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Pattern of reproductive biology of the endangered golden mahseer *Tor putitora* (Hamilton 1822) with special reference to regional climate change implications on breeding phenology from lesser Himalayan region, India

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ABSTRACT

Mahseer is an important group of endemic game fish found in the Indian subcontinent inhabiting in streams, riverine pools and lakes. Besides commercial fishery, it also forms lucrative sport fishery in the Himalayan rivers. Samples of golden mahseer (*Tor putitora*) were collected from the river Kosi at Ramnagar area (lesser Himalayan region) of Uttarakhand, India during 2014–2016 to study reproductive biology and trace any changes in breeding phenology from earlier records. The observed breeding season was from July till September. In males (310–565 mm, 355–1750 g) and females (315–580 mm, 260–2500 g), GSI values surged from late June to early July and peaked in August. Absolute and relative fecundity ranged from 4217 to 8365 and from 3667 to 7348 per kg, respectively. The maximum water temperature was usually recorded in May (30.5°C) and minimum (18.4°C) in January. Sex ratio was estimated at 1:1.25 with χ^2 value of 3.20 and the difference was non-significant. The breeding phenology of golden mahseer may likely have gone through two distinct steps of transformation viz. shifting-prolongation (1911–1981) and reduction-stabilization (1981–present). Even after a probable reduction in duration of breeding season and shift (delay) in onset of breeding in Golden mahseer population of lesser Himalayan region during 1911–1981, some stabilization in breeding phenology appears to have been attained since 2000s. It is predicted that the species appears to be continuously adapting to changing climate in lesser Himalayas.

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Introduction

Mahseer is famous for its delicacy as food fish, but it gains much more attention due to its capabilities as an excellent game fish. Mahseers are declining in their natural habitats due to various anthropogenic activities which are further exacerbated by climate change. Realizing its importance, several organizations are working towards its conservation. Golden mahaseer *Tor putitora* (Hamilton 1822) is a very popular sport fish among the anglers across the world. This ‘endangered’ species is widely distributed in South and South-East. *T. putitora* is regarded as an important game fish of great conservation value in countries like Afghanistan, Bangladesh, Bhutan, India, Iran, Myanmar, Nepal, Pakistan, Thailand and Sri Lanka. The fish is a typical freshwater, benthic-pelagic omnivore inhabiting streams, riverine pools and lakes; especially the rapid streams with rocky bottom. Thermal habitat preference lies within 13–30°C. The species is potamodromous in nature and regarded as an altitudinal migrant (Jha and Rayamajhi 2010; IUCN 2017; Fishbase 2018). In general, they do not reach sexual maturity till 4+ year age class (Nautiyal 1994), although males attain sexual maturity faster than females. Therefore, large-scale

harvests of the fish prior to its achieving breeding maturity leads to population size depression (Bhatt and Pandit 2016). However, there are recent ‘unverified’ reports of probable reduction in age at maturity in both sexes from Uttarakhand, India (CIFRI 2016a, 2016b). Although efforts are under way to further validate the observation, the question that remains worthy of exploration is – whether such phenomenon is a result of long-term growth overfishing on golden mahseers or attainment of faster maturity under changing climate or both. In India, the Golden mahseers are mostly restricted to cold-temperate regions of Himalayas and Western Ghats in India (Lakra et al. 2010). In general, mahseers are facing the threat of extinction and many species under this group, like *T. putitora* itself, are categorized as endangered. The major threats include overfishing, loss of habitat, decline in habitat quality, loss of breeding grounds and other anthropogenic effects, especially the prolific creation of dams that have directly resulted in declines across several locations. (Jha and Rayamajhi 2010). Considering the importance of Mahseers, four Indian states have declared them as their state fish to further intensify and improve accountability towards effective conservation (Sarkar et al. 2015). Interests on mahseer due to its commercial value and

conservation status have encouraged researchers to provide more information on this species and contribute scientifically towards the much-needed biological database for devising conservation measures (Nautiyal et al. 2008; Sarkar et al. 2008; Bhatt and Pandit 2016). In general, the present scenario of mahseer fish species is well known for conserving and restoring the fish in Indian waters (Lakra et al. 2010; Sarkar et al. 2015; Bhatt and Pandit 2016).

