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Long-term decline of the western Pacific leatherback, *Dermochelys coriacea*: a globally important sea turtle population

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Abstract. The leatherbacks nesting at Bird's Head Peninsula, Papua Barat, Indonesia, account for 75% of the total leatherback nesting in the western Pacific and represent the last sizeable nesting population in the entire Pacific. Sporadic nest counts at Jamursba Medi Beach at Bird's Head have indicated a declining trend from the 1980s through 2004, although a relatively high amount of nesting has recently been documented at Wermon Beach, located 30 km east of Jamursba Medi. We used expanded year-round nesting surveys from 2005 to 2011 at these two primary nesting beaches to obtain more robust estimates of the nesting population size and to evaluate long-term nesting trends. We found a 29% decline in nesting at Jamursba Medi and a 52% decline at Wermon from 2005 through 2011. We found that the estimated annual number of nests at Jamursba Medi has declined 78.3% over the past 27 years (5.5% annual rate of decline) from 14,522 in 1984 to 1,596 in 2011. Nesting at Wermon has been monitored since 2002 and has declined 62.8% (11.6% annual rate of decline) from 2,994 nests in 2002 to 1,096 in 2011. Collectively, our findings indicate a continual and significant long term nesting decline of 5.9% per year at these primary western Pacific beaches since 1984. Mark-recapture with PIT tags, initiated in 2003, resulted in the tagging of 1,371 individual nesting females as of March 2012. Observed clutch frequencies ranged from 3-10 per season with a mean of 5.5 ± 1.6 and, based on nest counts, provide an estimate of approximately 489 females nesting in 2011. The persistent and long term decline we report for the Bird's Head leatherback population follows other dramatic declines and extinctions of leatherback populations throughout the Pacific over the last 30 years. These findings highlight the urgent need for continued and enhanced conservation and management efforts to prevent the collapse of what might be the last remaining stronghold for leatherbacks in the Pacific.

Key words: Bird's Head Peninsula, Papua Barat, Indonesia; conservation; decline; *Dermochelys coriacea;* leatherback sea turtle; nesting trend; western Pacific.

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Introduction

Although widely distributed in the Atlantic, Pacific and Indian Oceans and spanning from ~71° N (Carriol and Vader 2002) to 47° S (Eggleston 1971), leatherbacks (*Dermochelys coriacea*) are currently listed as Critically Endangered globally (IUCN 2012). In comparison to the Atlantic, where several nesting populations have been increasing in recent years (Dutton et al. 2005, Thomé et al. 2007, Turtle Expert Working Group 2007, Stewart et al. 2011), the status of leatherback populations in other oceans is of greater concern. The South African nesting population in the Indian Ocean appears to be depleted after more than 30 years of monitoring (Hughes 1996, Nel 2006) and the status of the other important populations in Sri Lanka and the Andaman and Nicobar Islands is unclear (Andrews et al. 2006, Hamann et al. 2006). In the Pacific, leatherbacks appear to have declined by over 95% since 1980 (Spotila et al. 2000) primarily because of excessive harvest of eggs and females, incidental by-catch in fisheries, and coastal development on nesting beaches (Chan and Liew 1996, Sarti et al. 1996, Spotila et al. 1996, Spotila et al. 2000, Lewison et al. 2004, Kaplan 2005, Bellagio 2007, Sarti et al. 2007, Liew 2011).

In the eastern Pacific, the leatherback nesting population on the coast of Mexico was historically robust and one of the largest nesting populations globally (Marquez et al. 1981, Sarti et al. 1996). However, nesting in Mexico continuously declined over several decades resulting in fewer than 1,000 nesting females per season by the mid 1990s (Sarti et al. 1996, Sarti et al. 2007) and decreasing to an estimated range of 27 to 346 females nesting annually (FNA) between 2002 and 2004 on the four major index beaches in Mexico (Sarti et al. 2007). On the Pacific coast of Costa Rica, nesting has declined from about 1,367 nesting females per season in 1988–1989 to approximately 261 females in 1999–2000 (Reina et al. 2002), and the number of nesting females per season has not significantly increased in recent years (Santidrián et al. 2007). In the western Pacific, Terengganu, Malaysia, represented a major nesting beach with approximately 10,000 nests per year reported in 1956 (Siow and Moll 1982, Chua 1988, Chan and Liew 1996). Unfortunately, a catastrophic decline in the 1970s and 1980s resulted in the collapse and apparent loss of this nesting population (Chan and Liew 1996, Bellagio 2007, Liew 2011).

The western Pacific currently has primary leatherback nesting sites in the Solomon Islands, Papua New Guinea (PNG), and Papua Barat, Indonesia, with nesting to a lesser extent in Vanuatu, all of which are part of a single regional genetic stock (Dutton et al. 2007). Within this regional stock, the north coast of Bird's Head (Vogelkop) peninsula in Papua Barat (formerly the western portion of Irian Jaya), Indonesia, hosts the largest remaining nesting population, accounting for 75% of the total leatherback nesting in the western Pacific (Dutton et al. 2007). Leatherback nesting along the north coast of Bird's Head was first described by Salm (1982), who noted during his initial aerial survey that it was impossible to directly count every nest because of the high density. Nevertheless, it was estimated that there were about 4,000 leatherback and green turtle nests on five main beaches located along the northern coast of Bird's Head (Salm 1982). In recent years, only low levels of scattered nesting have occurred on four of these main beaches, whereas the Jamursba Medi area has continued to support a relatively high level of nesting. Subsequent surveys in 1984 and 1985 determined that Jamursba Medi, which consists of three beaches (Fig. 1), was the major nesting area for leatherbacks in the region with as high as 13,360 nests estimated for 1984 (Bhaskar 1987).

