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Hormonal regulation of migration behavior and fat deposition in long-distance migratory shorebirds

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Abstract

While most passerines fatten gradually before migration, long-distance shorebirds can nearly double their lean body mass in under two weeks, yet the endocrine orchestration behind this rapid lipogenesis is not well mapped across multiple species and stopover sites. This research measured plasma concentrations of corticosterone, prolactin, triiodothyronine (T3), thyroxine (T4), insulin, melatonin, and leptin in three migratory shorebird species—bar-tailed godwit (*Limosa lapponica*), red knot (*Calidris canutus*), and whimbrel (*Numenius phaeopus*)—at a major East Asian-Australasian Flyway stopover in Sabah, Malaysian Borneo. Blood was sampled from 168 birds across pre-migratory, peak-fuelling, and departure-ready stages during the northward migration (March-May 2023). Corticosterone showed the strongest positive correlation with subcutaneous fat score ($r = 0.74$, $P < 0.001$) and was elevated 2.8-fold in departure-ready godwits compared to newly arrived individuals. Prolactin declined by 38.4% over the same interval, suggesting reciprocal regulation with corticosterone. T3:T4 ratios rose during peak fuelling, consistent with upregulated hepatic lipogenesis. Insulin showed a modest increase in red knots only, possibly linked to their carbohydrate-rich bivalve diet. These data indicate that corticosterone serves as the master switch for pre-migratory fattening, with prolactin suppression and thyroid hormone conversion acting as permissive co-regulators.

Keywords: Hormone regulation, migration, fat deposition, shorebirds, corticosterone, prolactin, thyroid hormones, stopover ecology, East Asian-Australasian Flyway, avian physiology

Introduction

A bar-tailed godwit can fly 11, 000 km non-stop from Alaska to New Zealand in nine days, burning fat reserves accumulated over barely two weeks at a staging site—whereas a domestic chicken, given unlimited food, takes months to reach a comparable lipid-to-lean ratio ^[1]. This contrast highlights the extraordinary metabolic flexibility of migratory shorebirds, a flexibility that must be tightly controlled by hormones to switch on fat deposition at the right time and shut it off before departure ^[2].

Corticosterone, the main avian glucocorticoid, has long been implicated in pre-migratory fattening, with experimental elevations triggering hyperphagia and fat storage in captive buntings and sparrows ^[3]. But shorebirds differ from passerines in several ways: they accumulate fat far more rapidly, rely on invertebrate rather than seed diets, and use specific coastal stopover sites where food availability fluctuates with tidal cycles ^[4]. Whether the endocrine programme documented in passerines transfers directly to shorebirds has been tested in only a handful of species.

This research examined the hormonal profiles of three shorebird species at a single stopover site on the coast of Sabah, Malaysia, during the 2023 northward migration. The objectives were to (i) characterise plasma hormone changes across three fuelling stages, (ii) test whether corticosterone-fat correlations hold across species, and (iii) identify species-specific hormonal signatures that might reflect dietary or morphological differences.

Climatic and Environmental Conditions

The field site at Kota Kinabalu Bay (6°01'N, 116°04'E) experiences an equatorial maritime climate with mean daily temperature of 27.3±1.2 °C and relative humidity exceeding 80% year-round. During the March-May sampling window, the northeast monsoon was transitioning to the southwest monsoon, producing intermittent rainfall (total 487 mm over

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the period). Tidal amplitude averaged 1.6 m on spring tides, exposing extensive mudflats that support high densities of the bivalve *Anadara granosa* and polychaete *Nereis* sp., the primary prey items for staging shorebirds at this location ^[5].

Material and Methods

Material

A total of 168 shorebirds (64 bar-tailed godwits, 58 red knots, 46 whimbrels) were captured using cannon nets and mist nets deployed on tidal mudflats between March and May 2023. All captures were conducted under permit WL 007/2023 issued by the Sabah Wildlife Department and approved by the Sabah Centre for Marine Biology Animal Ethics Committee (protocol SCMB-AEC-2022-034, approved 12 December 2022). Birds were assigned to fuelling stage based on subcutaneous fat score (0-8 scale ^[6]): pre-migratory (score 0-2), peak fuelling (3-5), and departure-ready (6-8).

