forest still exist west of the lake. To the east, modification of college grounds and other human activities have converted the upland forest to private and commercial land use. These anthropogenic changes have been shown to significantly increase the temperature of streams draining into Lake Matoaka by almost 2°C (Murphy et al., unpubl. data). Less shading by forest may also increase soil temperatures, which in turn would affect sex determination of incubating turtle eggs (Janzen, 1994). Soil temperatures where female turtles nest may be lower in the undeveloped watershed surrounding the western arm of the lake, relative to the more developed eastern arm. Incubation temperature differences of 1–2°C have been shown to yield variation in the proportion of male musk turtle hatchlings from 23 to 94% (Vogt et al., 1982; Ewert and Nelson, 1991). Since most musk turtles generally show site fidelity, differences in hatchling sex ratios may contribute to location-specific variation in sex ratio of the adults.

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Axial Bifurcation in a Bicephalic *Chelonia mydas* Embryo

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Developmental anomalies in reptiles are reported only occasionally and have received little attention in general (Cunningham, 1937; Davies, 1974; Branch, 1979; Bellairs and Kamal, 1981; Miller, 1985). In marine turtles, the incidence of developmental abnormalities appears to be low, judging from the scant literature on the subject. Of the abnormalities known to occur in turtles, the common ones are albinism, pigmentation or pattern variations, malformation in scute patterns, size reduction or loss of body parts, malocclusion of jaws, twinning (Harrisson, 1963; Bellairs, 1983; Miller, 1985; Chan, 1985; Frye, 1991), and a recent case of conjoined twins (Haft, 1994). In this note, we describe, what is to our