The Golden Mahseer is an important endemic fish found in the Indian subcontinent and the species is commercially exploited in their own natural habitat (e.g. streams, rivers, lakes). Major areas of distribution in India include Himachal Pradesh, Uttarakhand and Jammu and Kashmir (Nautiyal et al. 2001; Bhatt et al. 2004). For an endangered fish like golden mahseer, the study of reproductive biology is vital for understanding the maturity, recruitment process, male–female ratio in the stock and changes in breeding phenology (Nautiyal and Lal 1985; Pathani 1994; Mayank et al. 2016). The gonadosomatic index (GSI) is useful in determining the stages of gonadal maturation and period of greatest reproductive intensity (Hojo et al. 2004). Knowledge of the fish length at first sexual maturity is indispensable to estimate the size of the spawning stock (Neja, 1992). Fecundity is effective in evaluating the commercial potentialities of its stock, variations in fish population, life history, fish culture for appropriate planning of the hatching and nursery operations and management of the fishery (Marimuthu et al. 2009). The GSI, fecundity and sex ratio of *T. putitora* has been studied by various researchers in different regions and habitats (Dunsford 1911, Pathani 1978, 1981, 1983; Pathani and Das 1979; Nautiyal 1984; Dobriyal et al. 2000; Mohan 2000; Nautiyal, Dwivedi, et al. 2007; Nautiyal, Rizvi, et al. 2007). But, there is no previous literature from the Kosi river at Ramnagar area of Uttarakhand which represents the 'lesser Himalayan region'. The river Kosi represent typical mahseer habitats including its rhithon, potamon zones and upland tributaries, which are sites for over-wintering migration and breeding, overlooked over the years perhaps for being a part of the lesser Himalayan belt. In this backdrop, an attempt has been made to study the reproductive traits like GSI, fecundity and sex ratio of Golden Mahseer, *Tor putitora* from the Kosi river at Ramnagar area of Uttarakhand. Additional attempts were also made to determine the changes (if any) in breeding phenology from earlier records and collate such changes with the changing climate of the region for sustainable management of natural population.

Material and methods

A total of 263 samples of golden mahseer *T. putitora* (Hamilton 1822) were collected between April 2014 and March 2016 from Kosi river in Ramnagar District, Uttarakhand, India (29°41'10" and 79°13'27"). Fishes were collected with the help of local fishermen with experimental fishing using cast nets and gill nets of different mesh sizes and from the local Ramnagar fish market. Species identification was done following Talwar and Jhingran (1991) and Patiyl et al. (2014). Length (mm) and weight (g) of each collected sample were measured. Fresh gonad samples were removed and stage of reproductive maturity was recorded. Gonads were weighted and preserved in 8%

formalin for further studies. After allowing the ovaries to attain hardness, they were taken out and dehydrated using cotton or blotting paper. The gonadosomatic index and fecundity were calculated using following formula:

Gonado Somatic Index (GSI) = Gonad weight*100/Body weight

Fecundity (F) = (Total weight of ovary)/(Weight of sample) × No. of eggs

Sokal and Rolhf (1973) have given the following formula, especially for two class calculation of chi-square.

$$\text{Chi-square } (\chi^2) = \sum (O_i^2/E_i) - n$$

where, O_i = Observed frequency; E_i = Expected frequency; n = Number of sample

An exhaustive literature review (peer reviewed journals, bulletins, annual reports, thesis and cross references) was done to compile historical records on breeding season of Golden mahseer from Indian waters following the strategies outlined in Myers et al. (2017). Out of these ($n=25$), only reports from Uttarakhand region ($n=9$) were selected and plotted in a graphical chronogram using Systat SigmaPlot v11.0 keeping the observed breeding season as reference. Metadata for climate change trend in lesser Himalayan regions of Uttarakhand, which includes the present study area, were extracted from Uttarakhand state action plan for climate change (UAPCC 2014).