A decline in nesting at Jamursba Medi was initially apparent from nest count surveys between 1981 to 2004 during the main months of the nesting season and from anecdotal reports from villagers (Hitipeuw et al. 2007). Another major nesting beach on Bird's Head, Wermon, is located approximately 30 km east of Jamursba Medi (Bhaskar 1987, Hitipeuw et al. 2007). Jamursba Medi and Wermon beaches (Fig. 1) represent the majority of nesting for leatherbacks in this region (Benson et al. 2007*a*, Dutton et al. 2007, Hitipeuw et al. 2007) and now the largest nesting aggregation in the Pacific (Dutton et al. 2007). Given the nesting decline at Jamursba Medi recorded between 1981 and 2004 and the importance of this population both in the Pacific and globally (Hitipeuw et al. 2007), a more comprehensive program was initiated in 2005 to

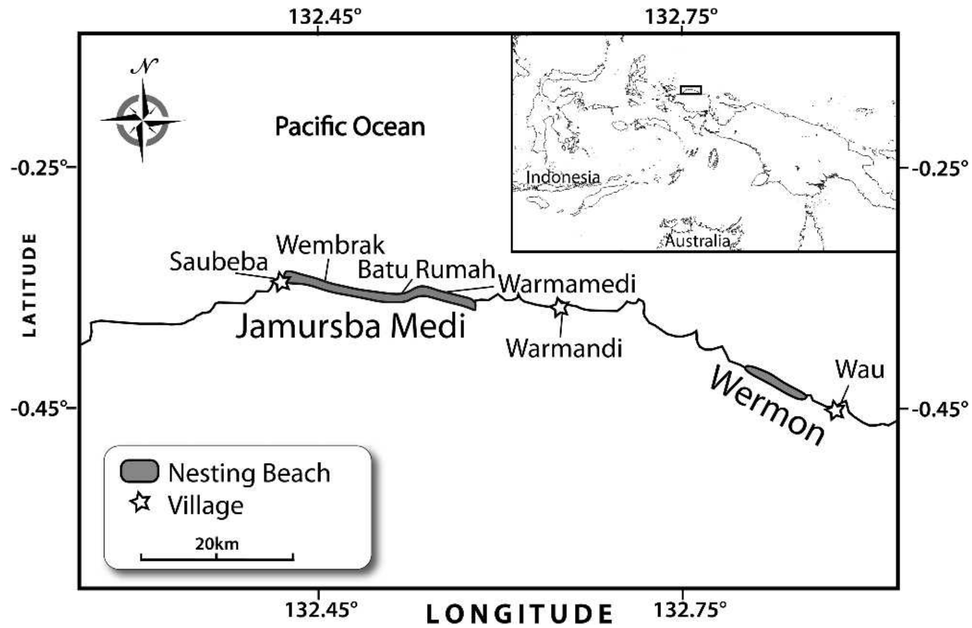

Fig. 1. The north coast of Bird's Head peninsula, Papua Barat, Indonesia, showing leatherback nesting beaches at Jamursba Medi and Wermon.

accurately evaluate and monitor leatherback nesting activities throughout the nesting season at Jamursba Medi and Wermon and to implement appropriate management strategies. The main objective of our study was to evaluate the trends in annual number of nests from 1981 to 2011 in Jamursba Medi and from 2002 to 2011 in Wermon. We also evaluate the spatial and temporal distribution of nests and provide an estimate of the number of females nesting.

The current study provides vital information regarding the population status of the one of the most important leatherback nesting aggregations in the Pacific and allows us to assess management priorities and protection measures. With the establishment of the new governmental regency of Tambrauw, which is in charge of implementing and enforcing the conservation policies in Papua Barat Province, the development of a science-based management plan is a prerequisite for ensuring the implementation of effective policies.

Methods

Study site

Jamursba Medi (0°20′–0°22′ S and 132°25′–132°39′ E) is the principal nesting site for leatherbacks on Bird's Head and is comprised of three beaches (from west to east: Wembrak, Batu Rumah and Warmamedi, respectively, Fig. 1) that together span 17.9 km of coastline. The second nesting site is a 6-km beach located at Wermon (0°41′–0°43′ S and 132°80′–132°86′ E) (Hitipeuw et al. 2007). Jamursba Medi and Wermon are separated by 30 km of terrain composed of cliffs, rocky outcroppings, perennial rivers, and/or estuaries. These beaches are subject to seasonal patterns of erosion and accretion. Changes in the currents brought on by the monsoons that begin in September can cause major erosion at Jamursba Medi that often removes the entire beach until accretion begins again in March (Hitipeuw et al. 2007). This cycle of erosion is not as extreme in Wermon where the beach is generally more suitable for leatherback nesting in the boreal and austral summer (Hitipeuw et al. 2007).

Estimating historical annual nesting abundance and trend

In the current study (2005 to 2011), beaches were surveyed year round on foot by local personnel from the village communities neighboring Jamursba Medi and Wermon. The number of nesting emergences (as determined by characteristic tracks and accompanying nest pits in the sand as evidence of successful nesting) was recorded on a daily basis throughout the year. The proportion of annual nesting activity occurring in each month of the year at each of the beaches was calculated by determining the average number of nests for each month over a seven year period (2004–2011) at Wermon and over a six year period (2005–2011) at Jamursba Medi, and then dividing that average by the average total number of nests per year over the seven or six year period, respectively. These monthly proportions were used to estimate an adjusted total number of nests for each year from partial nest counts between 1984–2004 at Jamursba Medi using the below equation (Hitipeuw et al. 2007):

$$\mathrm{Ni}/\mathrm{Pi} = N$$

where N is the estimated number of nests laid for an entire year; Ni is the observed number of nests during a given survey period; and Pi is the proportion of annual nesting period surveyed. This approach facilitated a meaningful trend analysis for this multi-year time series. The resulting yearly estimates were combined with data from the current study in order to generate a long-term nesting trend from 1984 to 2011. We did not include the data from Salm (1982) in the trend analysis because of the level of uncertainty in nest counts from these earlier surveys.

