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Some Thoughts on the Laboratory Cage Design Process

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A block to progress in the design of cages and other restricted environments for animals has been the notion that animal and human needs are necessarily in conflict. The process of design should list the established and suspected animal needs separately from a list of human needs — husbandry and experimental. Comparison of the two lists will often show up more compatible needs than expected, and design features can be worked out to fulfill them. Adjustments may then be made where needs are less compatible until "sufficient" compatibility is achieved. An innovative design for a mouse cage is described, to show that this process can lead to harmony, new observations on animal needs, and to unforeseen benefits to both animals and humans.

Zusammenfassung

Ein neuartiger Mäusekäfig, der Cambridge Käfig, wird hier beschrieben. Dieser Käfig hat die folgenden Vorzüge für die Tiere: genügend Raum zum Nisten, gute Lüftung ohne Zugluft, Reduktion von Licht und Lärm, freier Zugang zum Wasser und weitläufiger Bewegungsraum. Die Vorzüge für den Menschen sind niedriger Preis, einfaches Säubern und Unterbringen sowie mehr entwöhnte Junge per Weibchen, Anpassungsmöglichkeit der Zusatzteile, wie sie für Verhaltensexperimente notwendig sein könnten, und relativ geringe Heizungskosten zum Warmhalten der Nester.

Introduction

In the third edition of the UFAW handbook (Tuffery, 1967, p. 297), there is a section on "The Cambridge Mouse Cage," which describes "an important advance in the design of cages" that takes as its starting point "the mouse's wishes and convenience, as deduced from behaviour studies." Clearly, this prestigious guide to the care and management of laboratory animals was recommending that the users of the guide take note of a proposed advance in the conceptualization and design of mouse cages. However, as far as I am aware, no one has taken much notice of the handbook's recommendation. By hindsight, one can surmise that this has occurred because of ambivalence about considerations of animal welfare.

The present article outlines the sort of thinking process that ought to underlie the design of all restricting environments for animals in the 80's, when one hopes that it has at last become respectable to consider animal needs as well as those of human beings. In this paper, I have taken as an illustration of this concept the very breeding cage described in the UFAW handbook mentioned above.

Needs in Conflict

One block toward progress in improving cage designs has been the assumption that human and animal needs must necessarily be in conflict. For example, humans must restrict the activity of their animals, whereas the animal wants freedom; humans want disease-free ani-

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mals, but the animal's behavior in relation to excretion is unhygienic; humans want a cage that is easy to clean, store and assemble, but an animal wants his "micro-environment" to be "natural," and natural environments do not lend themselves to easy handling.

This block led, in instances where the animal's needs *were* considered, to a design that largely thwarted humans. Jewell (1964) was probably the first to consider a mouse's actual needs. His design included a nest area and a separate exercise area; but it was costly, unhygienic, and difficult to wash, store, and assemble. The design also proved less than ideal for the mouse — but this deficiency occurred because investigation into mouse needs had simply not gone far enough (Wallace, 1981a). It appears as though Jewell's cage was not perceived by the scientific community as a move in the right direction. Or, if it was seen as a real advance by people who had humane ideas, these ideas were considered by many to be unscientific at the time of Jewell's work, and no one had sufficient interest to do much more investigation into an area like improved cage design.

When I was asked in 1959 to set up a mouse breeding laboratory, and encouraged to put my own ideas into it, I was very unsatisfied with current cage designs. I did not know where to start to work on improving them, but a particular comment implying an inevitable *thwarting* of human ends indicated a potentially fruitful direction to follow. The comment was about a typical "shoe-box" mouse cage (Fig. 1), "But even this one, where the bottle is well off the cage bottom, gets too damp because the mice *will* tend to build their nests up to the bottle spout, and the water siphons out." I was also shown a shallow cage, with the comment: "This one not only siphons out, [but] the mice [also] shore sawdust over the sides of the cage and make a mess on the laboratory floor."