Results

Reproductive biology and habitat quality

In this study, it was observed that the values of GSI increase from June onwards reaching a peak in August. In male, peak value of GSI (1.31) was observed in the month of August and female (3.08) was also observed in the same month. This indicates the peak spawning season in the month of August with a water temperature of 21.2–26.4 (Figure 1). The minimum value of GSI was recorded in November for male and in December for female. The fecundity of *T. putitora* was directly correlated to the length of fishes. Absolute and relative fecundity ranged from 4217 to 8365 and from 3667 to 7378/kg body weight among the different-sized female fish (Table 1). Total length of the fishes ranged between 310 and 565 mm (355–1750 gm) for male and 315 and 580 mm (260–2500 gm) for

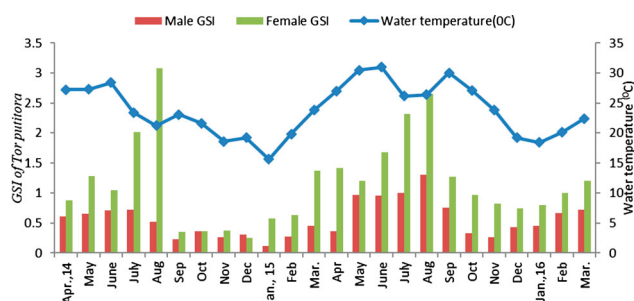
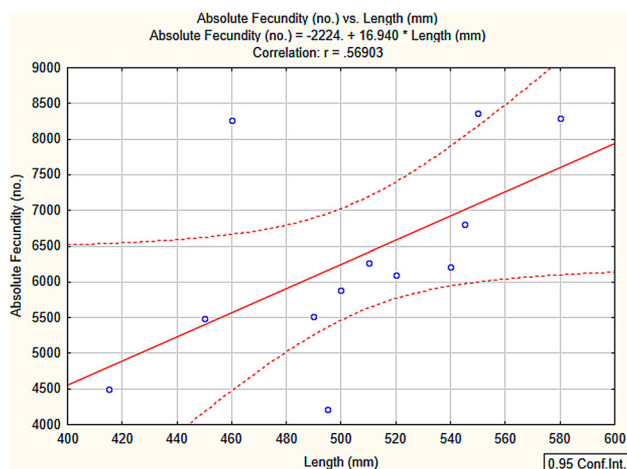


Figure 1. Dynamics of Gonadosomatic index (GSI) of *T. putitora* with water temperature variation.

Table 1. Fecundity of *T. putitora* from the Kosi river.

Months	Length of fishes (mm)	Weight of fishes (g)	Fecundity (absolute/relative per kg)
June 2015	495	1150	4217/3667
June 2015	490	1390	5519/3970
July 2015	520	1200	6093/5070
July 2015	415	980	4495/4590
July 2015	540	1410	6213/4400
July 2015	545	1500	6803/4535
August 2015	510	1530	6263/4093
August 2015	450	1240	5482/4420
August 2015	550	1700	8365/4920
August 2015	460	1200	8265/6880
September 2015	580	1700	8298/4881
September 2015	500	1450	5879/7348

female. Based on observations, the females appeared to mature sexually only after attaining a total length of 415 mm. The relationship between total body length and absolute fecundity showed a mild but significant strength ($r = .569$, $p < .05$) as depicted in Figure 2. The presence of brooders, GSI and fecundity along with its seasonal cycle enabled to conclude that the spawning season of the *T. putitora* commences from July and extends up to September. The male proportion of fishes was recorded higher in 311–350 mm, 351–390 mm and 391–430 mm size groups and sex ratio was 1:0.8, 1:0.15 and 1:0.87, respectively. Remaining size groups of female fishes were higher compared to male. The chi-square values ranged from 0.10 to 12.56. In stock, female fishes were higher compared to male and sex ratio was 1:1.25 (male:female). The chi-square value was 3.20 and the difference was non-significant (Table 2). The range of the physicochemical parameters of the river Kosi at Ramnagar is depicted in Table 3. The water temperature varied from 18.4°C to 30.5°C. Maximum water temperature was observed in the month of May (30.5°C) and minimum (18.4°C) during January. Dissolved oxygen was recorded in very high concentration (6.6–14.46 mg/l). No free carbon dioxide was encountered. The other important parameters such as TDS, conductivity, transparency, velocity, chloride, carbonate, bicarbonate and total alkalinity varied between 123.9 and 143.8 µs, 17.5 and 115 cm, 0.46 and 2.95 m/s, 11.25 and

**Figure 2.** Bivariate regression relationship between total body length and absolute fecundity of *T. putitora* from River Kosi (Lesser Himalayan region).**Table 2.** Sex ratio of *T. putitora* from the Kosi river.