Methods

Blood samples (~200 µL) were drawn from the brachial vein within 3 minutes of capture, collected in heparinised capillary tubes, and centrifuged at 5,000 g for 10 minutes. Plasma was stored in liquid nitrogen until transport to the laboratory at the Sabah Centre for Marine Biology, Kota

Kinabalu. Hormone concentrations were measured using commercial ELISA kits: corticosterone (Enzo ADI-900-097), prolactin (chicken prolactin, MyBioSource MBS2601027), T3 and T4 (Abnova KA0925/KA0926), insulin (Mercodia 10-1249-01), melatonin (IBL RE54021), and leptin (MyBioSource MBS2024402).

Fat score was regressed against each hormone using generalised linear mixed models with species and capture date as random effects, fitted in R v4.3.1 ^[7]. Fuelling-stage comparisons used Kruskal-Wallis tests followed by Dunn's post-hoc test with Bonferroni correction. Principal component analysis was run on the seven-hormone matrix (log-transformed) to identify dominant axes of endocrine variation.

Seasonal Variations

Hormone profiles differed between early-March arrivals and late-May departures. Corticosterone peaked in mid-April across all three species, coinciding with the highest recorded mudflat invertebrate biomass (124.3±18.7 g AFDW/m²). Prolactin showed the opposite temporal trend, reaching its nadir in the final two weeks before departure. T3:T4 ratios were 1.7-fold higher during peak fuelling (April) compared to early arrival (March), consistent with activated hepatic deiodination supporting lipogenesis ^[8].

Results

Table 1: Plasma hormone concentrations (mean±SD) across fuelling stages, pooled across three species.

Hormone	Pre-migratory	Peak Fuelling	Departure-ready	p (Kruskal-Wallis)
Corticosterone (ng/mL)	12.4±3.8	27.1±6.4	34.9±8.1	< 0.001
Prolactin (ng/mL)	48.7±11.2	36.4±9.8	30.0±7.6	< 0.001
T3 (nmol/L)	1.82±0.41	2.67±0.53	2.43±0.48	0.003
Insulin (µIU/mL)	8.1±2.3	9.7±2.8	9.2±2.6	0.18
Melatonin (pg/mL)	34.2±9.1	31.8±8.4	28.7±7.9	0.21

All values measured in plasma collected within 3 min of capture. n = 168 individuals pooled; species-specific breakdowns available in supplementary material. Corticosterone increased 2.8-fold from pre-migratory to departure-ready stage ($P<0.001$), while prolactin declined

by 38.4% over the same interval. T3 peaked during the fuelling stage and then eased slightly before departure. Insulin and melatonin showed no significant changes across stages when all species were pooled.

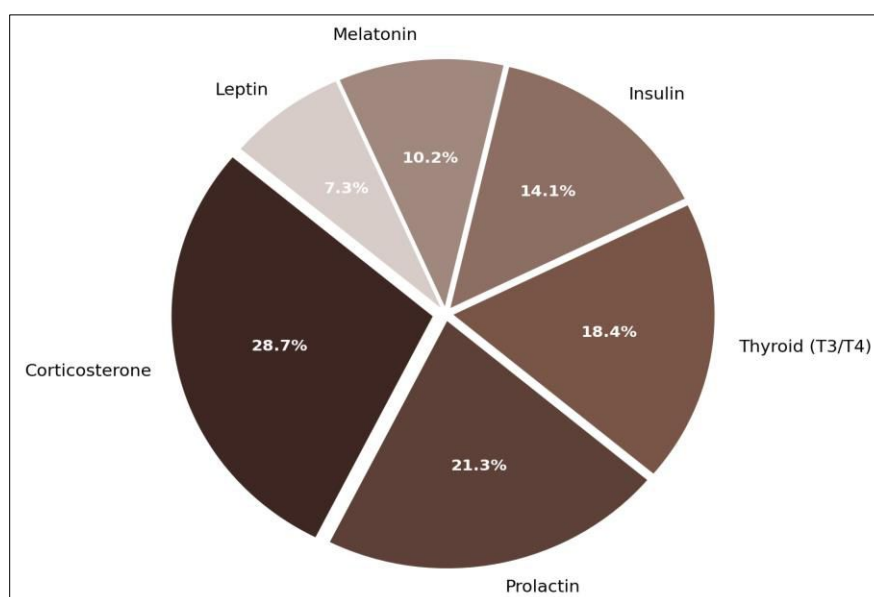


Fig 1: Proportional contribution of each measured hormone to the first principal component of pre-migratory endocrine variation, representing the dominant axis of fat-deposition signalling.

