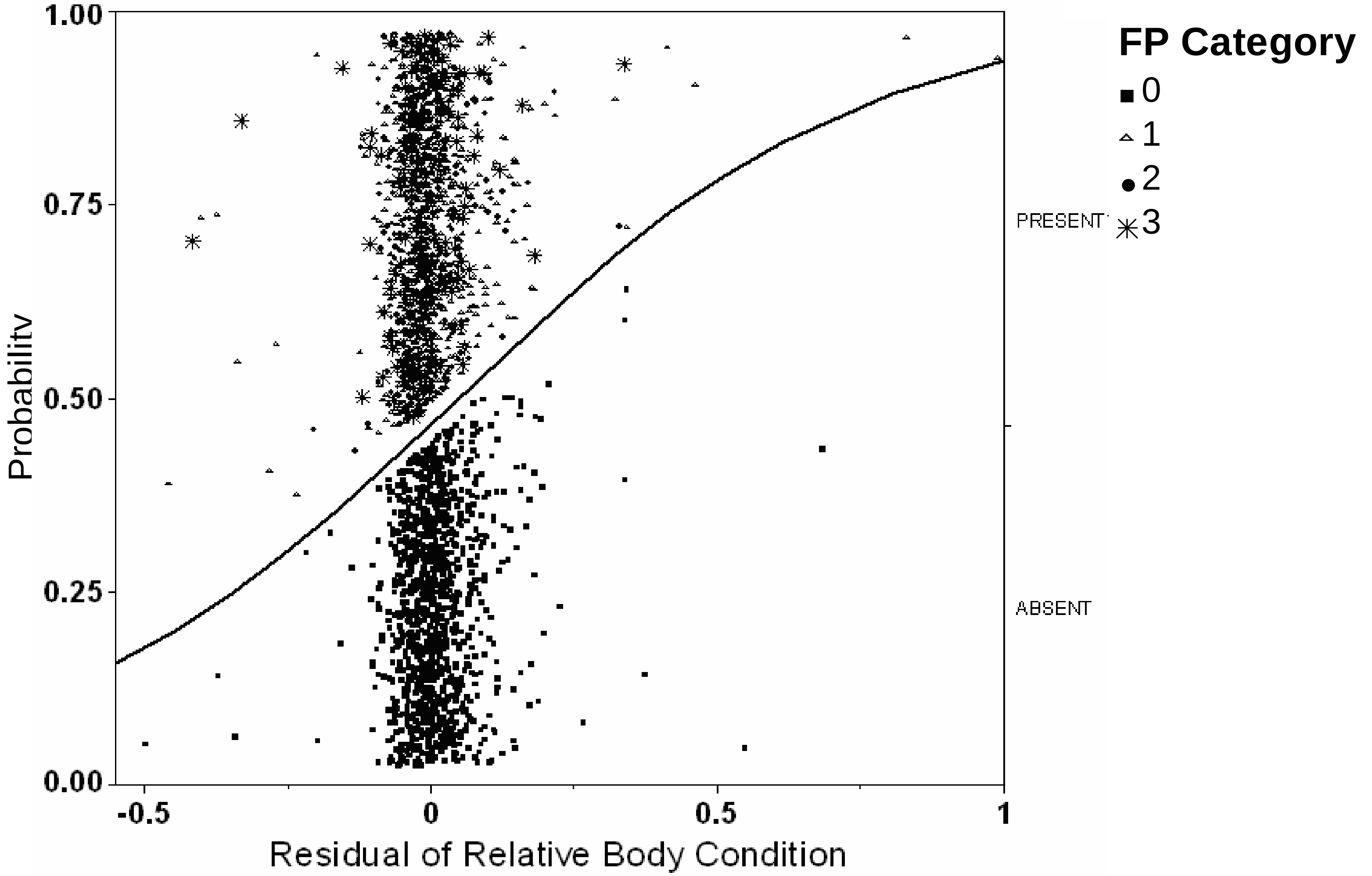

Figure 10. Cumulative logistic plot of the probability of a turtle captured in Indian River Lagoon being in Fibropapillomatosis Category 0, 1, 2 or 3 as a function of its relative body condition calculated from the residuals of log straight-line carapace length versus log body mass. The logistic probability curve partitions the probability axis into absence of fibropapillomatosis in the lower right and present in the upper left. The probability of a captured turtle without fibropapillomatosis (absent) of a given relative body condition is given by the height of the probability curve.