Size groups	No. of males	No of females	Sex ratio (M:F)	Chi-square (χ^2)	Remarks
311–350	5	4	1:0.8	0.10	Non-significant
351–390	20	3	1:0.15	12.56	Significant
391–430	24	21	1:0.87	0.20	Non-significant
431–470	31	45	1:1.45	2.56	Significant
471–510	24	38	1:1.58	3.16	Non-significant
511–550	10	21	1:2.1	3.90	Significant
551–590	3	14	1:4.67	7.12	Significant
Stock	117	146	1:1.25	3.20	Non-significant

11.36 mg/l⁻¹, 8 and 19 mg/l⁻¹, 105 and 118 mg/l⁻¹ and 110 and 133 mg/l⁻¹, respectively (Table 3).

Changes in breeding phenology

The breeding phenology of Golden mahseer in Uttarakhand region, India, appears to have undergone a transition over the last 10 decades. Analysis of metadata from published reports on Golden mahseer breeding phenology during 1911–2007 has been graphically represented in Figure 3 and compared with the present observation. Based on visual interpretation, it is perceptible that the present breeding phenology may likely have changed from what existed during 1911–1981. On a deeper note, the breeding phenology of golden mahseer may likely have gone through two distinct steps of transformation – (a) shifting and prolongation (1911–1981); (b) reduction and stabilization (1981–present). We hypothesize that the key driver behind these changes are a synergy of both recruitment overfishing and impact of climate change, with climate change being the most important factor.

Regional climate change patterns

The climate change pattern of lesser Himalayan regions in Uttarakhand, of which the present study is also a part has been quantified recently (UAPCC 2014). Multi-decadal climate data analysis from the weather station in Almora District (Uttarakhand), representative of the lesser Himalayan region (also nearest to present study site), has revealed – (a) annual mean air temperature has increased by 0.46°C in five decades (1955–2007); (b) 23% less average annual rainfall each decade (1955–2007); and (c) monsoon-peak shifted from July to August. Furthermore, multiple variants of recent climate simulation models have unanimously predicted the future climate

Table 3. Physicochemical characteristic of the Kosi river water.

Water parameters	Kosi river
Air temperature (°C)	24.1–37.0
Water temperature (°C)	18.4–30.5
Dissolved oxygen (mg/l)	6.6–14.46
Total dissolved solids (ppm)	123.9–143.8
Conductivity (µs)	217.5–252
pH	7.7–8.05
Transparency (cm)	17.5–115
Velocity (m/s)	0.46–2.95
Depth (cm)	45–215
Chloride (mg/l)	11.25–11.36
Carbonate (mg/l)	8–19
Bicarbonate (mg/l)	105–118
Total alkalinity (mg/l)	110–133

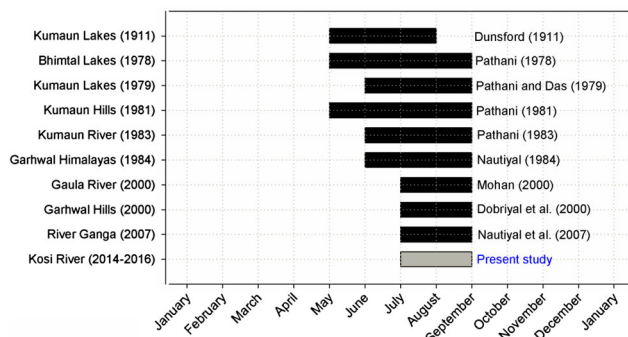


Figure 3. Chronogram of reported breeding season of Golden Mahseer *T. putitora* from Uttarakhand region, India (cited references provided in the references list).

scenario of the region. The annual mean air temperature has been forecast to increase from $0.9^{\circ}\text{C} \pm 0.6^{\circ}\text{C}$ to $0.6^{\circ}\text{C} \pm 0.7^{\circ}\text{C}$ in the 2030s. Seasonal air temperatures have also been forecasted to rise in all seasons except during winter. There is likely to be an increase in the Temperature–Humidity Index (THI) in many parts, thereby indicating that in the 2030s, most places in this region are likely to remain under a high temperature stress. In terms of precipitation, annual rainfall may increase from 60 to 206 mm in the 2030s and may vary between 1268 ± 225.2 mm and 1604 ± 175.2 mm. All seasons in the region are forecasted to have an increased rainfall, with the maximum increase (+12 mm) during monsoon months (June, July, August and September) i.e. breeding season of golden mahseers. However, the future peak of monsoon may shift from August to September.