Estimated and observed annual nest numbers at Jamursba Medi (for 27 years) and Wermon (for 9 years) were from April 1 of each given year to March 31 of the next year (e.g., the 2010 nesting season refers to April 2010 through March 2011). This yearly interval was chosen because it corresponds biologically to the nesting seasons at both beaches. These numbers were log-transformed (natural log) and the nesting trend evaluated between 1984 and 2011 at Jamursba Medi using a Generalized Liner Model (GLM). A similar analysis was also performed on a subset of the data from 1993 to 2011, during which monitoring was enhanced at Jamursba Medi. Finally, the more comprehensive year-round survey data from Jamursba Medi (2005–2011) and Wermon (2004–2011) were analyzed separately. The nesting trends from both beaches were compared by including an interaction effect in the GLM. Additionally, if there was no significant different between the trends, the GLM was re-run without the interaction term to test whether there was a significant difference in the mean number of nests between Jamursba Medi and Wermon. All analyses were done using the R software version 2.14.1 (R Development Core Team 2011).

Estimating clutch frequency and the numbers of females

Beginning in 2003, previously untagged females encountered during night beach patrols were tagged with a Passive Integrated Transponder (PIT) (AVID brand) injected into the right shoulder following standard procedures described in Dutton and McDonald (1994). In addition to morning nest count surveys by local villagers, starting in 2005 teams of students and biologists carried out night-time monitoring at the two beaches for the entire peak nesting season on Jamursba Medi from April to September and on Wermon from October to March. For tagging purposes, two team members patrolled the nesting beach from 20:00 to 05:00 hours in order to collect morphological data on nesting leatherbacks and to PIT-tag turtles. On these nights, saturation tagging was conducted, where every female encountered on night patrols is evaluated for tags and untagged females receive a PIT tag (Dutton et al. 2005).

The tagging effort was sporadic from 2003 to 2008 but intensified starting in 2009, when saturation tagging was conducted five nights per week throughout the nesting season and for seven nights a week during several dedicated 14-day periods at the beginning, middle, and end of the main nesting season. Since leatherbacks generally nest every 8–12 days, most nesting females should be encountered once during a 2-week period (Tucker and Frazer 1991, Reina et al. 2002, Dutton et al. 2005, Sarti et al. 2007). This strategy was used to optimize efforts to tag the majority of females present during the main nesting seasons at both Jamursba Medi (May–September, i.e., the boreal summer) and Wermon (October–March, i.e., the austral summer). Saturation PIT tagging was also carried out at Wermon (June–August) starting in 2009 using the same methodology during the boreal summer, but not during the austral summer at Jamursba Medi (October–March) because of limited personnel and difficult access to the beach during the monsoon period.

The PIT-tag data allowed for a preliminary estimation of average clutch interval (CI) and estimated clutch frequency (ECF), which was then used to estimate the number of females nesting. ECF is the average number of nests per season per female and CI is the number of days between consecutive ovipositions (clutches of eggs laid) per female. We calculated ECF per female from the PIT-tag data from 2003 to 2011 with the following assumptions: (1) the number of predicted nests per season was based on the initial and all subsequent sightings of an individual turtle, (2) if the interval between subsequent sightings of an individual was distinctly longer than the typical 9–12 day internesting period (e.g., 18 days or more) observed for leatherbacks, a nesting(s) was assigned between the two consecutive sightings (Rivalan et al. 2006), (3) only successful ovipositions were considered, and (4) only females with a minimum of three documented ovipositions during a nesting season were used in the analysis.

The total number of FNA was estimated for Jamursba Medi and Wermon using two different estimates of ECF. Similar to the analysis of the nesting trend, the yearly interval used in the FNA predictions was from April 1 of one year to March 31 of the next year and was designated by the earlier year. We used the same method outlined in Hitipeuw et al. (2007) in which the total number of nests annually for a given beach is divided by the ECF reported for various nesting populations in the Atlantic and the eastern Pacific. These ECFs ranged from 4.4 nests per female (Sarti et al. 2000) to 5.8 nests per female (Hitipeuw et al. 2007). We also estimated the FNA at Jamursba Medi and Wermon using the ECF predicted in the current study from the PIT tag data collected from 2003 to 2011 (as described above). Additionally, we estimated the number of females nesting during the boreal (April–September) and the austral (October–March) summer seasons in the current study (2005–2011).

In addition to ECF and FNA estimates, the PIT tag data were also evaluated to determine the movement of nesting females between these two beaches within the same nesting season and between the boreal and austral summer nesting seasons.

Results

Long-term nesting trends

Leatherback nesting was observed year round at Jamursba Medi and Wermon, however, there was a unimodal distribution of nesting activity through the year at Jamursba Medi with a peak in June to July and a bimodal distribution at Wermon with peaks during December to February as well as the one also observed from June to July at Jamursba Medi (Fig. 2). The number of nests per month ranged from 22.4 ± 6.9 (mean ± SD) in January to 575.7 ± 75.8 in June at Jamursba Medi and from 58.9 ± 19.4 in September to 198.8 ± 26.6 in January at Wermon (Fig. 2). The annual number of nests observed at Jamursba Medi ranged from 2,626 (in 2005) to 1,596 (in 2011) with a yearly mean of 2,122 ± 409 nests over this seven-year period. The annual number of nest observed at Wermon ranged from 1,497 (in 2005) to 1,080 (in 2009) with a mean of 1,304 ± 167 nests per year (Table 1). On average, 59.9% of all nesting occurred at Jamursba Medi and the other 40.1% at Wermon.