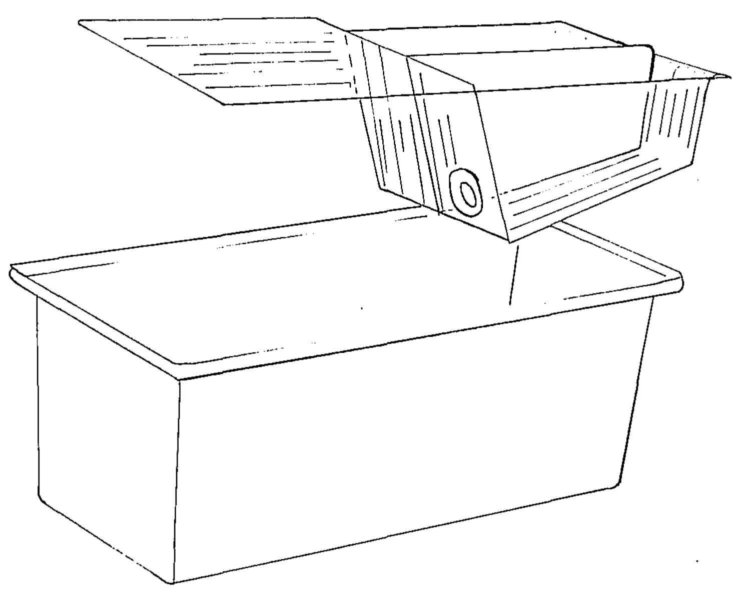

FIGURE 1. *A typical modern mouse cage.* Note its "shoe-box" shape. The lid is basically a flat wire sheet bent in three places to form a trough, with two compartments separated by a fixed divider. There is no shelter, and the area under the two compartments is too high (3 cm) at the ridge for making a snug nest area. It fits onto a deep, narrow-rimmed plastic box. The overall internal dimensions of the box are: 30 cm x 12 cm x 12 cm (height); volume, 3,120 cc.

It occurred to me that in these kinds of cages the needs of the mice were being thwarted equally as much as the needs of humans. That is, in shovelling sawdust around, the mice were trying to achieve something that the designers had made impossible: a "snuggable" nest area in which manipulation of the bedding provides a nest whose temperature can be controlled by the mouse. The provision of bedding was useless unless the mice could use it to construct such an area. I have since been sent a photograph (see Barnett, 1975) of a rat's attempt to achieve the same effect in a typically "unsnug" rat cage.

I then tested this idea using mice of many strains. Only some of the results of these experiments were published, as there was no interest in the topic at the time, but the most successful design was described in a series of papers that quoted figures quantifying success in the terms that were then exclusively acceptable: mouse productivity, low labor input, and low capital cost of production (Wallace, 1965, 1968; Wallace and Hudson, 1969; and Wallace, 1971a). The final version of my cage is known as the "Cambridge cage" or the "Wallace design" (shown in Fig. 2 and 3, with a mouse and litter in occupation). (Cages meeting these design criteria may be purchased from Cope and Cope Ltd., 57 Vastern Road, Reading, U.K., or Philip Harris Biological Ltd., Oldmixon, Weston-Super-Mare, Avon, U.K.)

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FIGURE 2. *The Cambridge cage.* The lid is basically a flat expanded wire sheet, bent in three places to form a trough, with a relatively large food compartment separated by a removable divider from the bottle compartment. There is a shelter formed by a solid sheet placed on the shallow slope of the food compartment, and the area under the food compartment is low enough (2.2 cm) at the ridge so that the nest area under the shelter can be made "snug." It fits onto a shallow smooth-rimmed plastic bowl. The overall internal dimensions of the bowl are: 27 cm x 22 cm x 8 cm (height); volume, 4,750 cc.