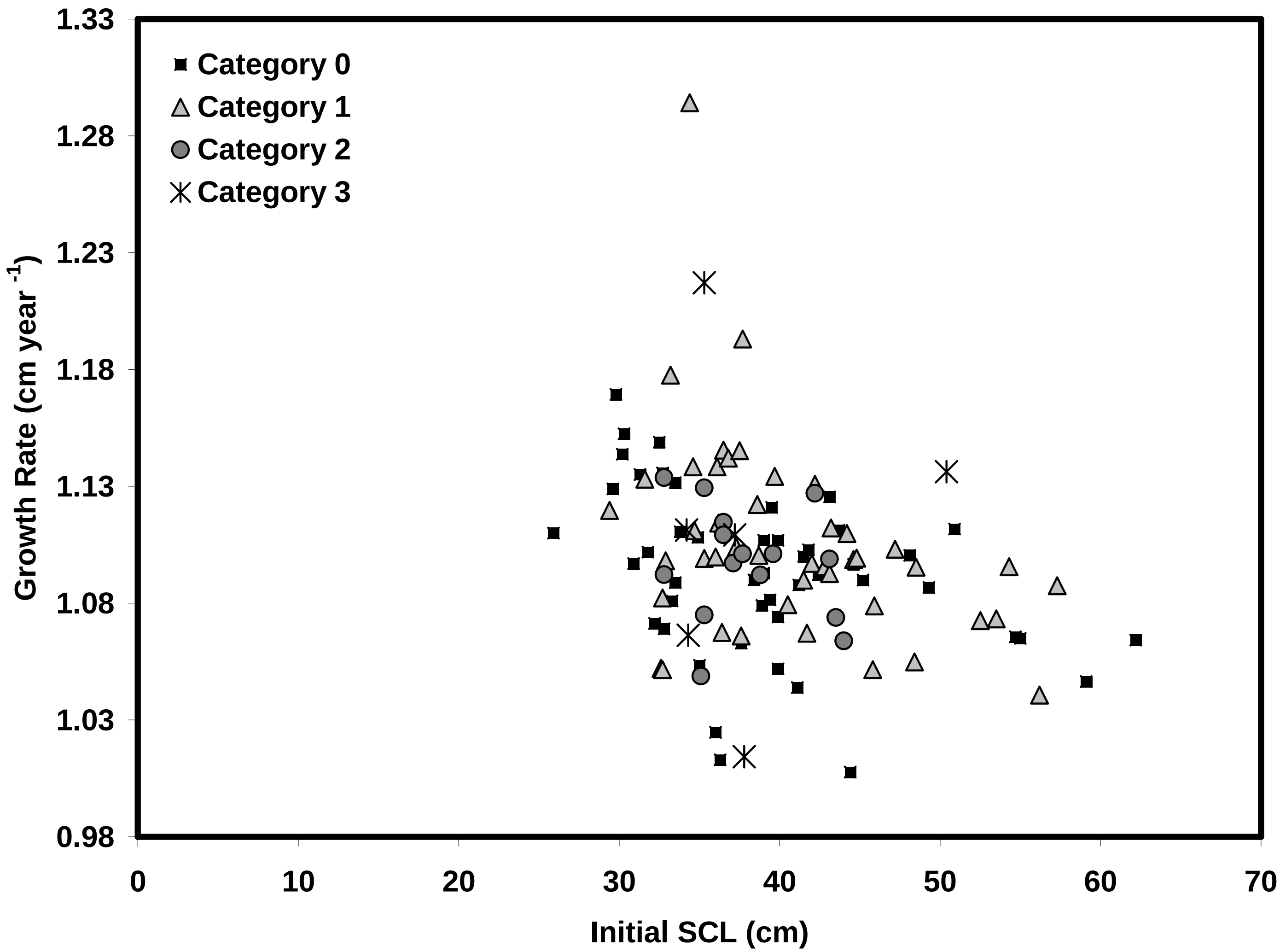

Figure 11. Geometric mean growth rates (cm year^{-1}) of *Chelonia mydas* in Indian River Lagoon as a function of initial straight-line carapace length (SCL) per fibropapillomatosis category.