Trend analysis for nest count estimates between 1984 and 2011 at Jamursba Medi indicates an overall significant decline of 78.3% over the 27-year period (GLM, $r^2 = 0.65$, $p < 0.0001$; Table 1, Fig. 3), ranging from 14,522 (in 1984) to 1,596 (in 2011) (Table 1). The results also indicate a 64.0% decline between 1993 and 2011 (GLM, $r^2 = 0.74$, $p < 0.001$) at Jamursba Medi based on monitoring data for this period. There was also a 62.8% decline at Wermon from 2,994 nests in 2002 to 1,096 in 2011 (GLM, $r^2 = 0.78$, $p < 0.01$; Table 1, Fig. 3). In comparison, during our current study (2005–2011), nesting declined 29.0% at Jamursba Medi (GLM; $r^2 = 0.92$, $p < 0.01$), and 52.2% at Wermon (GLM; $r^2 = 0.52$, $p < 0.01$). There was no significant difference between the annual rate of decline at Jamursba Medi and Wermon (ANOVA, $F = 3.49$, $p = 0.07$), but Wermon has significantly fewer nests (18% less) than Jamursba Medi (ANOVA, $F = 45.3$, $p < 0.001$). Collectively, the data from the previous and current studies (1984–2011) indicate an average rate of decline of 5.9% per year of

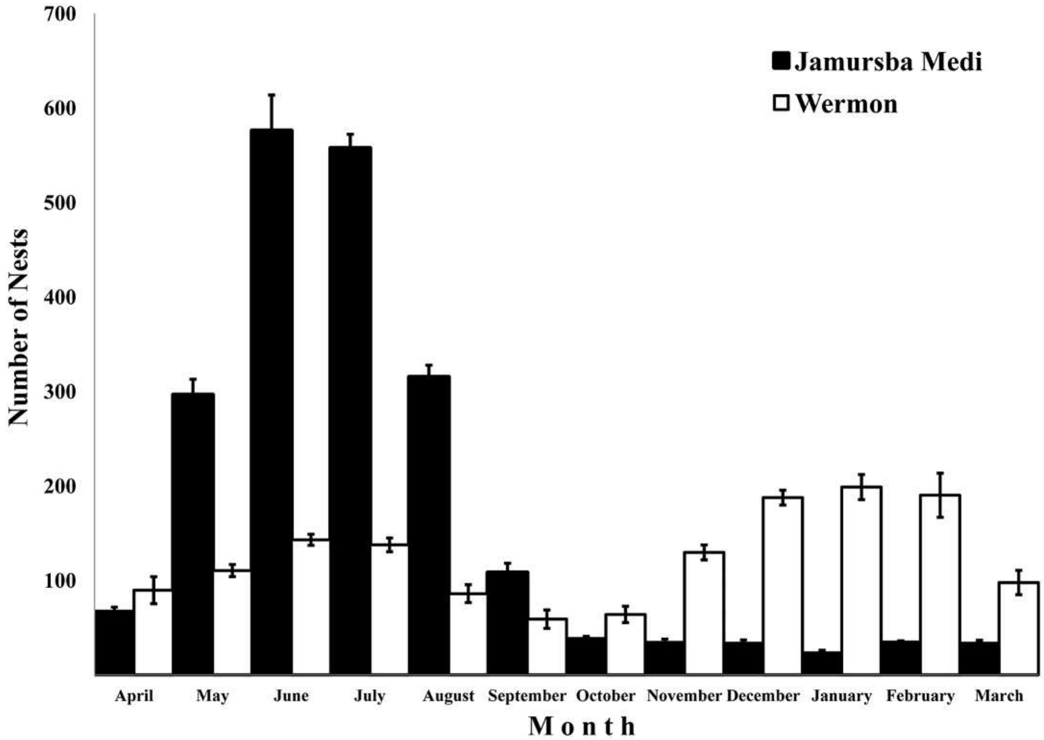

Fig. 2. Numbers of nests (mean ± SD) laid per month from 2005 to 2011 at Jamursba Medi and 2004 to 2011 at Wermon.

leatherback nests at Jamursba Medi and Wermon (Fig. 3).

Estimated number of females nesting annually and seasonally

Based on the two published ECFs used by Hitipeuw et al. (2007), we estimate the number of FNA to have changed from a high of 453–597 in 2005 to a low of 275–363 in 2011 at Jamursba Medi and a high of 258–340 in 2005 to a low of 189–249 in 2011 at Wermon (Table 2). Collectively for the two beaches, we estimate a total of 464–612 FNA during the most recent year of the study (2011).

We also obtained an ECF for Bird's Head leatherbacks from observed nesting of 193 PIT-tagged individuals between 2003 and 2011 at both Jamursba Medi and Wermon. Our ECF ranged from 3 to 10 with a mean of 5.5 ± 1.6 days. Using this ECF, we estimated 477 FNA in 2005 to 290 FNA in 2011 at Jamursba Medi, and 272 FNA in 2005 to 199 FNA in 2011 at Wermon (Table 2). Collectively for the two beaches, we estimate a total of 489 FNA during the most recent year of the study using our ECF for Bird's Head leatherbacks.