Discussion

Reproductive biology and habitat quality

Reproductive processes in fishes are controlled by endo and exogenous aspects; endogenous aspects are represented by hormonal metabolism and exogenous by environmental factors, which are seasonally variable. Fish species need – specific environmental conditions during the reproductive period to guarantee the growth and survival of offspring (Jorgensen et al. 2006). Among reproductive traits, the gonadosomatic index (GSI) is widely used by biologists to indicate the maturity and periodicity of spawning and predicting the breeding season of a fish. The GSI values are directly proportional to the stage of maturity (Nautiyal 2011). Similar results on annual GSI pattern were observed for *T. putitora* by Arjamand et al. (2013) and in other cyprinids by Alam and Pathak (2010) from India. According to Nautiyal and Lal (1985), fecundity varied from 26,998 to 98,583 in the weight range of 3500–23000 gm. The higher fecundity was observed by Pathani (1981) in the same fish which ranged from 7108 to 18,486 and total lengths ranged from 33.90 to 51.70 cm. The mean value of absolute fecundity was estimated at 5566 eggs for fishes with mean total body length of 395 mm and mean body weight of 455 gm from a Mahseer hatchery in Jammu and Kashmir, India (Arjamand et al. 2013). The fecundity of large size fishes is linearly related to total length of fish. The Golden mahseer stocks of Garhwal hill region usually exhibit lower fecundity

than the present stock from lesser Himalayan region (Nautiyal and Lal 1988; Nautiyal 1994). In the present study, a mild but significant relationship between total body length and absolute fecundity may be due to the presence of higher number of eggs (more packed ovaries) in better conditioned females than in larger females; probable influence of condition factor exists besides the variable 'length' – not tested in the present study. This interference of fitness (condition factor) in determining egg production of females has been discussed in Jorgensen et al. (2006). Fecundity has significance in population assessment, recruitment success and hatchery production of a species (Mayank et al. 2016). The sex ratios have their own significance for they are helpful in detecting differential fishing, if any, in different periods of the year in the various size groups and thus the abundance of the sex at a time or throughout the year. In the present study, the slightly skewed population favouring abundance of females over males (overall sex ratio irrespective of size groups: 1.25 females per male) was found to be statistically insignificant. This has also been reported before from golden mahseer population(s) of greater Himalayan belt; reports from lesser Himalayan region do not exist for any plausible comparison. For example, Nautiyal (1994) reported that female ratio was higher than the males of *Tor putitora* in the Alaknanda and Nayar rivers during the spawning season attributed to difference in the time of ripening. This was also reported by Pathani (1994) in Golden mahseers from the Kumaun Lakes of Uttarakhand. Examination of sex ratio in *T. putitora* in the Ganga river (near Hardwar) revealed that males were predominant in the lower size and age classes and in most of the months, while females in the higher size classes and in winter (Bhatt et al. 2004). In general, male mahseer remain higher compared to female in immature stock while higher female in mature stock (Pathak et al. 2014; Mayank et al. 2016). The recorded size ranges of males (310–565 mm, 355–1750 gm) and females (315–580 mm, 260–2500 gm) from River Kosi in the present study were higher than the earlier reports from Himalayan foothills (Zafar et al. 2002; Langer et al. 2013) and lesser Himalayan region (Naeem et al. 2011; Patiyl et al. 2014). Interestingly, the maximum total body length reported by Naeem et al. (2011) for females (402 mm) and Patiyl et al. (2014) for pooled sex (wild: 452 mm, farmed: 547 mm) had close resemblance with the present study.