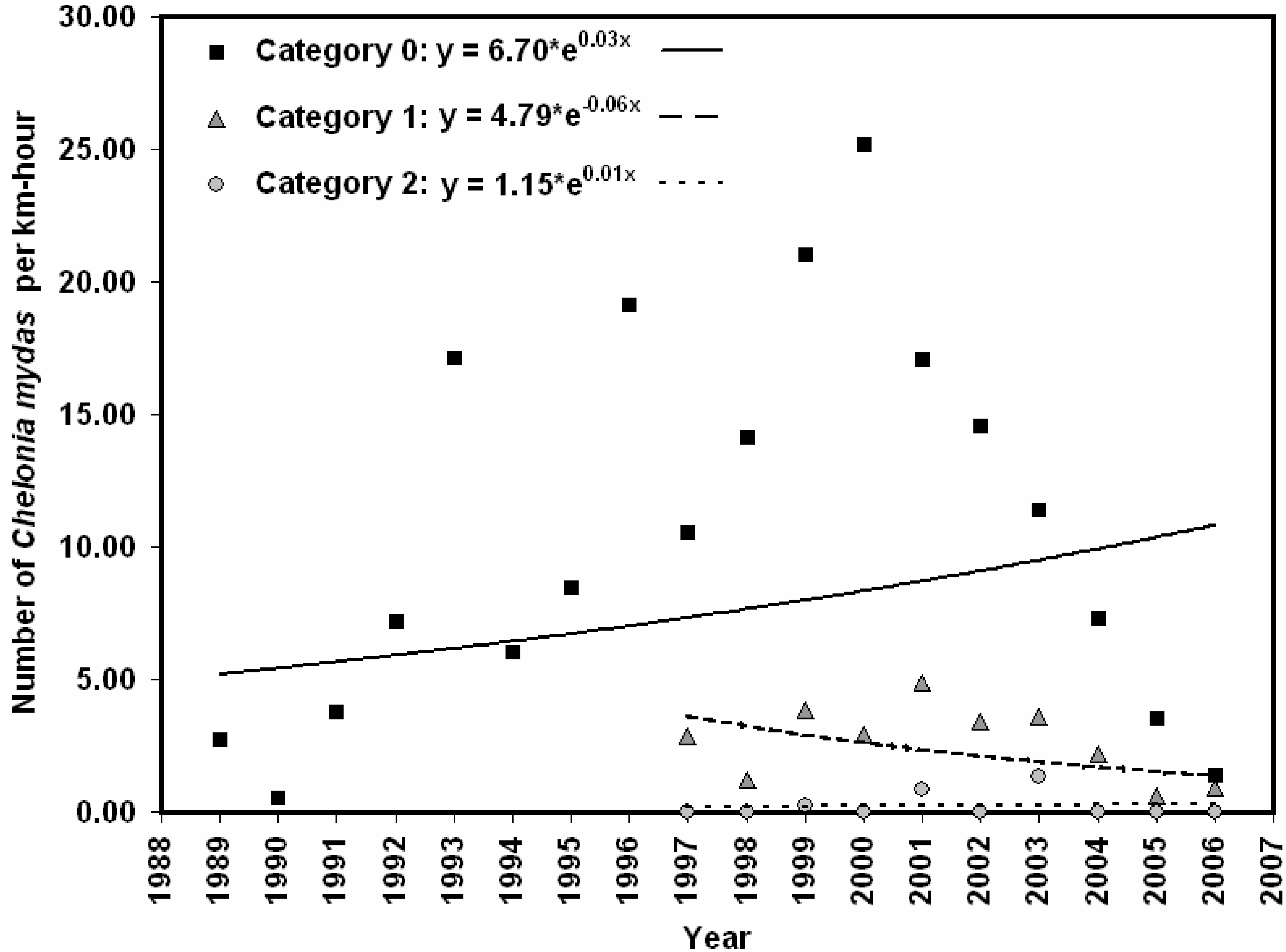

Figure 12. Number of *Chelonia mydas* in each fibropapillomatosis category captured per km-hour within Sabellariid Worm Reef during the 17-year study.

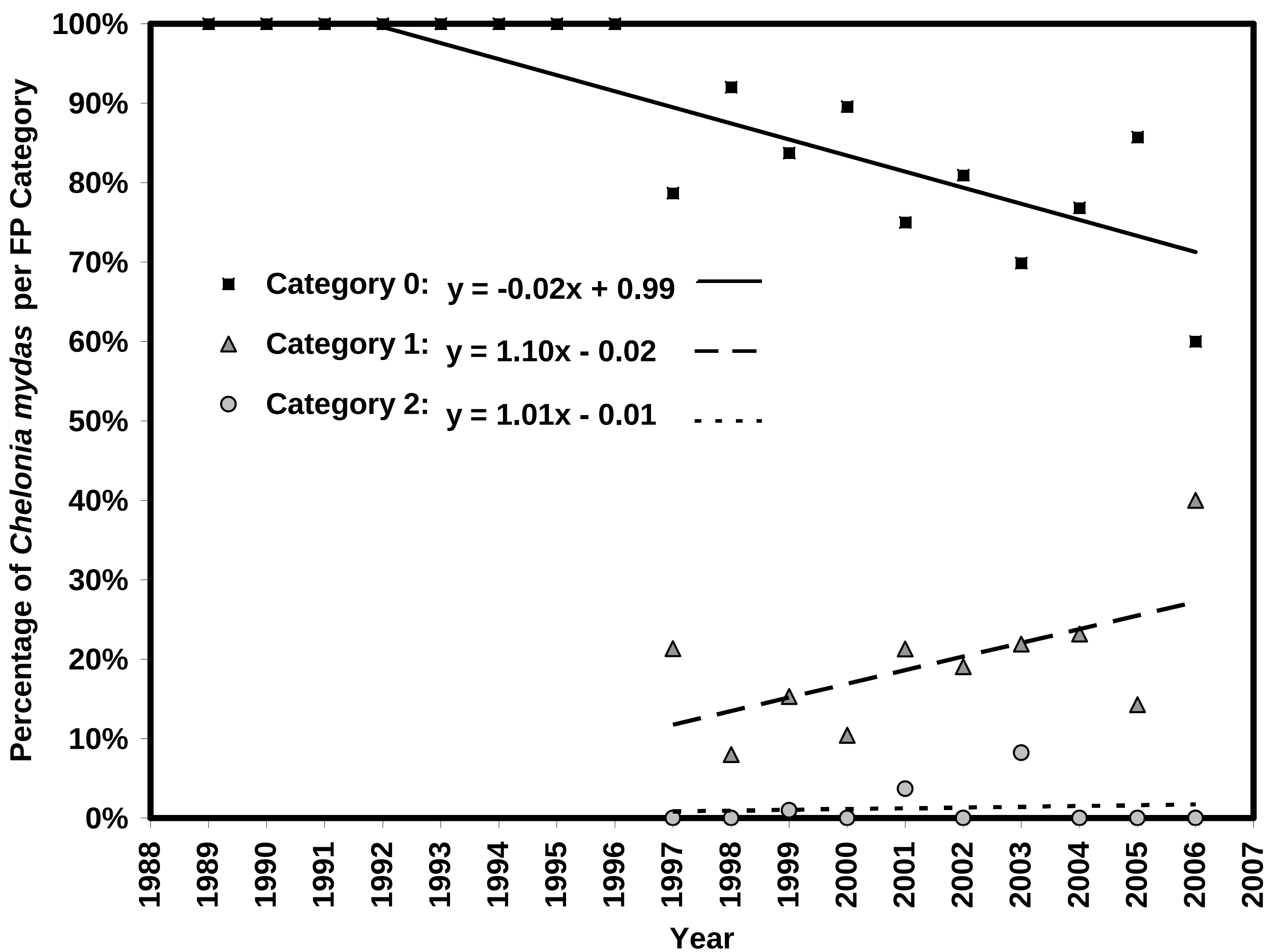

Figure 13. Percentage of *Chelonia mydas* in each fibropapillomatosis category captured within Sabellariid Worm Reef during the 17-year study.