A total of 1,371 nesting females were PIT-tagged from 2003 to 2011. Re-sightings of some females indicated movement of nesting females between Jamursba Medi and Wermon during the boreal summer nesting season. A small number of nesters (0.5% [n = 1] in 2009, 2.56% [n = 5] in 2010, and 2.9% [n = 6] in 2011) were observed at both beaches during the boreal summer nesting season. We were not able to evaluate the extent of beach interchange during the austral summer due to the logistical challenges of monitoring Jamursba Medi during these months. Furthermore, turtles tagged during the main boreal summer (April–September) were different individuals than those nesting during the main austral summer (October–March) season. No turtles were ever observed to nest during both boreal and austral summer nesting seasons.

Based on our ECF, we estimate that more females nested at the Bird's Head beaches each

Table 1. Number of observed nests recorded during specific surveys and number of annual nests at Jamursba Medi estimated from different surveys conducted between 1981–2004, and annual number of observed nests from 2005–2011 at Jamursba Medi and from 2004–2011 at Wermon. For comparison purposes the adjusted number of nests for the entire year was calculated for data from 1981–2004, whereas actual year-round data were available for 2005–2011 at Jamursba Medi and from 2004–2011 at Wermon.

Survey period	Jamursba Medi: No. nests recorded	Jamursba Medi: Adjusted no. nests in peak season†	Jamursba Medi: Adjusted and/or actual no. nests for entire year	Wermon: Adjusted and/or actual no. nests for entire year	Source
Sep 1981	4000+	7143			Salm 1982
Apr–Oct 1984	13360	13360	14522		Bhaskar 1985
Apr–Oct 1985	3000	3000	3261		Bhaskar 1987
Jun–Sep 1993	3247	4092	4448		Bakarbessy, *unpublished data*
Jun–Sep 1994	3298	4156	4517		Bakarbessy, *unpublished data*
Jun–Sep 1995	3382	4262	4633		Bakarbessy, *unpublished data*
Jun–Sep 1996	5058	6347	6929		Bakarbessy, *unpublished data*
May–Aug 1997	4001	4489	4879		La Muasa, *unpublished data*
May–Sep 1999	2983	3155	3429		Teguh, *unpublished data*
Apr–Dec 2000	2264	2192	2383		KSDA-YAL, *unpublished data*
Apr–Oct 2001	3056	3056	3321		Wamafma, *unpublished data*
Mar–Aug 2002	1865	1972	2143		WWF 2003
Nov 2002–Mar 2003				2994	WWF, *unpublished data*
Mar–Nov 2003	3601	3487	3790		WWF 2003
Apr–Jun 2003 and Nov2003–Mar 2004				2786	WWF, *unpublished data*
Mar–Aug 2004	3183	3309	3597		WWF, *unpublished data*
Apr 2004–Mar 2005				2805	WWF, *unpublished data*
Apr 2005–Mar 2006	2626	2416	2626	1497	WWF-UNIPA, *unpublished data*
Apr 2006–Mar 2007	2674	2460	2674	1335	WWF-UNIPA, *unpublished data*
Apr 2007–Mar 2008	2107	1938	2107	1483	WWF-UNIPA, *unpublished data*
Apr 2008–Mar 2009	2077	1911	2077	1287	UNIPA-WWF, *unpublished data*
Apr 2009–Mar 2010	2055	1891	2055	1080	UNIPA-WWF, *unpublished data*
Apr 2010–Mar 2011	1720	1582	1720	1354	UNIPA-WWF, *unpublished data*
Apr 2011–Mar 2012	1596	1468	1596	1096	UNIPA-WWF, *unpublished data*

† Adapted from Hitipeuw et al. (2007).

year during the boreal summer than during the austral summer season, with 72% of nesting on average occurring during the boreal summer between 2005 and 2011 (Table 3).

Discussion

Annual nesting and population trend

Leatherback nesting at Bird's Head occurs year-round in contrast to many other beaches both in the Pacific and the Atlantic where nesting is seasonal, occurring either in the austral summer as in Papua New Guinea (Benson et al. 2007*b*, Steckenreuter et al. 2010) and in Pacific Mexico and Costa Rica (Chaves et al. 1996) or in the boreal summer as in the Caribbean and eastern Atlantic (Godley et al. 2001, Dutton et al. 2005, Troeng et al. 2007). However, in Papua Barat, Indonesia, the temporal distribution of nesting activity differs between the beaches of Jamursba Medi and Wermon even though they are only 30 km apart. The nesting distribution at Wermon is bimodal (Fig. 2), with peaks during both the boreal and austral summer nesting seasons, whereas peak nesting only occurs at Jamursba Medi during the boreal summer. A bimodal seasonal nesting distribution has also been found for leatherbacks in French Guiana where nesting occurs primarily in the boreal summer, with a small pulse of nests laid in the austral summer (Chevalier et al. 1999). This temporal variation may be related to multiple demographic stocks using the same nesting beach at different times of the year (Dutton et al. 2007). Our PIT-tag recapture results support this hypothesis suggesting that there are two temporally distinct nesting groups in Bird's Head, with some females nesting during the boreal summer and different ones nesting during the austral summer. There are no records of 'transitional' females whose nesting season spanned the time period between the boreal