Needs Must Be Considered Dispassionately

I hope that, in today's climate, human and animal needs can be looked at dispassionately, without assuming that these needs must necessarily be in conflict. The process of design should be studied and better ways found for testing the design against both human and animal needs, initially ignoring the question of compatibility. Then, when both sets of needs have been investigated and listed, the question of compatibility can be tackled as an exercise in its own right. This will lead to progressive adjustments in design within the limits imposed by each set of needs, until sufficient compatibility is achieved. The word "sufficient" is important. Complete compatibility is never achieved, but there comes a point in making changes in design when the cost of further improvement threatens to outweigh the further benefits that can be achieved in the light of present technology and of our current understanding of animal needs. Any "sufficiently compatible" design should be described in ways that indicate areas worthy of further research.

Needs Which Are Compatible May Even Be in Harmony

A design that achieves sufficient compatibility between human and animal needs has *had* to incorporate an understanding of the broader issues in animal ethology. Other areas that are not sufficiently understood will then become apparent, because the new design will permit the observation of behaviors that have not previously been studied. Once these are recognized, the design itself may be amenable to further improvement or, as in my design, it may be found that the design is already compatible, without any need for alteration, with new kinds of ethological observations. That is, there may be a harmonizing of human and animal needs in the "sufficiently compatible design," an unexpected, and therefore pleasing, development.

Such a serendipiditous outcome occurred in the designing of the Cambridge cage when a "snuggable" nest area had been provided, and the mice began to

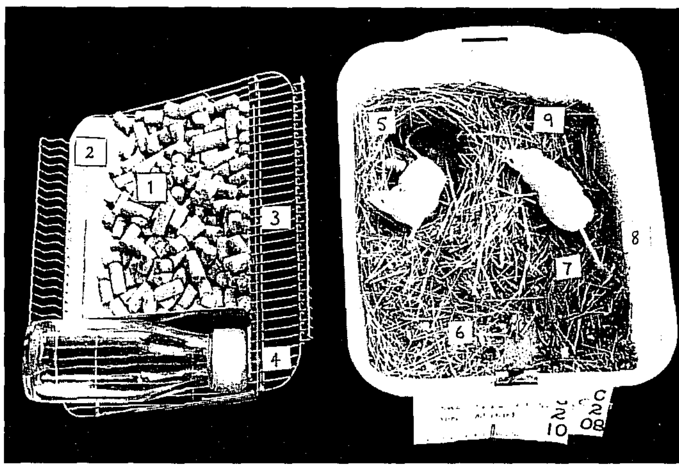

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FIGURE 3. *The design features meeting mouse needs.* (1) The food (hard pellets) in the overhead trough is accessible through the *upright* bars. The space between the bars allows manipulation by paws and jaws. (2) The shelter excludes drafts all round the area above the nest: it and the nest area (5) form a tunnel opening at the end under the bottle. The shelter also reduces light and noise. (3) Access to food and water is on the right side only, so that the unsheltered part of the wire frame (3) allows ventilation of this area, where excretion occurs (7 and 9); on this open side the mice can hear and smell other mice in neighboring cages. (4) The capillary tube allows easy access for drinking, is too narrow to allow pollution by mice or bedding, is low enough for the smallest weanling to reach, and does not drip unless the cage is severely jolted. (5) The nest area, with nest opened to show young inside. Mice lower the nest temperature as the young grow, by enlarging the aperture of the tunnel (2) at the point where they leave the nest for food and water. Note that there are no excreta in the nest area, and that mice have built the bedding up to the ridge of the trough (when the lid and shelter are on) and up inside the nest area, thereby exluding drafts from under the trough. Mice nest under the bottle persistently only if the wall holding the racking is cold (e.g., an outside wall with no insulation). The woodwool is pliable and chewable: the mice have lined the nest with smaller softer pieces. (6) The area under the bottle is not used by the mice for nesting (as in other cages where this causes the water to siphon out), but instead, they keep the bedding here pressed down for egress to the activity area (7). (7) The right side of the cage, with the front (6), form an activity area and the mice excrete on this side (7 and 9), where it is well ventilated (3). The whole floor area is larger than in other cages of similar volume, thus maximizing the available activity area. (8) The sides of the bowl are high enough for "looping the loop" in the exercise area (a possible response to confinement), grooming and social encounters; they are lower than other cages of similar volume, thereby maximizing ventilation through the open bars. Wild mice thrive and breed better in this cage than others: restriction of activity seems to be the only cause of trouble (see Wallace, 1981, which emphasizes the importance of the shape and size of the activity area). (9) Urination spot: mice usually choose this site. The sawdust along this side is absorbent, which prevents excreta from being carried on the feet to other parts of the cage.