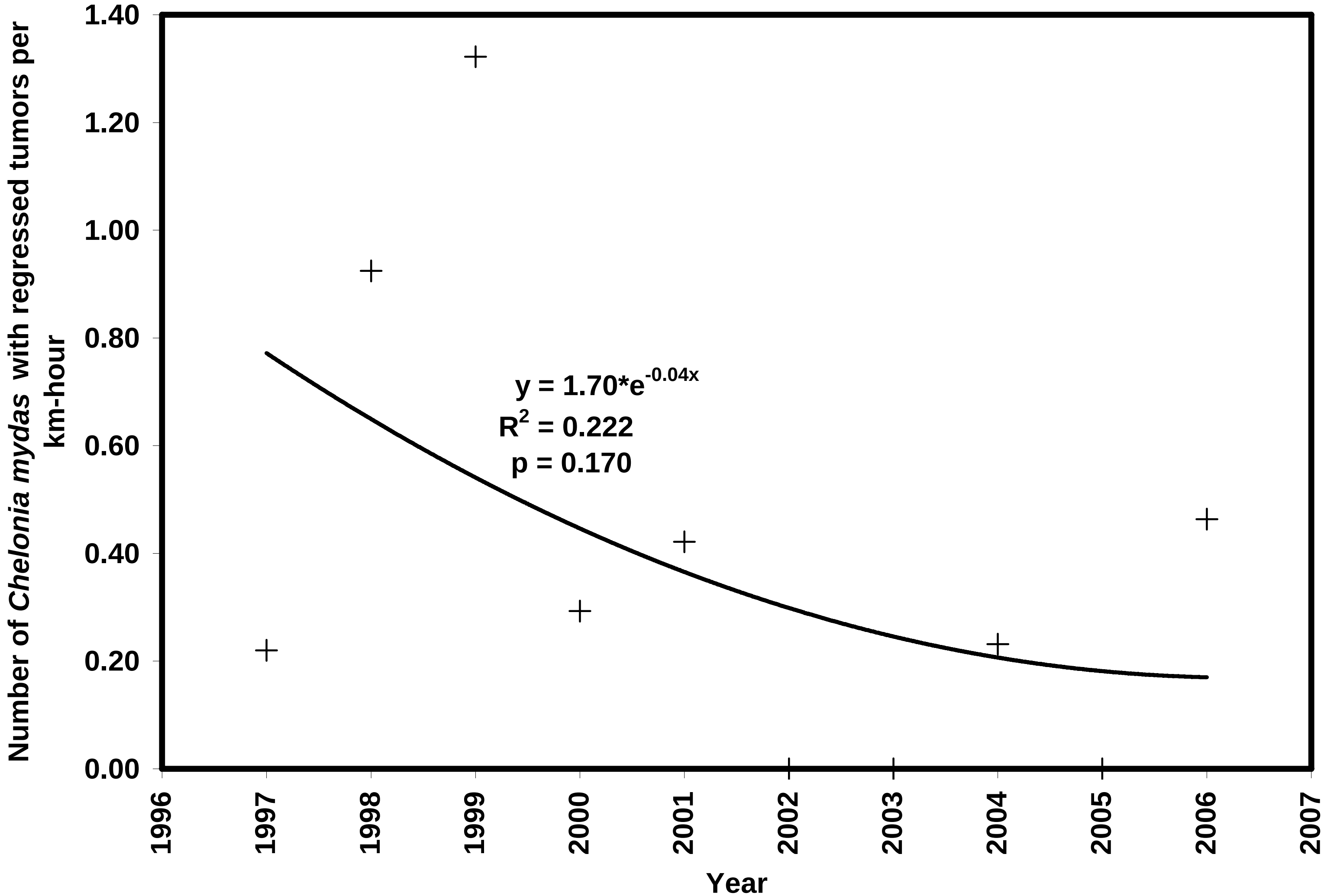

Figure 14. Number of *Chelonia mydas* with evidence of regressed tumors captured per km-hour within Sabellariid Worm Reef during the 8 years when fibropapillomatosis was found there.