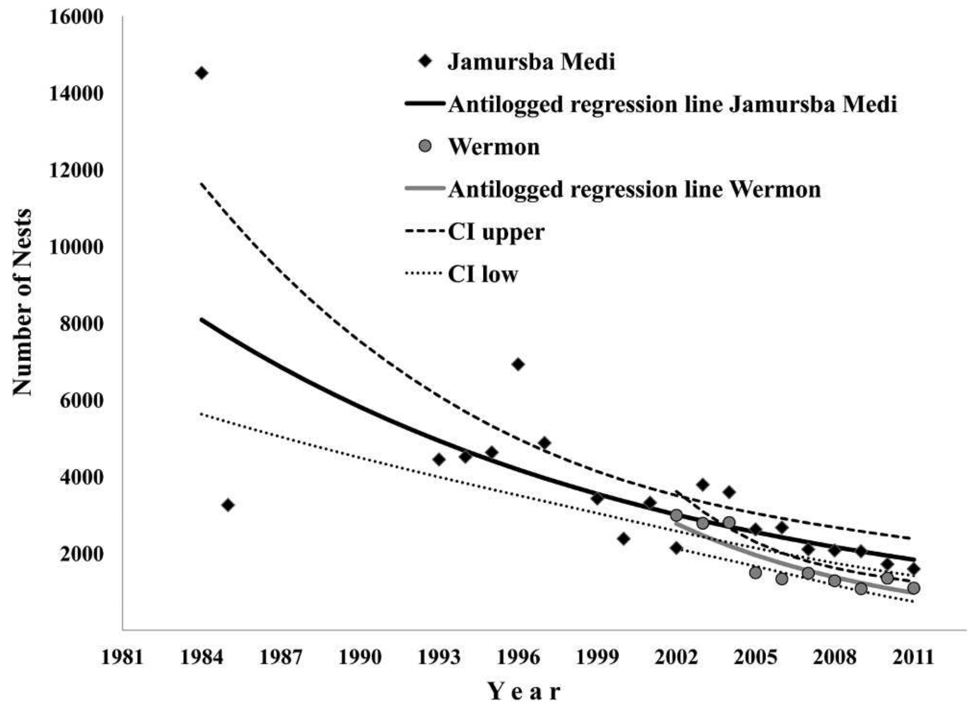

Fig. 3. Leatherback nesting abundance (number of nests) trend at Jamursba Medi from 1984–2011 and Wermon from 2002–2011. Annual nest numbers shown for Jamursba Medi include estimates for 1984–2004 and observed numbers for 2005–2011. Beaches were not monitored from 1986–1992 and during 1998. Annual nest numbers for Wermon estimates for 2002–2003 and observed numbers for 2004–2011. The annual interval spans April 1 of each year indicated to March 31 of the following year.

and austral nesting seasons. Satellite tracking studies also demonstrate that females nesting during the boreal summer at Jamursba Medi and Wermon tend to depart around September and migrate to foraging areas in the northern hemisphere, whereas the Wermon austral summer nesters depart by late April and migrate to forage in the southern hemisphere (Benson et al. 2007*a*, Benson et al. 2007*b*, Benson et al. 2011, Bailey et al. 2012). Further, there may be multiple foraging groups that nest within a specific season. Results from stable isotope analysis of tissues sampled from Jamursba Medi females during the boreal summer identified two groups corresponding to animals foraging in the eastern Pacific and those foraging in the western Pacific (Seminoff et al. 2012). Dutton et al. (2007) have proposed that a spatio-temporal demographic structuring occurs among Bird's Head leatherbacks and that they are members of a regional (western Pacific) metapopulation that appears to be part of a single genetic stock based on mtDNA analysis. Genetic analyses are currently underway to provide a better understanding of this metapopulation (Dutton, *unpublished data*).

Our results, together with those from previous studies reviewed by Hitipeuw et al. (2007) indicate a significant and continuous decline in the population of leatherbacks nesting at Jamursba Medi (1984–2011) and Wermon (2002–2011). This has significant conservation implications since 75% of leatherback nesting in the western Pacific occurs at Bird's Head (Dutton et al. 2007), and recent aerial surveys indicated that Jamursba Medi and Wermon are the two main nesting beaches in the region (Benson et al. 2009). When evaluating the magnitude of the decline, it is of particular importance to note that there were relatively high nesting numbers in 1984 and high nest count variability between 1984 and 1985. The number of nests reported by Bhaskar (1985) for 1984 (14,522; Table 1, Fig. 3) was significantly greater than for any other year reported. Interestingly, it was followed by a sharp decline in

Table 2. Numbers of females nesting annually (FNA) at Jamursba Medi and Wermon estimated from different surveys between 1984–2011.

Year†	Adjusted and/or actual no. nests for entire year		No. estimated females for entire year‡		No. estimated females based on number of nests per season§	
	Jamursba Medi	Wermon	Jamursba Medi	Wermon	Jamursba Medi	Wermon
1984	14522		2504–3300		2640	
1985	3261		562–741		593	
1993	4448		767–1011		809	
1994	4517		779–1027		821	
1995	4633		799–1053		842	
1996	6929		1195–1575		1260	
1997	4879		841–1109		887	
1999	3429		591–779		623	
2000	2383		411–542		433	
2001	3321		573–755		604	
2002	2143	2994	369–487	516–680	390	544
2003	3790	2786	653–861	480–633	689	507
2004	3597	2805	620–818	484–638	654	510
2005	2626	1497	453–597	258–340	477	272
2006	2674	1335	461–608	230–303	486	243
2007	2107	1483	363–479	256–337	383	270
2008	2077	1287	358–472	222–293	378	234
2009	2055	1080	354–467	186–245	374	196
2010	1720	1354	297–391	233–308	313	246
2011	1596	1096	275–363	189–249	290	199

† The annual interval spans April 1 of each year indicated to March 31 of the following year.
‡ Adapted from Hitipeuw et al. (2007).
§ Based on PIT tag data.