confine their sawdust shovelling to the sides of this area; it was then observed that the mice exited chiefly at one end of the area. The observation of this behavior was utilized in completing the design such that the whole cage could be kept dry. The areas of access to food and water were placed so that the use of this chief exit ensured that the mice kept the spout of the bottle free of bedding as they squirmed under it. In addition, a user of the cage design pointed out that the dip in the center of the cage lid provided some barrier to the onslaught of dominant animals in male store cages, thereby reducing fighting.

Again, tests of different "shelter" materials, in which observations were made on the relationship between these materials and nesting, has produced data (unpublished) on the relative importance of control — by the animal in the nest area — of smell, light, and noise levels, as well as of temperature. Or again, the use by females and young of a particular spot for urination, which can be more clearly observed in this design than in previous ones, has led to experiments (unpublished) about the female (rather than male) use of urine in communication. Lastly, the simple shape of the parts of this design has led to the use of the cage in conjunction with certain other experimental accessories in which the behavioral aspects of the study are important; these were experiments in which other designs were not adaptable (Wallace, 1968, 1981b; Wallace and Hudson, 1969; Wallace, 1977).

A Lesson From the Work in Mouse Cage Design

In today's climate of changing attitudes toward animal welfare and rights, as well as to the human right to the esthetic satisfaction of attending to these concerns, any cost-benefit analysis must include factors that evaluate these intangibles. The following figures (Fig. 2-5) and tables (Tables 1 and 2) indicate that these factors were appreciated in the design process of the Cambridge cage and indicate how this process may be applied to other species.

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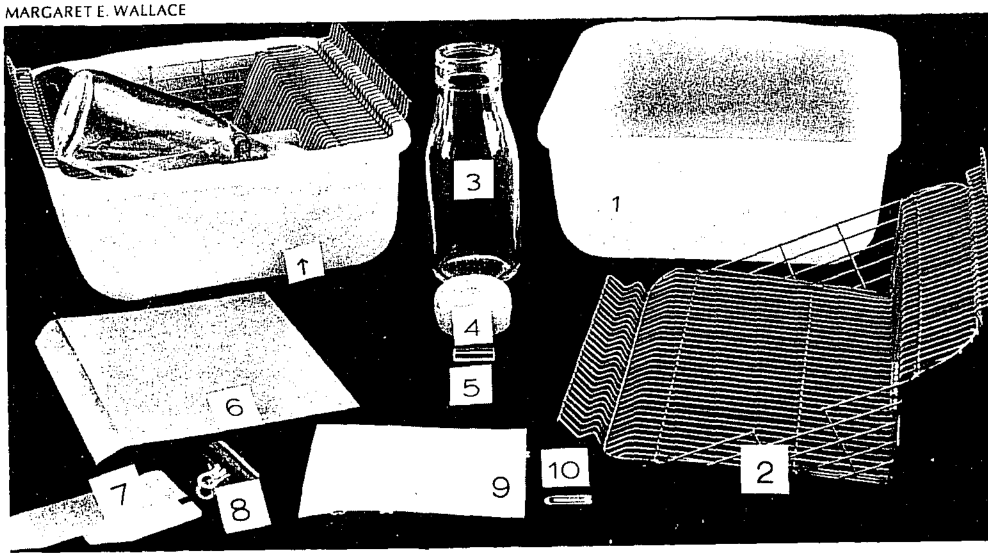

