

Supplemental Table 1. Empirical evidence for genes as leaders and followers in evolutionary transitions between genetic polymorphism and polyphenism and between alternative phenotypes and monomorphism.

Transition ^a	Taxon	Trait	Description	Evidence ^b	Confidence of inferred transition ^c	Desirable additional evidence ^d	References
Genes as leaders							
Polymorphism → polyphenism (L1)	Carabid beetles (genus <i>Calathus</i>)	Wing length	Short-winged sedentary and long-winged dispersal morphs	Var, Pop, Exp, Phyl	**	1, 2	[1-4]
Polymorphism → polyphenism (L1)	Water striders (genus <i>Gerris</i>)	Wing length	Short-winged sedentary and long-winged dispersal morphs	Var, Pop, Exp, Phyl	*	1, 2	[5-7]
Polymorphism → polyphenism (L1)	Teleost fish	Sexual morphs	Several transitions from genetic to temperature-dependent sex determination	Exp, Phyl	*	1, 2, 3	[8, 9], but see [10]
Polymorphism → polyphenism (L1)	Reptile ancestor	Sexual morphs	Transition from genetic to temperature-dependent sex determination	Exp, Phyl	***		[10]
Polymorphism → polyphenism (L1) ^e	Pygmy grasshoppers (family Tetrigidae)	Colour morphs	Possible transition from genetic colour polymorphism to morph induction via the rearing environment ^e	Exp, Var	*	0, 3	[11-13]
Polymorphism → polyphenism (L1) ^f	Locusts in the genus <i>Schistocerca</i>	Colour morphs	Possible transition from genetic colour polymorphism to morph induction by crowding ^f	Exp, Phyl	*	2, 3	[14-16]
Polymorphism → Monomorphism (L2)	Damselflies	Female-limited colour morphs	Multiple losses of different morphs in species of the genera <i>Ischnura</i> and <i>Enallagma</i> and in populations within the species <i>Ceriagrion tenellum</i> .	Var, Exp, Pop, Phyl	***	1, 2, 3	[17-20]
Polymorphism → Monomorphism (L2)	Poison frog (<i>Dendrobates pumilio</i>)	Colour morphs	Multiple losses of some morphs in different populations	Exp, Pop	*	2, 3	[21]
Polymorphism → Monomorphism (L2)	Happy-face spider (<i>Theridion grallator</i>)	Colour morphs	Colour polymorphism typically present in both sexes, but limited to one sex in some island populations	Exp, Pop	*	2, 3	[22]

Polymorphism → Monomorphism (L2)	Side-blotched lizards (<i>Uta stansburiana</i>)	Alternative mating strategies (throat colour)	Eight independent losses of one or several morphs in different subspecies (sneaker morph always lost)	Var, Exp, Pop, Phyl	***		[23]
Polymorphism → Monomorphism (L2)	Northern swordtails (genus <i>Xiphophorus</i>)	Alternative mating strategies (male size)	Y-linked size polymorphism, large males have been lost in a subset of species	Var, Exp, Pop, Phyl	**	1,2	[24-26]
Polymorphism → Monomorphism (L2)	Mocker swallowtails (<i>Papilio dardanus</i>)	Female-limited, mimetic colour morphs	Mimetic morphs have been lost in several subspecies (at least two independent losses)	Var, Exp, Pop, Phyl	***	3	[27-29]
Polymorphism → Monomorphism (L2)	Cotton-stainers (genus <i>Dysdercus</i>)	Mimetic colour morphs	Polymorphic mimicry typical across the genus, transition to monomorphism in <i>D. blotei</i>	Phyl, Pop	**	1	[30]
Polymorphism → Monomorphism (L2)	Tree snails (genus <i>Amphidromus</i>)	Shell chirality	Transitions from enatiomorphic to sinistral or to dextral (at least one of each transition)	Var, Exp, Pop, Phyl	**		[31, 32]
Polymorphism → Monomorphism (L2)	Water striders (genus <i>Gerris</i>)	Wing length	Long-winged morph has been lost in a subset of species	Var, Exp, Pop, Phyl	*	0, 1, 2	[6, 7]
Polymorphism → Monomorphism (L2)	Carabid beetles (genus <i>Calathus</i>)	Wing length	Some species have lost the short-winged, others the long-winged morph	Var, Exp, Pop, Phyl	***	1, 2	[1-4]
Genes as followers							
Polyphenism → polymorphism (F1)	Mud plantains (genus <i>Heteranthera</i>)	Style position	Stochastic left-right asymmetry typical in the genus, replaced by a genetic factor in <i>H. multiflora</i>	Var, Exp, (Phyl)	**	3	[33-36]
Polyphenism → polymorphism (F1)	Bloodworts (family Haemodoraceae)	Style position	Stochastic left-right asymmetry typical in the family, replaced by a genetic factor in <i>Barbaretta aurea</i> and <i>Wachendorfia thyrsiflora</i>	Var, (Phyl)	**	1	[34-37]
Polyphenism → polymorphism (F1)	Reptiles	Sexual morphs	Several transitions from temperature-dependent to genetic sex determination	Exp, Phyl	**	1, 2, 3	[10, 38, 39]
Polyphenism → polymorphism (F1) ^g	Teleost fish	Sexual morphs	Possibly several transitions from temperature-dependent to genetic sex determination ^g	Exp, Phyl	*	1, 2, 3	[8] but see [9]