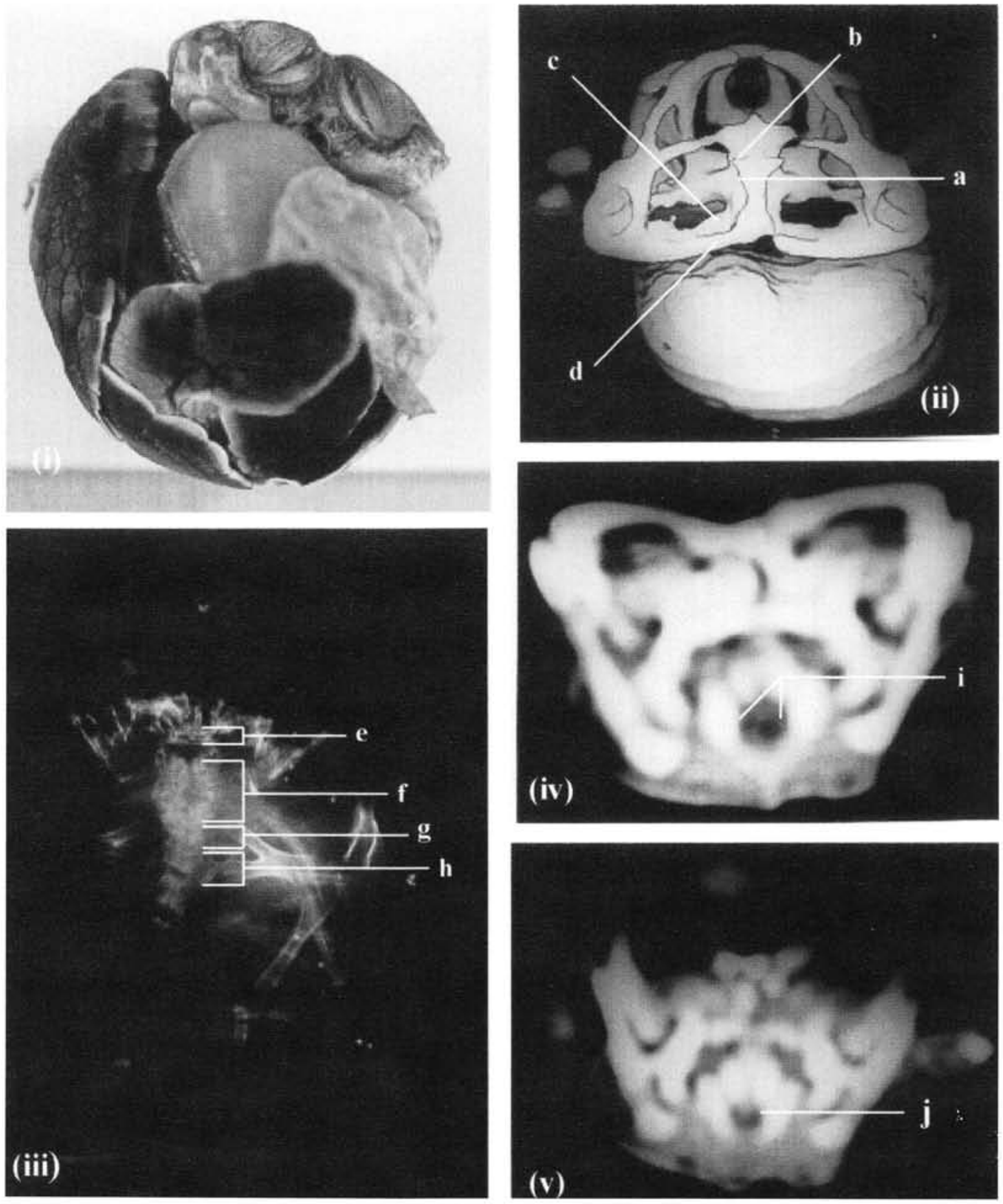

Figure 1. (i) Conjoined bicephalic embryo of *Chelonia mydas* with fully developed flippers and residual yolk, **(ii)** CAT scan of embryonic heads showing point of separation: *a*, jugal bones; *b*, postorbital bones; *c* , maxilla; *d*, mandible, **(iii)** Radiograph of dorso-ventral view of embryo: *e*, laterally extended atlas, *f*, C2–C6; *g*, C7; *h*, first dorsal thoracic vertebrae, **(iv)** CAT scan of cervical region: *i*, two separate neural spaces with septum, **(v)** CAT scan of thoracic region showing one neural space (*j*) without any septum in a normal vertebra.

knowledge, a first case of incomplete bicephaly in the green turtle, *Chelonia mydas*.

Methods. — A dead deformed *C. mydas* embryo with incomplete head bifurcation was recovered from an unhatched egg collected at the sea turtle hatchery on Talang Talang Besar Island, the largest of three turtle nesting islands situated off the southwest coast of Sarawak (109°46'E, 1°44'N), Malaysia. A beach hatchery on this island has been used since the early 1950s to manage stocks of green turtles. In this hatchery operation, entire clutches of eggs were collected for incubation in the beach hatchery. In recent years, a proportion of the nests have been left to incubate *in situ* (Diong et al., 1999a, 1999b).

The deformed embryo was staged (Miller, 1985) and x-rayed at 25 kV, 28 mAs (Siemens Mammomat X-ray machine) to study the skeletal structures associated with the abnormality. As radiography alone was not able to analyze fully the skeletal anomaly, the embryo was subjected to a computerized axial tomography (CAT) scan to determine skeletal malformation arising from its incomplete head duplication. The specimen was deposited in the Sarawak Museum, Kuching, Malaysia (MU/480/3.49a).

Results. — The near-term embryo was aged at stage 28; its body was darkly pigmented but lighter than in hatchlings, the skin at the base of the limbs was not pigmented. The malformed embryo showed incomplete cranial bicephaly

(Fig. 1-i). The right and left heads were equally developed and exact counterparts of each other. The two heads were symmetrically aligned with the axis of the body. Each head had two eyes, one mouth, and a fully formed beak. Both heads shared a thickened neck which joined the separate heads to one common body. The body had one set of front and hind flippers, one tail, one cloaca, and one residual yolk mass.

Computerized axial tomography (CAT) scans showed that the bicephaly was incomplete. The right and left embryonic heads (midplane) were angled 90º to each other, separated proximally at a common jugal bone and along a bony ridge on the distal border of the proximal orbits of the two heads comprising the postorbital-jugal bones (Fig. 1-ii). Partial separation was limited to the skulls; the mandibles were entirely separate, without any fusion point. The distal unseparated skull was connected to one common axial skeleton (Fig. 1-iii). Radiography revealed that the cervical vertebrae (C) 1 and 2 were conjoined mesially to form one common atlas which was unusually broad and supported the two separated heads. Cervical vertebrae 2 to 6 were incompletely bifurcated (Figs. 1-iii, 1-iv). The spinal column from C2 to C5 was expanded laterally; neural tissues from C2 to C7 appeared as two distinct bundles separated by a soft tissue septum (Fig. 1-iv). The centra in these vertebrae were not joined; they had two lateral ventral walls but no medial wall. The neural tube was incompletely divided. Radiographically, the last cervical vertebra, C7, was normal, as were the other vertebrae that form the thoracic and caudal regions of the axial skeleton (Figs. 1-iii, 1-v).

Discussion. — The bicephalic embryo described here is a case of conjoined twins in *Chelonia mydas* involving partial head separation. It differs from one other known case of conjoined twins in *C. mydas* (see Haft, 1994) in which separation occurred further distally, resulting in a hatchling with two fully functional, independent heads, each with a neck of its own, one common body, and single pairs of front and hind flippers.

Incomplete head bifurcations initiate in early development and typically start at the tip of the head fold. The axial bifurcation that forms later during somite formation may have resulted from lateral dichotomization of the cervical vertebrae. This could have happened from the partial separation of blastomeres at some stage of early embryonic development. Developmental anomalies may also arise due to mutation or the genetic constitution of the zygote (Ewert, 1979). The most likely cause of the incomplete bicephaly is a miscoding or misdirection in the genetic code that controls the division of cells in the head. The frequency of malformation in marine turtles has been reported to be low, ranging from 0.17 to 0.6% in samples ranging from about 5000 to 90,000 eggs (McGehee, 1979; Blanck and Sawyer, 1981; Miller, 1982; Miller, 1985). The incidence of malformed embryos in the Sarawak green turtle population is unknown. Nest contents in the hatchery that are routinely dug out for disposal after hatchling emergence should be analyzed for incidence of malformations. A comparison of incidence of malformations from hatchery and *in situ* nests may shed some light as to whether hatchery practice and hatchery incubational environment or other genetic factors may be a contributory factor to abnormal development in this population.

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