FIGURE 4. *The design features meeting human requirements.* The assembled cage is indicated by an arrow. It shows the food trough, comprised of the shelter (on the left side) and upright bars of wire frame (on the right side), and the divider (see also Fig. 2); the trough holds food for 1 to 2 weeks so that filling up the trough coincides with the change to a clean bowl. At the tip of the arrow is the lowest

point of the trough, 2.2 cm above the bowl floor—this amount of clearance prevents the mice from being crushed underneath. All of the parts required for the cage are cheap, light, stackable, and strong; materials are plastic, stainless steel, and aluminum. All of the parts are easily cleaned and assembled. The bar interval and fit of all the parts allow no escapes. The design is adaptable to accessories (see Table 3 and Fig. 5, item 7). The separate parts include: (1) Plastic bowl: made of polypropylene, but can be made in transparent polycarbonate for behavior studies; there are no ridges to be gnawed, and the lid protects the rim from gnawing. The cost of the bowl is minimal because it was made commercially for another purpose, which covered the cost of the mould. (2) Wire frame of lid: upturned rim smooth and simple for comfortable handling (Fig. 2). The card numbered 2 rests against the indented end, which accommodates the cage clip (8) when the lid is put on and taken off. (3) Bottle: capacity allows sufficient water to last a long weekend; sloping "shoulders" and wide neck facilitate cleaning. The bottle can be carried in its compartment spout upwards (the jerking of a handler while walking can cause spills). (4) Bottle cap: pliable plastic for close fit and rapid removal for filling. It is protected from being gnawed where it protrudes through the wire frame (2), by a short, thick bar. (5) Capillary tube for cap: easily cut from purchased lengths, edges flamed smooth; the bore does not block with grit and it minimizes drips as the mice drink. Its thickness protects it from siphoning out on contact with bedding. The resulting dry bedding minimizes smell. (6) Shelter: simple shape; can be made of transparent material for some behavior studies (or the shelter can be gently raised at its upper edge so that the mice can be seen without disturbance). The draft-free nest area to which the shelter contributes enhances breeding output. (7) Divider: prevents food from interfering with the siting of the bottle; simple shape. (8) Card clip: holds cage card by insertion into a slit in the bowl rim (see Figs. 2 and 3); it can be quickly moved to a clean bowl. (9) Cage card: usable on both sides; numbered 1-12 along the bottom so that the clip (10) may indicate the number of young in a litter. (10) Plastic paperclip: in four colors; has both narrow and broad sides and can be placed in different positions, it gives eight items of information about the cage contents. This and the page information complement a simple and versatile experimental loose-leaf record system (Wallace, 1971; Luker and Luker, 1971).

Long-Term Evaluation of a Design

It may be asked: Is there any evidence that the design process, as illustrated by the work on the mouse cage described above, is more than a "paper exercise"? A bonus arising from writing about this process 20 years after the cage came into use is that this question can be answered in terms of my own experience and impressions, as well as those of other users. A synopsis of the cage's advantages include:

1. The design exceeds standard requirements. The cage is more labor-saving than other designs, and produces more weaned young (see especially Wallace and Hudson, 1969). It is more productive even when inappropriately tested (Wallace, 1971a, especially p. 150).

2. The design stands up to human economies: Where the animal room has a few hours of relatively low heat (15 °C), the nest area design, with the recommended bedding, ensures maintenance of a warm nest. If external changes of air are reduced periodically (e.g., during electricity failure), the dryness of bedding slows the buildup of ammonia.

3. The design stands up to more of the animals' needs than those for which it was initially tested. It produces more weaned young per female than other designs, when the cage contains a breeding trio and two litters, a superovulating female, strains of mutants with known high mortality, and wild mice (Wallace, 1981). The cage also enhances the fertility and viability of "difficult" mutants (e.g., shakers, circlers, and otherwise retarded or handicapped mice, especially those sensitive to sound and cold), and it requires less frequent cleaning when holding mice with polyuria.