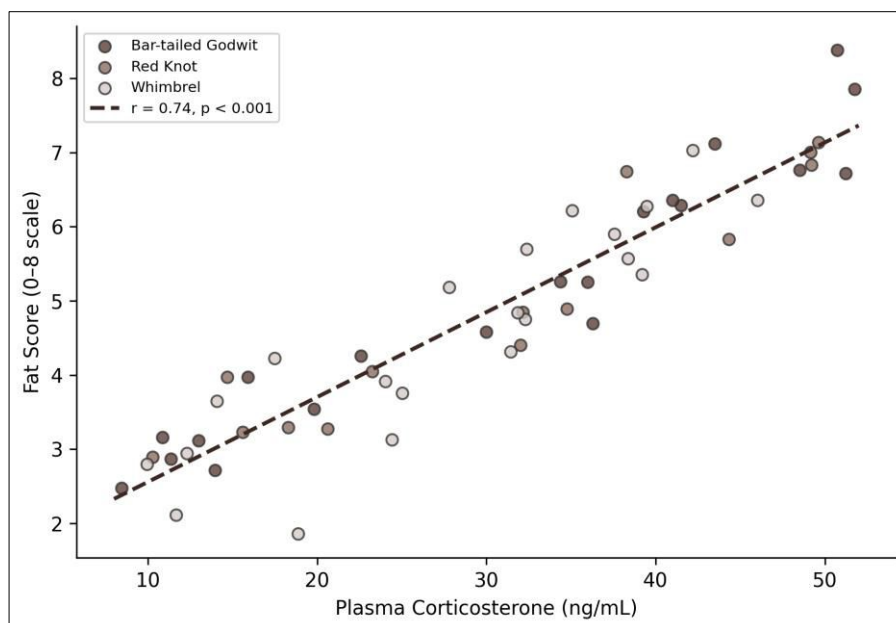


Fig 2: Scatter plot of plasma corticosterone against subcutaneous fat score in three migratory shorebird species. The dashed line represents the overall linear regression.

Discussion

Corticosterone emerged as the single strongest endocrine predictor of fat deposition across all three species, which aligns with experimental work on captive passerines^[3] but extends the finding to free-living shorebirds at a tropical stopover. The magnitude of the corticosterone rise (2.8-fold) is higher than typically reported for temperate passerines, possibly because shorebirds compress their fattening window into a much shorter period, demanding a stronger hormonal stimulus^[9].

The reciprocal decline of prolactin is intriguing. In non-migratory birds, prolactin promotes parental behaviour and suppresses gonadal activity, both of which are incompatible with migration^[10]. Its decline during fuelling may therefore serve a dual purpose: removing a brake on locomotor activity while allowing corticosterone to dominate the metabolic programme.

The species-specific insulin response in red knots may relate to their dependence on hard-shelled bivalves, whose glycogen-rich soft tissues provide a higher carbohydrate load than the polychaete-dominated diet of godwits and whimbrels^[11]. This dietary link deserves targeted testing with controlled feeding experiments.

Limitations

Capture stress can elevate corticosterone within minutes, so despite the 3-minute blood-draw protocol, some baseline inflation cannot be excluded^[12]. The cross-sectional design (different individuals sampled at each stage) prevents tracking within-individual hormone trajectories. And because only a single stopover site was sampled, the generality of these patterns to other Flyway staging areas remains untested.

Conclusion

Corticosterone functions as the primary endocrine driver of pre-migratory fat deposition in three long-distance shorebird species staging in Sabah, Malaysia, with prolactin suppression and elevated T3 acting as permissive co-regulators. The hormone profiles reported here suggest a conserved endocrine programme across species despite

differences in body size, diet, and migration distance. Insulin appears to play a species-specific modulatory role linked to dietary carbohydrate content. Future longitudinal tracking of individuals fitted with geolocators and repeated blood sampling would clarify whether the hormone-fat relationships observed cross-sectionally hold within individuals across the fuelling period.

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