THE MALE
After alternately diving with the female to spawn, the male collects mouthfuls of air to deposit in the egg chamber.

THE FEMALE
Following spawning the female leaves the burrow permanently, leaving the male to attend to all the brood care.

EGG CHAMBER
After eggs are fertilised underwater, the male brings down air to increase oxygen levels for larval development.

EARLY FRY
When water touches the eggs, it stimulates the larvae to emerge. When ready to hatch, the male removes all the air.

The *secret life* of MUDSKIPPERS

What goes on underground stays underground – until now! One aquarist shares his experiences of breeding mudskippers.

DID YOU KNOW?

After hatching, the male usually starts digging a new burrow, though sometimes he goes back and reuses an older one.

HANS-GEORG RUPP
A keeper and breeder of 50 years, he specialises in brackish water fish and inverts.

ILLUSTRATION: STEVE HALL

A DECADE AGO, mudskippers were briefly the focus of mainstream media attention after Professor Atushi Ishimatsu and his co-workers made an unusual discovery.

They were studying the underground burrows of Shuttle's mudskipper, *Periophthalmus modestus*, which the male digs in the mud of the intertidal zone, where the mudskippers live. During earlier research, Ishimatsu and his team had confirmed the existence of an air pocket in purpose-built egg chambers inside the burrow. But now they were able to show that in this bubble above the water level, the mudskipper's eggs, sticking to the walls and ceiling of the chamber, were apparently well supplied with air brought in by the male, in his mouth, during low tide. Without this extra air, the environment would be too low in oxygen for the larvae to develop.

But that wasn't all! The biologists were also able to demonstrate the hatching of the larvae was triggered by the fact that the male removed the air from the egg chamber at the end of larval development. This took place at nocturnal high tide, when the raised water level meant the eggs dipped into the water. And since the entrances to the burrow were submerged during high tide, the larvae were able to leave the burrow.

Still, one question remained unresolved. Exactly when did the males bring the air into the egg chamber? Two possibilities presented themselves: either the males would bring air into the egg chamber before egglaying, so that spawning and insemination would take place above the water level; or the whole process took place before the introduction of the air.

Because the nests of male mudskippers performing courtship displays had been found with air in the egg chamber – but as yet no eggs – the researchers speculated that spawning and insemination took place out of the water. They knew scientists had already observed this in the Four-fingered lipsucker, *Andamia tetradactylus*, and thought this might be the case with mudskippers too.

SHUTTERSTOCK

Males display and fight for territory.

Now we know!

Now, however, we know more. Three years ago I wrote an article about the successful breeding of the Dusky gilled mudskipper, *Periophthalmus variabilis*, in the aquarium. I had observed that sometimes an increase in water could be seen inside the entrances of the 'Y' or 'J'-shaped burrow during the artificial low tides I created, but only after the female had left the burrow permanently.

Until then, the female had shared the burrow with the male for several hours and the pair had taken turns to dive down the muddy water-filled shaft. Since the female evidently no longer visited the burrow, and the larvae hatched about nine days later, the suggestion was that the alternate diving of both fish was related to spawning and insemination of the eggs, and the subsequent increase in water inside the burrow was caused by the air introduced by the male displacing the water from the egg chamber after laying and fertilising.

> "The eggs, sticking to the walls and ceiling of the chamber, were apparently well supplied with air brought in by the male, in his mouth"

As plausible as all that may sound, I couldn't be certain from the evidence. It couldn't be ruled out that there was already a thin layer of air inside the egg chamber before spawning, and that the male introduced additional air only after mating, which would cause the increase in water I'd observed.

HANS-GEORG RUPP

At a scientific congress in 2011, professors Ishimatsu and Graham formulated some key questions concerning the reproductive behaviour of mudskippers and asked for direct video evidence on the question of exactly where they spawn – in air or in water. Again, the biologists confirmed the hypothesis of spawning in air, and suggested that the oxygen brought in before the act of spawning could possibly lead to the oxidation of the egg chamber walls, and would therefore minimise the loss of oxygen during larval development.

Unfortunately, any firm proof of the conditions under which spawning and insemination take place failed to appear, because there was no easy way to see into the egg chamber from the outside. Introducing an endoscope into the egg chamber via the entrances of the burrow was no good because this would disturb the breeding behaviour of the fish. Inserting one directly into the egg chamber would be difficult because the chamber is hidden deep in the mud and would be impossible to locate precisely. In addition, researchers would have to be very careful not to introduce any air into the egg chamber when they inserted the endoscope, and the artificially manufactured endoscope access would have to be hermetically sealed again so that no air later introduced by the male could escape from the chamber. Last but not least, the problem of how to prevent contamination of the endoscope lens as it's inserted into the egg chamber would need to be solved.

Also, of course, in the egg chamber itself you'd only be able to observe spawning and insemination if it took place in the air space – otherwise the turbidity of the water would make it impossible to record the process.

Breakthrough!

At last, after 36 filmed breeding cycles and several thousand hours of video footage, my mudskippers solved the problem in their own way and revealed their secret! Twice the male built his burrow directly against the glass wall of the tank. This was covered with black card in such a way that not only the burrow's shaft but also the egg chamber could be easily observed once the cardboard was removed.

In two non-consecutive breeding cycles, I was actually able to observe and capture the spawning and insemination inside the egg chamber. It turned out that males and females not only dive alternately into the shaft of the burrow, as I'd already observed, but actually into the egg chamber too.