Polyphenism → polymorphism (F1) ^h	Social insects	Queen and worker castes	Probably several transitions to genetically determined castes; reverse transitions are also possible ^h	Exp, Phyl	*	1, 2, 3	[40-42]
Polyphenism → Monomorphism (F2) ⁱ	Priapum fish (family Phallostethidae)	Position of the intromittent organ	Conspicuous left-right asymmetry in most species of the genus, up to four species are exclusively left-sided or exclusively right-sided ⁱ	Var, Phyl	**		[36, 43]
Polyphenism → Monomorphism (F2) ⁱ	Fiddler crabs (genus <i>Uca</i>)	Claw morphology and size	Conspicuous claw asymmetry in males of most subgenera, transition to 'right-handedness' only in <i>Gelasimus</i> ⁱ	Var, Exp , Pop, (Phyl)	***	(1, 3)	[44 , 45 , 46]
Polyphenism → Monomorphism (F2)	Hawk moths (family Sphingidae)	Colour morphs in caterpillars	Distinct colour morphs typical across the family, loss of one morph in <i>Manduca sexta</i> and other species (exact number of losses unknown)	Var, (Exp), Phyl	**	0,1,2	[47-49]
Polyphenism → Monomorphism (F2)	Ants (genus <i>Cardiocondyla</i>)	Alternative male strategies	Fighting, harem-defending morph vs disperser; prob. four independent losses of the disperser phenotype	Var, Exp, Pop, Phyl	***	1	[50-52]
Polyphenism → Monomorphism (F2)	Several ant and bee species	Queen and worker castes	Independent losses of the worker caste in several social parasites, loss of the queen caste in some species with worker reproduction	Var	*	0, 2, 3	[53, 54]
Polyphenism → Monomorphism (F2)	Spadefoot toads (genus <i>Spea</i>)	Omnivorous and carnivorous morphs	Carnivorous morph induced by shrimp ingestion, non-inducible in some populations	Var, Exp	*	3	[55, 56]
Polyphenism → Monomorphism (F2)	Water striders (<i>Aquarius remigis</i>)	Wing length	Genetic variation for threshold, long-winged morph becomes non-inducible in some populations	Var, Exp, Phyl	**	3	[57]
Polyphenism → Monomorphism (F2)	Horned beetles (genus <i>Onthophagus</i>)	Horn morphology and size	Probably many independent losses of horns (exact number unknown)	Var, Exp, Phyl	**	3	[58]
Polyphenism → Monomorphism (F2) ^j	Fig wasps	Disperser and fighter morphs ^j	Independent losses of either the fighter or the disperser morph	Var, Phyl	*	0, 3	[59, 60]