4. The design is adaptable for use with accessories. The bottle and trough areas may be altered without trouble for some behavior studies (Wallace, 1977;

Wallace, 1981b). The localization of soiled bedding allows a vacuum cleaner to be used, with a hood placed over the mice in the nest, for minimal disturbance of difficult breeders (Wallace and Hudson, 1969). The long slope of the lid has no projections so that a simple retainer, in conjunction with a chute, allows speedy transference of wild or otherwise hyperactive mice to clean cages without handling them (Wallace, 1968). The versatile record system, with its page layout and special cage cards, has been adopted for mouse keeping in schools as well as in laboratories (Wallace 1971b; Luker and Luker, 1971).

Acknowledgments

Thanks are due to the editors of *Laboratory Animal* for permission to use the photograph in Figure 2, and of the *Journal of the Animal Technicians Association* and of *Laboratory Practice* for permission to reprint the photographs in Figures 3 and 4.

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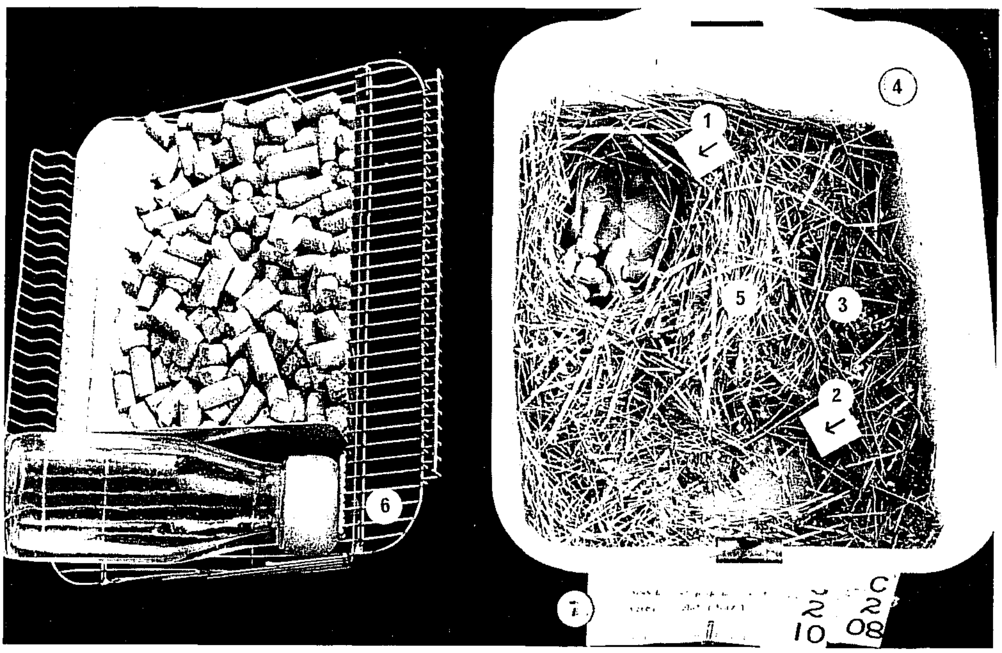

FIGURE 5. *Bonus features of a harmonious design.* (1) Localization of the nest: allows mice to keep it clean, so that it may be moved intact to a clean cage, or protected by a hood for vacuum cleaning. These measures ensure minimal disturbance for the mice and retention of a familiar smell, which probably contribute to good lactation (removed roof of nest is indicated by an arrow). (2) Localization of nest exit: nest and food positioning results in this exit passing under the bottle, thereby keeping the spout clear of bedding (spout position is shown by an arrow). (3) Localization of excreta: this and the round corners of the bowl aid hand scraping or vacuum cleaning. Excreta under the low ventilated (open) bars are kept dry and smell is minimal. (4) Retention of smell: the plastic bowl retains some "mousey" smell after washing, possibly reducing stress of females and fighting of males after transference to a clean cage. (5) Localization of bedding building: besides keeping the nest warm, this places a partial barrier between stored males, possibly reducing fighting. (6) Accessible spout: the low height of the spout is accessible even to circlers and retarded mutant weaklings. (7) Versatile labeling: two cards are shown here, one for each of two females in a trio—each card can accompany its female if they are separated for parturition (the labeling is part of a complete breeding record system).