In the first breeding cycle, because

HABITAT
Mudskippers have some unique adaptations to inhabit the rich, muddy intertidal zones of tropical estuaries.

SHUTTERSTOCK

Shuttle's mudskipper, the first species known to make an air chamber.

ALPSDRAKE CREATIVE COMMONS

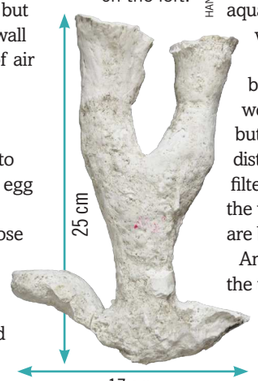
the water was so murky, only the male and female's alternate on-the-back swimming at the ceiling of the chamber could be filmed. Once she had left the burrow and the male had begun to introduce the air, yellowish eggs could be seen on the glass wall and on the edge of the dome-shaped ceiling of the egg chamber. Although the actual attachment of the eggs wasn't recorded, it was clear they had been deposited there when the chamber was flooded.

In the second cycle, I was able to film both the glass wall of the egg chamber and the entrance to the burrow at the same time. This not only showed which of the fish was currently inside the burrow, but also the spawning onto the glass plate in the water-filled egg chamber itself.

Since the eggs were not only attached to the chamber ceiling but also to these areas of the glass wall exposed after the introduction of air by the male, this explained why, again and again, I found single larvae a day or two before the hatching of the clutch. It's easy to imagine how small waves in the egg chamber, caused by the male bringing in new air, submerge those eggs that hang just above the water level, and trigger the hatching of single larvae.

Due to the alternate diving and on-the-back swimming of the male and female in the egg chamber, and because no more insemination was observed after the female had left the burrow, we can assume that not only spawning but also insemination had taken place in the water-filled egg chamber.

Plaster cast of a burrow with egg chamber on the left.



HANS GEORGE RUPP

Mudskippers to try at home

Setting up a mudskipper tank requires some ingenuity and lots of water chemistry management. Mudskippers are brackish fish, so they need a mixture of fresh and saltwater. With the aid of a hydrometer to measure specific gravity, you're aiming for a gravity reading of between 1.005 and 1.015, using a marine salt – aquarium tonic salt is different and won't do the job.

The tank needs to be designed in such a way as to allow a wet and a dry area. This should involve a high bank of incredibly fine sand, or even aquarium mud, into which the fish will make a burrow.

Filtration is difficult, partly because you need a filter that can work with a shallow area of water, but also since biological activity is disturbed in brackish conditions. The filter should be greatly oversized for the water volume, as mudskippers are both greedy and messy.

Another consideration is keeping the tank sealed. Mudskippers climb – and very well, even up sheer panes of glass. Unless the tank is locked down like Fort Knox, they'll be out and on the floor.

Mudskippers 'walk' on their pectoral and pelvic fins.

SHUTTERSTOCK

Making a burrow, one mouthful at a time.

SHUTTERSTOCK

NEIL HEPWORTH

FACTFILE

DWARF INDIAN MUDSKIPPER

- **Scientific name:** *Periophthalmus novemradiatus*
- **Origin:** Coastlines of the Philippines, Malaysia, Thailand and India
- **Habitat:** Estuarine mangrove swamps over mud
- **Size:** Reaches around 6.5cm fully grown
- **Tank size:** 80x30cm footprint minimum
- **Water requirements:** Brackish, ideally with an SG of 1.005 to 1.010, and hard, alkaline water; 7.5 to 8.5pH, hardness 15 to 25°H.
- **Availability and cost:** Only specialist retailers carry these, with prices starting around £15 each

Water volume
40 l+

map could be re-centered if poss. area should include philippines

We Recommend... Two to try

ATLANTIC MUDSKIPPER

For a common species, this one is pretty hard to find on sale. Because of their size, it's advised to house them singly or in sexed pairs – these are highly territorial fish!

In the tank they spend more time out of water than in it, but the rule still applies – good filtration is necessary.

Note that these are excellent and fast jumpers. Large fish in particular can perform a dazzling leap, so be cautious when lifting the lid for maintenance.

DWARF INDIAN MUDSKIPPER

Possibly one of the most fun fish you'll ever keep, these are tiny compared to other 'skippers, and eventually (read 'quickly') become hand tame, jumping into an open palm to grab food.

Aim to provide about 30x30cm of floor space per individual, and a tank no smaller than 80x30cm for reasons of water quality. Create a bank at one or both ends as the fish need lots of land, and decorate with plastic plants if you want the tank looking pretty – salt will kill almost any plant except mangroves, which get huge.

FACTFILE

ATLANTIC MUDSKIPPER

- **Scientific name:** *Periophthalmus barbarus*
- **Origin:** All along the western coastline of Africa
- **Habitat:** Estuarine mangrove swamps over mud
- **Size:** Around 15cm fully grown
- **Tank size:** 120x30cm minimum
- **Water requirements:** Brackish, ideally with an SG of 1.005 to 1.015, and hard, alkaline water; 7.5 to 8.5pH, hardness 15 to 25°H.
- **Availability and cost:** Only specialist retailers carry these, with prices starting around £20 each.

Water volume
108 l+

NEIL HEPWORTH

PFK