1985 with only 3,000 nests reported (Bhaskar 1987). It is not clear how comprehensive Bhaskar's surveys were in 1984 and 1985, and the estimates should therefore be viewed with caution due to potential variation in sampling effort resulting from two primary factors: (1) their efforts were focused on night patrols to tag nesting females and there was less emphasis on day time nest counts and (2) a large proportion of the leatherback nests at that time were disturbed by fishermen who were collecting eggs. On the other hand, a sharp decline in the number of nests during the mid 1980s may be valid, and the decline may have been partially due to local harvesting of eggs and turtles. Betz and Welch (1992) indicated that large numbers of eggs were being harvested from Jamursba Medi based on their visit to that beach in 1991. Many of the local villagers have said that from 1980 through 1993, fishermen would visit the beaches seasonally (from May to August, during seasonally calm weather at Bird's Head) and ship the eggs to nearby markets (Tapilatu, *personal observation*). The fishermen bartered with the local villagers from Saubeba and Warmandi to obtain permission to collect leatherback eggs. Approximately 4 to 5 wooden boats were observed visiting the beach weekly and returning with 10,000–15,000 eggs per boat (Betz and Welch 1992). During the egg collection season, the beaches would become crowded with temporary dwellings that housed egg collectors, and camp fires were common every night. In addition to taking leatherback eggs, fishermen would also set gillnets for sharks, which resulted in 2–3 female leatherback deaths per week (Bakarbessy, *personal communication*). Thus, Bhaskar's (1985) report of relatively high

Table 3. Estimated number of females (mean with SD in parentheses) nesting during the boreal (April–September) and austral (October–March) summer seasons from 2005–2011 at Jamursba Medi and Wermon.

Year†	Summer nesting season	
	Boreal	Austral
2005	563 (48)	186 (14)
2006	511 (42)	218 (15)
2007	452 (34)	200 (15)
2008	429 (36)	183 (14)
2009	413 (38)	157 (11)
2010	389 (29)	170 (11)
2011	382 (23)	93 (6)

† The annual interval spans April 1 of each year indicated to March 31 of the following year.

nesting numbers in 1984, as well as anecdotal reports of extensive egg harvesting and female deaths in shark gillnets support the hypothesis that the nesting population was severely impacted during the 1980s. This is consistent with information from local villagers who say that fewer turtles nest now than in the 1980s (Hitipeuw et al. 2007).

In response to the continued decline, the Sorong government enacted laws in 1993 that banned egg collection and protected nesting females (Bupati Sorong 1994). Additionally, regular nesting surveys began at Jamursba Medi in 1993. Although annual fluctuations were evident, there was an overall decline in nesting from 1996 to 2004. Our results indicate that this decline has continued through to 2011 (Table 1, Fig. 3). Our analysis of all the available datasets indicates an overall population decline of 78.3% at Jamursba Medi from a high of 14,455 nests in 1984 to a low of 1,532 nests in 2011. Nesting numbers at Wermon were unknown until recently; surveys in 2002 to 2004 indicated that there were relatively large numbers of nests on Wermon (World Wildlife Fund 2003, Hitipeuw et al. 2007). The first comprehensive surveys carried out by the World Wildlife Fund at Wermon in 2004 found almost as many nests laid on Wermon as on Jamursba Medi (Table 1, Fig. 3). It was hypothesized that the decline at Jamursba Medi may have been offset by an increase at Wermon (Hitipeuw et al. 2007). However, our findings are not consistent with this hypothesis and indicate that nesting at both beaches has declined significantly, and at the same approximate rate. However, the movement by nesters between beaches that we documented might contribute to the small peak in nesting during the boreal nesting season at Wermon. Indeed, the boreal nesting season at Wermon most likely represents "spill-over" from neighboring Jamursba Medi. If this is the case, the spill-over appears to be restricted to Wermon, since aerial survey showed no evidence of significant nesting at other beaches in the region (Benson et al. 2009). The extent of exchange between beaches during the austral summer season is unknown, since PIT-tag data on nesting females were not collected at Jamursba Medi during this time period.

Estimated clutch frequency and females nesting annually

Our estimated clutch frequency (ECF) of 5.5 ± 1.6 (mean ± SD) clutches per female per season is similar to other published estimates of ECF from leatherbacks in the eastern Pacific including Mexico (5.5 ± 1.9; Sarti et al. 2007), Playa Grande, Costa Rica (5.6 ± 1.2; Reina et al. 2002), and estimates reported for Atlantic leatherbacks in St. Croix (5.8; reviewed in Hitipeuw et al. [2007]) and Culebra, Puerto Rico (6.7 ± 2.7; Tucker and Frazer 1991). The maximum observed clutch frequency at Jamursba Medi and Wermon was 10 clutches compared to 12 clutches for Mexican beaches (Sarti et al. 2007) and similarly 12 clutches for St. Croix (Dutton et al. 2005). Considering that not all nesting events may have been observed along the entire distribution range or even within Jamursba Medi and Wermon, and that females may move between beaches, the actual ECF could be slightly higher than the current estimate and the estimated of number of nesting females would consequently be lower. Regardless, the results indicate a continual declining trend in the number of leatherbacks nesting annually at both Jamursba Medi and Wermon and that the overall Bird's Head leatherback population has been reduced to approximately 500 females nesting annually (FNA).

Conservation implications

Despite the decline in nesting numbers, Bird's Head remains the largest leatherback nesting aggregation in the Pacific, if only because the other populations are severely depleted or extinct. There may be a variety of reasons why this population has not collapsed in comparison to other Pacific rookeries, which may be facing potential extinction as suggested by Spotila et al. (1996, 2000). The nesting beaches on Bird's Head are in remote locations with a limited number of local residents in the area, thereby (1) limiting the historic levels of direct exploitation of eggs and females which resulted in the collapse of other rookeries in Malaysia (Chan and Liew 1996, Chua 1988, Liew 2011) and Pacific Mexico (Marquez et al. 1981, Sarti et al. 2007, Sarti et al. 1996), and (2) preventing the development of areas adjacent to the nesting beach, which has impacted nesting habitats in Malaysia, Costa

Rica, and Mexico (Chan and Liew 1996, Spotila et al. 1996, Sarti et al. 2007). However, the occasional harvesting of eggs at Jamursba Medi and Wermon, and the occasional harvesting of eggs and adults females on minor nesting areas on Bird's Head still need to be evaluated and addressed (Tapilatu, *unpublished data*).