The water quality of Ganga river system, of which River Kosi forms a northern tributary, dramatically alters, yet remains favourable for hardy and exotic species (Tiwari et al. 2016; Dwivedi et al. 2017). The habitat quality of River Kosi as observed during the present study is listed in Table 3. Since golden mahseers were present almost round the year in the studied river stretch, it may be assumed that the range of recorded habitat parameters is well within the tolerance limits of the species i.e. comfortable for *T. putitora*. Sharma et al. (2015) reported that among all the environmental parameters, water temperature has the most influential effect on GSI of either sex of Golden mahseer; ambient water temperature for breeding is usually 18–22°C (Sharma et al. 2014). The prime importance of water temperature in influencing GSI values of other coldwater fish species (Rainbow trout *Oncorhynchus mykiss* 4.5–20.5°C optimum; Snow trout *Schizothorax*

richardsonii 18–20°C) in Himalayan region has also been reported (Sharma et al. 2014). The parameter following water temperature that has influence on breeding is rainfall (Sharma et al. 2014), through manifestation into other water quality parameters probably by bringing sudden change. Further research is required to estimate environmental and biological breeding thresholds of *T. putitora* for a better understanding of climato-hydrological control on natural breeding (Sarkar et al. 2017, 2018; Karnatak et al. 2018).

Changes in breeding phenology and regional climate change patterns

Stenothermal Coldwater fishes like golden mahseer presumably have narrower thermal and flow (precipitation) windows within which they attain sexual maturity and spawn, most susceptible to negative impacts of climate change (Whitney et al. 2016). On the other hand, implications of warming climate and changing precipitation pattern are more readily realized in upland cold regions (IPCC 2014). There are ample evidences that coldwater fish species often respond to changing climate by adjusting their breeding phenology – a form of evolutionary adaptation to ensure survival of the species (reviewed in Lynch et al. 2016). In the Indian scenario, region-specific adaptation in reproductive phenology based on local trends of changing climate along River Ganga has already been suspected and documented for some fishes (Sharma et al. 2015; CIFRI 2016a). Additionally, an advancement of breeding season in Indian major carps (*Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*) by 2–3 months, decrease in age at first maturity in female Rainbow trout *Oncorhynchus mykiss* (from 3+ years to 2+ years) and reduction in length at first maturity of female *Tenulosa ilisha* (30.9 cm from 34.1 cm) have been documented from Indian waters (Sharma et al. 2015). Although it appears there may have been a reduction in duration of breeding season and shift (delay) in onset of breeding in Golden mahseer population of Uttarakhand region, some stabilization in breeding phenology appears to have been attained since 2000s as well. This might be due to phenotypic plasticity (reproductive) already present within the species that aided in adapting to changing climate over generations of natural selection; a hypothesis worth investigating. Whether the stabilized breeding season of golden mahseers in Uttarakhand region is presumably 'safe' for the species under continuously changing climate needs further validation to comment upon. For this purpose, attempts need to be directed towards quantifying the breeding thresholds (environmental and biology) of Golden mahseer (Sarkar et al. 2017; Karnatak et al. 2018; Sarkar et al. 2018). Quantification of such environmental and biological thresholds for breeding in fishes is crucial for a better understanding of population–environment interactions and assessing vulnerability of a species to climate change (Peer and Miller 2014; Whitney et al. 2016). Perceptions of local fishermen and anglers having experience in Mahseer fishing reveal a general awareness regarding the overall 'prolongation' of breeding phenology happening due to changing climate. The primary climatic factors that were listed from the qualitative survey included lesser pre-monsoon, warmer waters and erratic monsoon rains (CIFRI 2016b). However, no awareness exists

regarding a 'reduction and stabilization' phase of the breeding phenology over the recent decade which appeared following our historical data analysis (Figure 3). Further studies replicated periodically (in 5/10 years) are required to validate the present findings, assumption and/or speculations, important for such a 'conservation-priority' species.

To conclude, the species seems to have been continuously adapting to changing climate which further signifies the fact that anthropogenic stresses are to be kept minimal if they must be given a chance for successful replenishment of dwindling natural stocks. Conservation of wild population is not only important for sustainable fishery but also it plays important role in National development. This study has provided baseline information about the variation of reproductive potential of *T. putitora* with climatic implications in natural habitat and results described have important implications for sustainable fishery management and conservation programmes. Mahseer, which is the most promising fish of the State, can be protected and conserved through development of strong biological database of fish in the changing climatic scenario with concerted efforts from all the concerned stakeholders.

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Disclosure statement

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