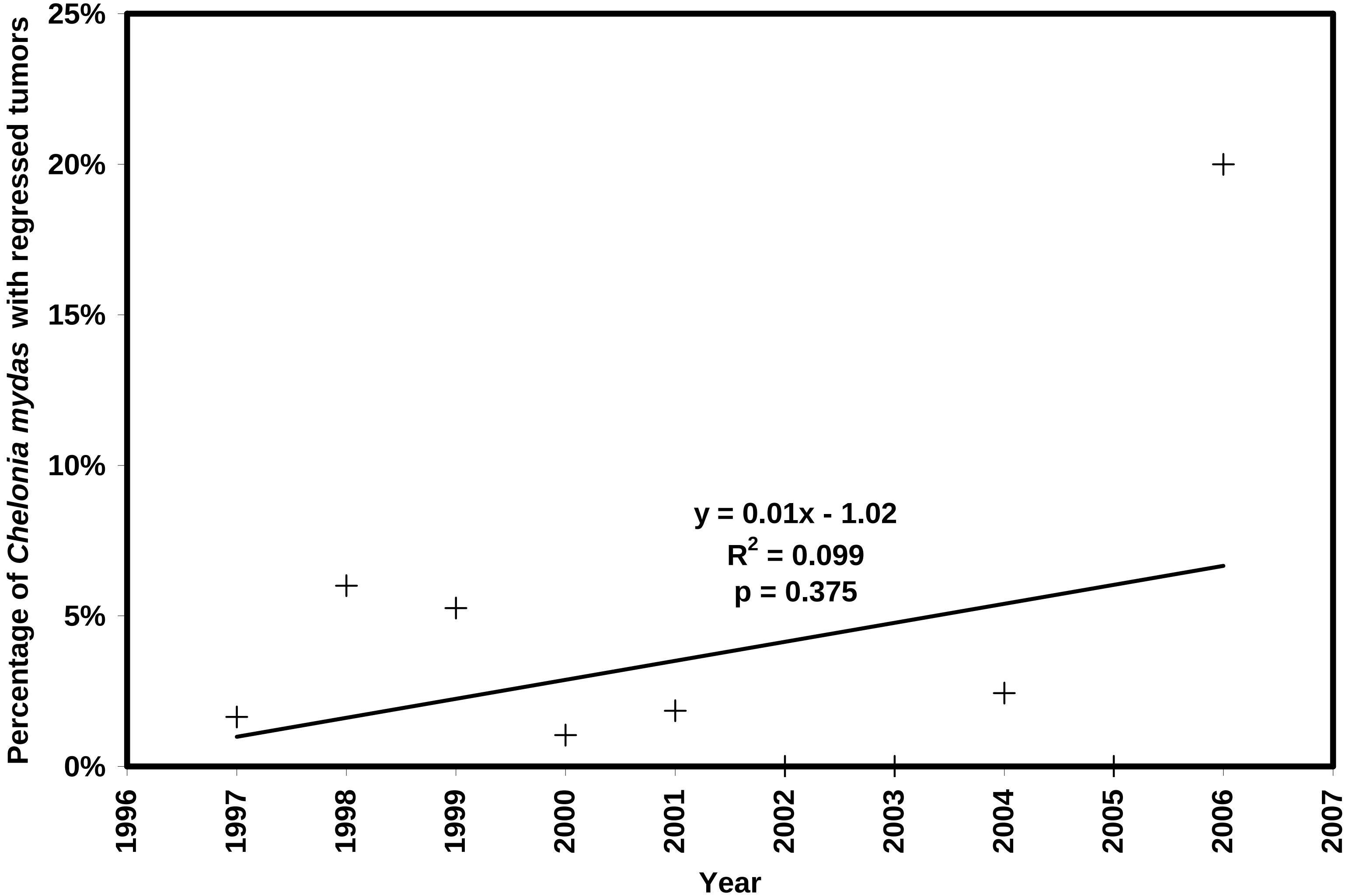

Figure 15. Percentage of *Chelonia mydas* with evidence of regressed tumors captured within Sabellariid Worm Reef during the 8 years when fibropapillomatosis was found there.

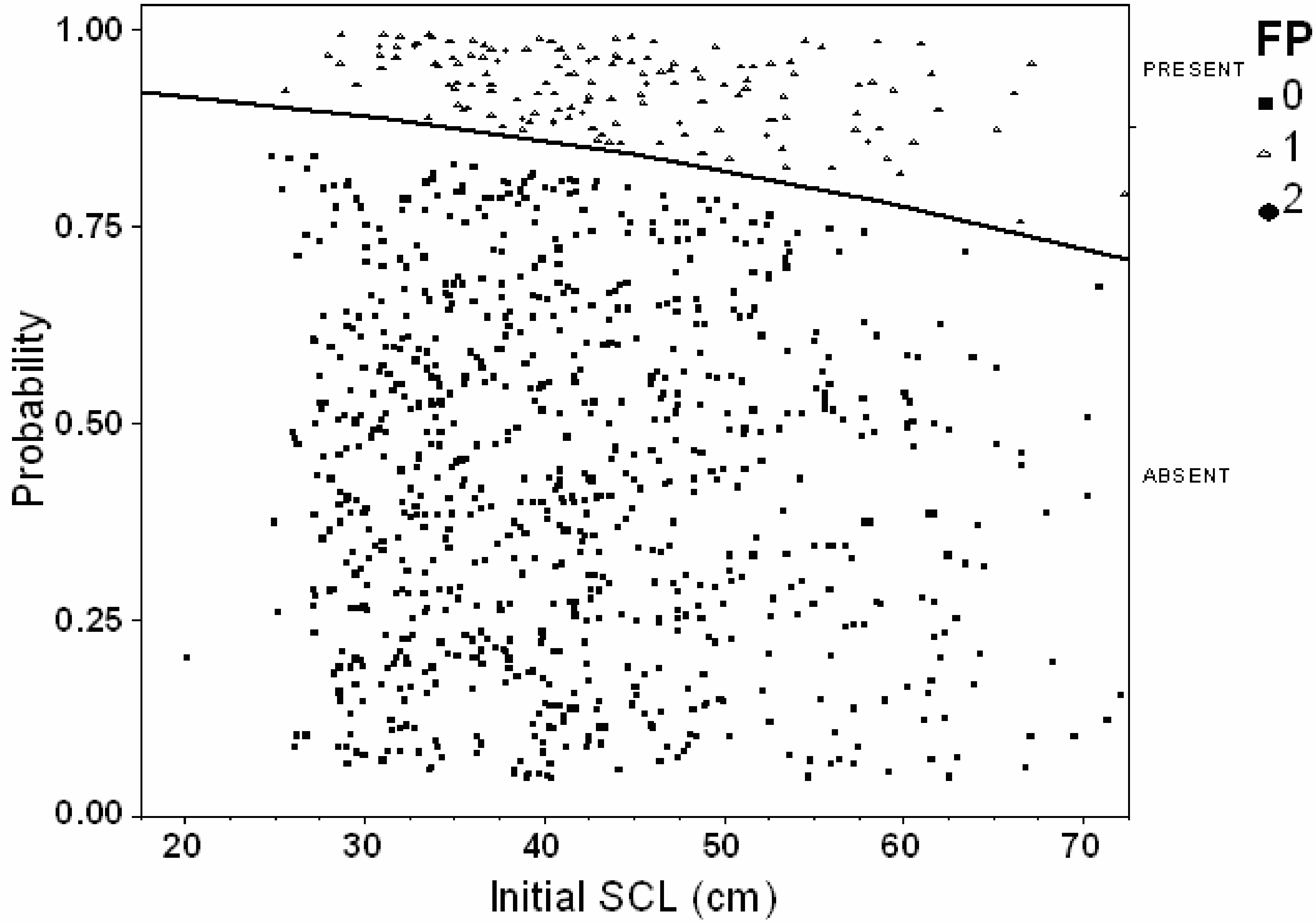

Figure 16. Cumulative logistic plot of the probability of a turtle captured in Sabellariid Worm Reef being in Fibropapillomatosis Category 0, 1 or 2 as a function of its initial straight-line carapace length (SCL). The logistic probability curve partitions the probability axis into absence of fibropapillomatosis in the lower right and present in the upper left. The probability of a captured turtle without fibropapillomatosis (absent) of a given initial SCL is given by the height of the probability curve.