TABLE 1. List of Animal (Mouse) Needs

BEHAVIOR	REQUIREMENTS
Activity	A living space permitting exploration, exercise, grooming and social interaction where territory can be marked; containing material providing sensory stimulation and adaptable for sleeping and nesting Dry, ventilated, and cooler than animal's body temperature
Eating	A balanced diet: hard enough to wear down growing teeth; and accessible enough to satisfy appetite and exercise paws, jaw, and the sense of smell
Drinking	Water (or moist enough food): with easy access, but ensuring a dry living space
Sleeping	A discrete area: for retention of body heat, and for social huddling (which may be a tactile need) Low light intensity "Mousey" smells (possibly desirable to the mouse?) and external noise should be controllable
Defecating	This seems to accompany activity and therefore can occur anywhere but the nest, so the nest area should be identifiable to the mouse Space restriction limits supply of food and water, so these must be inaccessible to excretory organs Activity areas should allow ventilation to dry out fecal pellets.
Urinating	An area away from the nest—restriction hinders territorial marking and escape of attacked males, so hiding places are desirable Use of urine for communication in mouse social groups, including females seems desirable
Nesting	An area where nest temperature can be controlled Bedding must be suitable for chewing and manipulating—the mouse uses bedding to form a "sweater" inside a "windcheater," *i.e.*, the bedding insulates, but the confines of the bedding must be conducible to the exclusion of drafts around the time of parturition, and permit a gradual increase of air exchange during rearing of young (Note that "draft" and "air exchange" refer to air exchanges between activity area and nest area, not between the cage and the animal room)

TABLE 2. List of Human Requirements

CRITERION	REQUIREMENTS
	In Relation to the Animal
Confinement	Cage parts must fit such that there is no crack or hole big enough for the smallest active mouse to get through
Productivity	Maximum number of weaned young per female; this consists of maximum ova shed, minimum implantation and antenatal loss, minimum female mortality at parturition, and minimum mortality of young to weaning
Health	Cage conditions must complement the "macro-environment" to ensure certain disease-free levels
	In Relation to the Cage
Hygiene	Materials and parts must be easily washed and/or autoclaved The cage and its contents must be dry enough to discourage the growth of pathogens and fungus The cage and its contents must not be smelly
Cost	Materials and their manufacture must be cheap The design must be easy to mass-produce with a minimum of hand labor The parts must be durable in use—washing, storing, assembly and handling
Comfort for the Handler	No sharp or rough surfaces The parts and the whole must be light to carry The cage must be easily put on and removed from shelves The lid must be easily put on and taken off The contents must be easy to inspect, with or without the removal of the lid Ease of servicing, handling and storing
Design Should Be Adaptable	The parts must be easy to clean, stack and store, and easy to assemble and dismantle The design should be adaptable to accessories concerned with research (*e.g.*, behavioral); with cleaning (*e.g.*, vacuum cleaning); with handling (*e.g.*, the chute); and with recording the status of the animals inside in terms of breeding and treatment

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Ethical Issues and Future Directions in Wildlife Management

John W. Grandy

Recent progress in protection of wildlife and wildlife refuges is currently being undermined by the efforts of James Watt, U.S. Secretary of the Interior, who believes that commercial interests should take precedence over the preservation of pristine wilderness areas and wildlife sanctuaries. The consequent loss, as populations approach extinction because of programs like decimation of habitats and predator control, is more than simply aesthetic: genetic material unique to each species will be

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