- ^a L1, L2, F1, and F2 refer to phenotype control transitions in Figure I in Box 1
- ^b Var: Presence of alternative phenotypes in several related species
Pop: Population or species-level variation in the presence of specific phenotypes
Exp: Experimental evidence for phenotype control (crosses between different morphs and/or identification of environmental cues)
Phyl: Reliable phylogeny
- ^c Confidence of inferred transition: *** high, ** medium, * low
- ^d 0: Confirmation of presumed trait determination
1: Experimental crosses in additional species of the group
2: Tests for interaction with environmental conditions
3: Reliable phylogeny
- ^e In pygmy grasshoppers (family Tetrigidae), genetic colour polymorphism has been inferred in several species of the genus *Tetrix* [11]. In *Tetrix ceperoi* and some populations of *T. subulata* however, it has been suggested that morph determination is further influenced by the rearing environment [12], which could indicate a genetic polymorphism to polyphenism transition. However, the influence of the rearing environment on colour morph is controversial, given that different populations of *T. subulata* display no environment-dependent plasticity, and that colour-morph specific mortalities under certain rearing conditions could provide an alternative explanation to the suggested environmental influence on morph determination [11, 13].
- ^f Several locust species in the genus *Schistocerca* (subfamily Cyrtacanthacridinae) display striking variation in colour phenotypes. In these species, colour morph is a plastic trait, with a shift from green morph types to black and yellow morphs triggered by physical contact and other cues of local crowding [14, 15]. In contrast, similar colour patterns are largely genetically determined in two species [16] belonging to subfamilies closely related to the Cyrtacanthacridinae [14] (the Australian plague locust *Chortoicetes terminifera*, subfamily Oedipodinae, and the migratory grasshopper *Melanoplus sanguinipes*, subfamily Melanoplinae) with a relatively minor influence of environmental factors on the green colour in one of them (*C. terminifera*) [16]. The polyphenism in *Schistocerca* may therefore have derived from a pre-existing genetic polymorphism.
- ^g In teleost fish, some authors argue that there were reciprocal transitions between genetic- and temperature-dependent sex determination [8], whereas others suggest that only transitions from genetic to environmental determination occurred in fish [9]. These discrepancies are mainly due to uncertainties in the phylogenies and the associated variation in ancestral state inferences, as well as uncertainties in the classification of species into the environmental or genetic sex determination categories [9]. The latter is also complicated by species with combined effects of genetic and environmental cues on sex determination [9, 61, 62].
- ^h Several transitions from polyphenism to genetic polymorphism may have occurred in social insect species. Queen and worker phenotypes are typically presumed to represent cases of polyphenism with relatively minor influences of genetic variation [54]. In some species however, queen and worker phenotypes are genetically determined [40-42, 63]. The relative contribution of genetic and environmental influences on queen and worker differentiation is however poorly documented most species, and reciprocal transitions between genetic polymorphism and polyphenism are possible in some groups [40, 63].
- ⁱ Note that the Phallostetid fish and fiddler crab case studies are the best supported examples in a wealth of additional examples indicating transitions from conspicuous asymmetry (stochastic polyphenism) to monomorphism. For the additional examples not included here, there is either incomplete experimental and/or phylogenetic evidence. However, the overall patterns strongly support the view that conspicuous random asymmetries are typically not genetic polymorphisms but stochastic polyphenisms. These examples have been comprehensively reviewed elsewhere (e.g., [36, 46, 64, 65]).

^j Many independent losses of either the fighter or the disperser morph have occurred in male fig wasps [59]. Fig wasp male phenotypes were traditionally considered to be genetic polymorphisms, maintained by frequency-dependent selection [66, 67]. However, some authors favour a conditional determination of the phenotype, with the disperser morph being induced by limited local mating opportunities [68-70]. Correlational data from natural populations are sometimes consistent with theoretical models assuming genetic morph determination and sometimes with models assuming conditional expression [60], suggesting that there could also be variation among species in the mode of phenotype control. Fig wasps might thus be an ideal study system for the evolution of phenotype control mechanisms, but their particular life-style makes experimental manipulations very difficult.

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