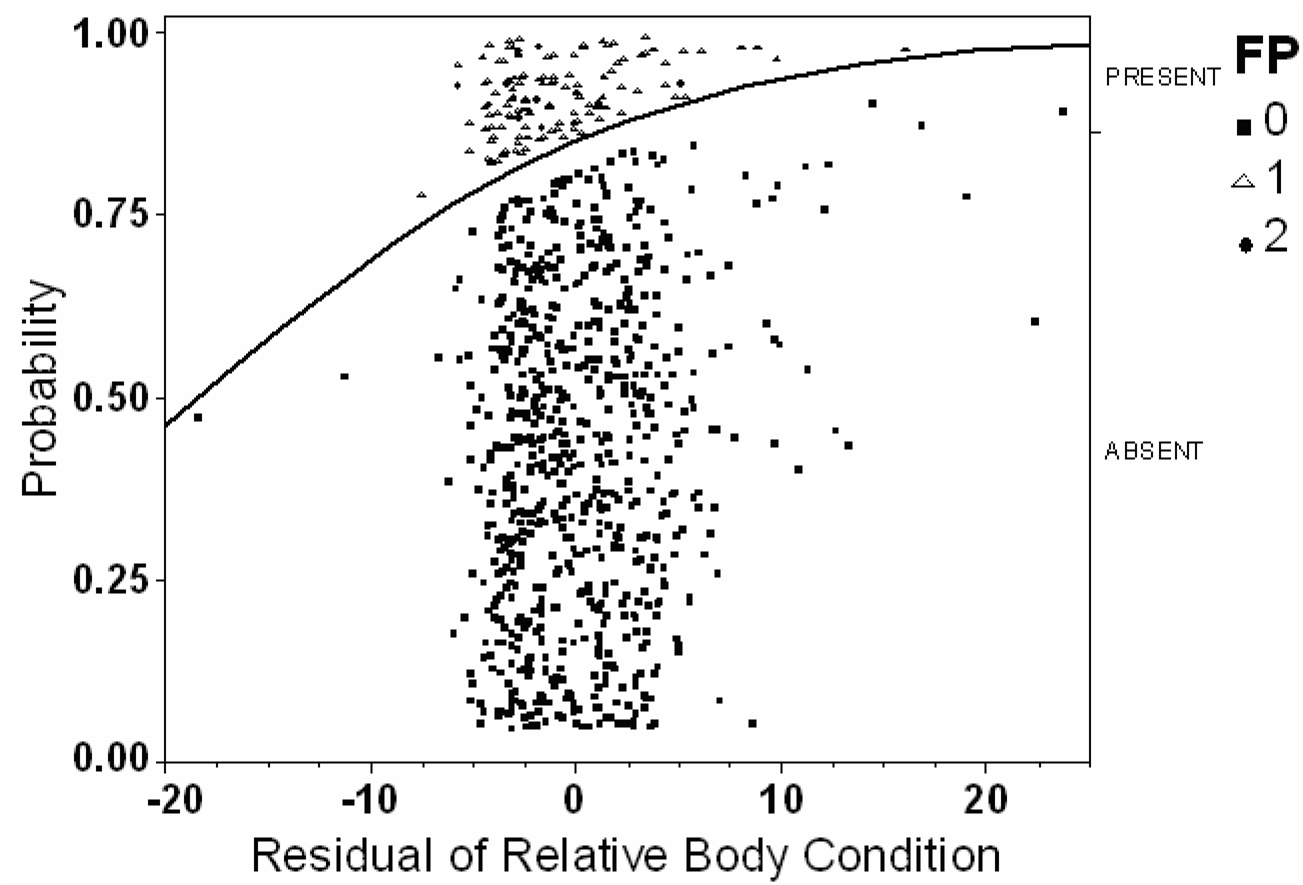

Figure 17. Cumulative logistic plot of the probability of a turtle captured in Sabellariid Worm Reef being in Fibropapillomatosis Category 0, 1or 2 as a function of its relative body condition calculated from the residuals of log straight-line carapace length versus log body mass. The logistic probability curve partitions the probability axis into absence of fibropapillomatosis in the lower right and present in the upper left. The probability of a captured turtle without fibropapillomatosis (absent) of a given relative body condition is given by the height of the probability curve.