The long-distance migratory habits of Bird's Head leatherbacks increase the probability of fisheries interactions as they travel through multiple fishing zones and encounter multiple types of fisheries (Benson et al. 2011, Bailey et al. 2012). The impact of commercial fisheries (Frazier and Brito Montero 1990, Nishimura and Nakahigashi 1990, Eckert 1993, Wetherall et al. 1993) and artisanal fisheries (Chu-Chen 1982, De Silva 1982, Polunin and Nuitja 1982, Siow and Moll 1982, Suwelo et al. 1982, Eckert 1993, Starbird and Suarez 1994, Suarez and Starbird 1996, Alfaro-Shigueto et al. 2007, Finkbeiner et al. 2011) on Pacific leatherbacks has been well-documented. Furthermore, some females nesting during the austral summer season migrate to waters off eastern Indonesia (Benson et al. 2011) where they may be subjected to relatively high mortality by traditional leatherback hunters from the Kei Kecil Islands (Starbird and Suarez 1994, Suarez and Starbird 1996). It was reported that the Kei islanders successfully hunted and killed 135 leatherbacks between November 2003 and December 2007 (SIRAN and World Wildlife Fund, *unpublished reports*). However, the use of multiple foraging grounds by the Bird's Head leatherbacks may also buffer the population to some extent against potentially severe impacts of fisheries, directed take, and environmental perturbation in the marine environment (Dutton 2006, Benson et al. 2011), and protection of key foraging areas could further mitigate these threats. For example, the Maluku Tenggara government recently designated a Marine Protected Area (MPA, ~150,000 ha) in waters surrounding the Kei Kecil Islands (WWF Indonesia 2012) in response to proposed temporal closures of a marine foraging ground for leatherbacks (Benson et al. 2011). Elsewhere, a large area (10,877,950 ha) in US waters in the northeastern Pacific has recently been designated critical habitat due to its importance as a distant foraging area for western Pacific leatherbacks (Wallace 2012).

Finally, the extent to which environmental factors have contributed to the decline of Pacific leatherback populations is unknown but could be significant. Multi-decadal climate oscillations and global climate change could have a variety of impacts including (1) increased nesting beach temperatures resulting in reduced hatching success and highly biased sex ratios, and (2) rising sea level and alteration of ocean current circulation that would affect beach erosion, beach topography, and hatchling and juvenile dispersal patterns and juvenile recruitment (Saba et al. 2008, Van Houtan and Halley 2011, Gaspar et al. 2012, Saba et al. 2012).

Regardless of the underlying causes, the current number of nesting females offers a glimmer of hope that this declining population is still large enough that it could recover if effective management measures can be implemented to address the major threats immediately. The management program at Jamursba Medi and Wermon has included experimental evaluation of small-scale hatcheries since 2006 (Tapilatu and Tiwari 2007, Tiwari et al. 2011) and relocation of doomed nests (i.e., nests that would be lost to erosion) to stable sections of beach. The hatcheries are used to mitigate low hatching success due to (1) predation of eggs and hatchlings by introduced pigs and dogs (Bhaskar 1987, Maturbongs 2000, Hitipeuw and Maturbongs 2002, Suganuma et al. 2005, Suganuma 2006), (2) beach erosion (Bhaskar 1987, Hitipeuw et al. 2007), and (3) elevated sand temperatures (Tapilatu and Tiwari 2007). Preliminary results indicate that nest relocation significantly enhances hatching success (Tapilatu and Tiwari 2007). Maximizing hatchling production at Bird's Head nesting beaches is paramount for the recovery of western Pacific leatherbacks (Tiwari et al. 2011).

Involvement of the local community members is a pre-requisite for the development of a stable long-term conservation program on these beaches. Through an intensive and collaborative effort between conservation organizations and the communities adjacent to Jamursba Medi and Wermon, villagers now participate side-by-side with biologists to patrol the beaches, maximize hatchling production, and protect in situ nests and nesting females (Hitipeuw et al. 2007). As evidence of their dedication to leatherback conservation, the local communities are actively addressing the threat of coastal development by asking the Papua Barat Provincial government to re-route the proposed trans-Papua Barat road 5–10 km inland from Jamursba Medi. Future efforts should focus on maintaining and enhancing co-management approaches and a traditional conservation ethic within the local communities and the new regency government to ensure the sustainability of a long-term conservation program.

However, beach conservation alone, while a necessary pre-requisite, is unlikely to tip the scales in favor of the recovery of this population. Under some scenarios complete protection at the nesting beach would compensate for fisheries-related mortality (e.g., 5% per year) with the population growing rapidly (Spotila et al. 1996). However, it has been suggested that annual fisheries-related mortality of leatherbacks in the Pacific has been significantly higher than 5% per year (Spotila et al. 2000, Alfaro-Shigueto et al. 2011). Furthermore, climate-driven oceanographic processes may further influence survival and population recruitment (Van Houtan and Halley 2011). Therefore, it is imperative to adopt a holistic approach (Dutton and Squires 2011) that addresses threats at all life history stages. A broad suite of management and conservation measures should be implemented at the nesting beaches and in national and international waters, to help reverse the decline of what might be the last remaining stronghold for leatherbacks in the Pacific, in a renewed effort to defy predictions of their extinction.

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