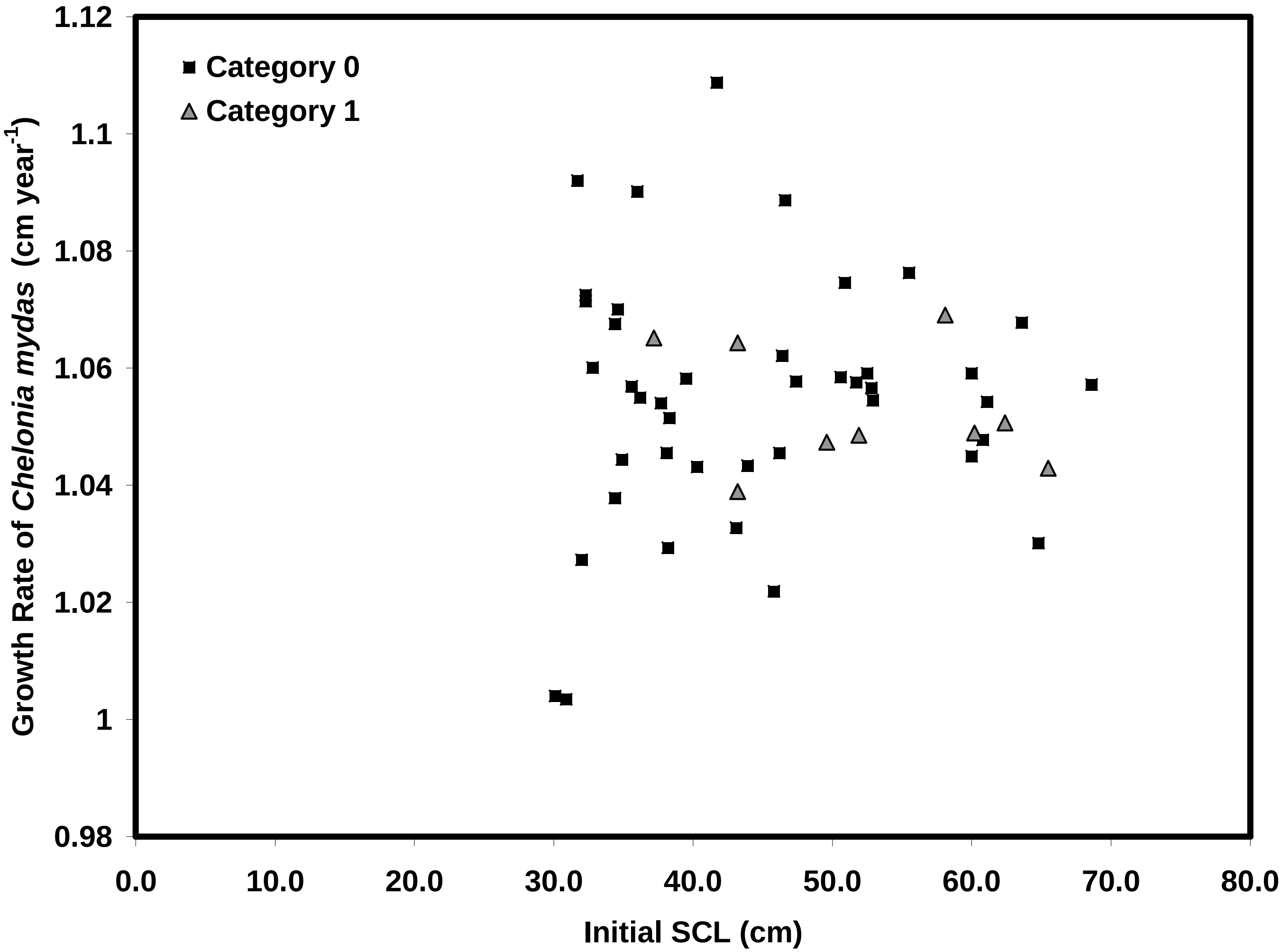

Figure 18. Geometric mean growth rates (cm year^{-1}) of *Chelonia mydas* in Sabellariid Worm Reef as a function of initial straight-line carapace length (SCL) per fibropapillomatosis category.

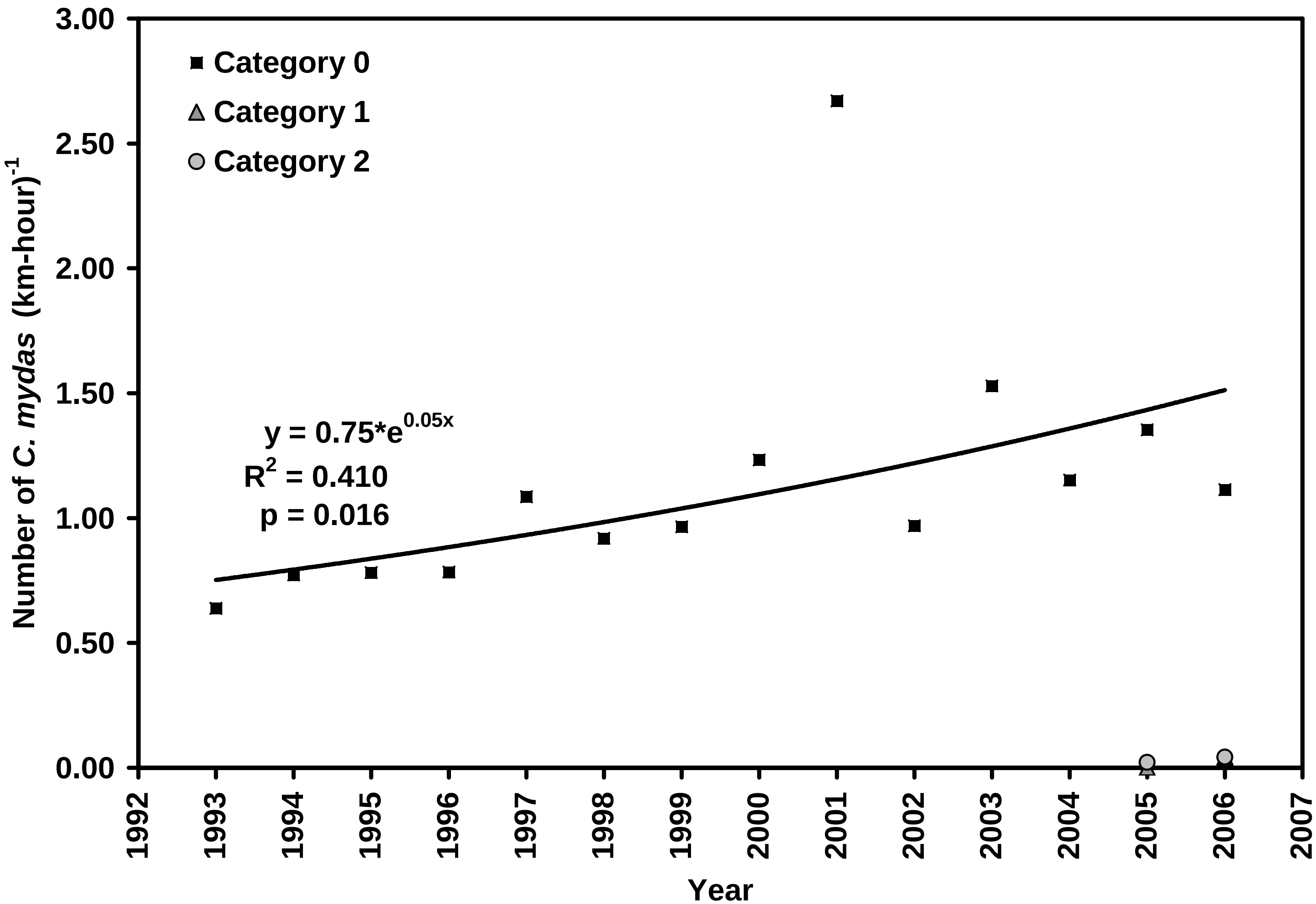

Figure 19. Number of *Chelonia mydas* per fibropapillomatosis category captured per km-hour within Trident Submarine Basin per over the 13-year study.

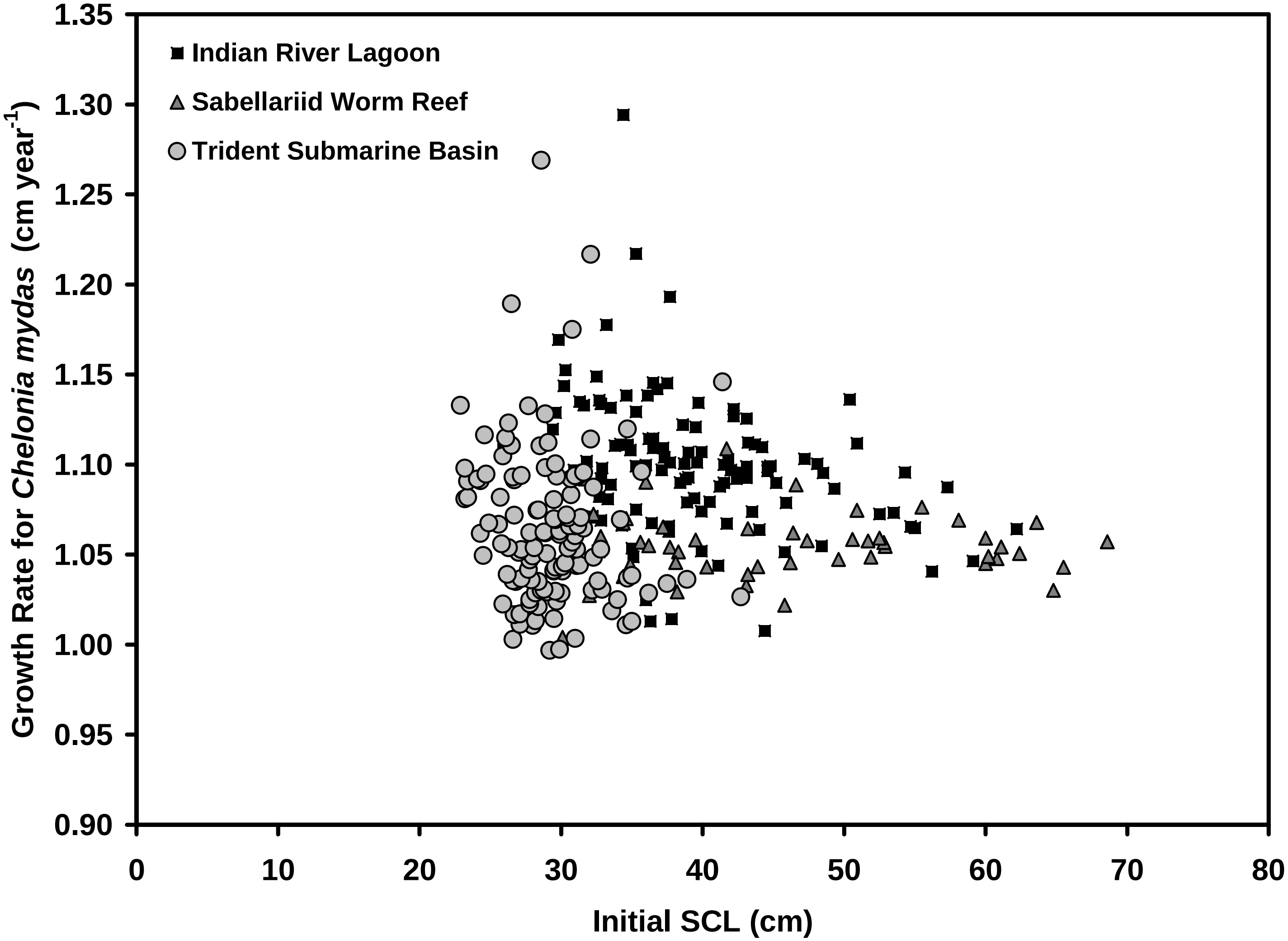

Figure 20. Geometric mean growth rates (cm year^{-1}) of *Chelonia mydas* as a function of initial SCL (cm) per site.

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