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(54) **Titre : NOUVEAUX RECEPTEURS DE MUTANTS DE SUBSTITUTION ET UTILISATION DE CEUX-CI DANS UN SYSTEME D'EXPRESSION GENIQUE INDUCTIBLE A BASE DE RECEPTEURS NUCLEAIRES**  
(54) **Title: NOVEL SUBSTITUTION MUTANT RECEPTORS AND THEIR USE IN A NUCLEAR RECEPTOR-BASED INDUCIBLE GENE EXPRESSION SYSTEM**

(57) **Abrégé/Abstract:**

This invention relates to the field of biotechnology or genetic engineering. Specifically, this invention relates to the field of gene expression. More specifically, this invention relates to novel substitution mutant receptors and their use in a Group H nuclear receptor-based inducible gene expression system and methods of modulating the expression of a gene in a host cell for applications such as gene therapy, large scale production of proteins and antibodies, cell-based high throughput screening assays, functional genomics and regulation of traits in transgenic organisms.

## ABSTRACT

This invention relates to the field of biotechnology or genetic engineering. Specifically, this invention relates to the field of gene expression. More specifically, this invention relates to novel substitution mutant receptors and their use in a Group H nuclear receptor-based inducible gene expression system and methods of modulating the expression of a gene in a host cell for applications such as gene therapy, large scale production of proteins and antibodies, cell-based high throughput screening assays, functional genomics and regulation of traits in transgenic organisms.

**NOVEL SUBSTITUTION MUTANT RECEPTORS AND THEIR USE IN A NUCLEAR  
RECEPTOR-BASED INDUCIBLE GENE EXPRESSION SYSTEM**

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**FIELD OF THE INVENTION**

This invention relates to the field of biotechnology or genetic engineering. Specifically, this invention relates to the field of gene expression. More specifically, this invention relates to novel nuclear receptors comprising a substitution mutation and their use in a nuclear receptor-based inducible gene expression system and methods of modulating the expression of a gene within a host cell using this inducible gene expression system.

**BACKGROUND OF THE INVENTION**

15 Various publications are cited herein.

However, the citation of any reference herein should not be construed as an admission that such reference is available as "Prior Art" to the instant application.

In the field of genetic engineering, precise control of gene expression is a valuable tool for studying, manipulating, and controlling development and other physiological processes. Gene expression is a complex biological process involving a number of specific protein-protein interactions. In order for gene expression to be triggered, such that it produces the RNA necessary as the first step in protein synthesis, a transcriptional activator must be brought into proximity of a promoter that controls gene transcription. Typically, the transcriptional activator itself is associated with a protein that has at least one DNA binding domain that binds to DNA binding sites present in the promoter regions of genes. Thus, for gene expression to occur, a protein comprising a DNA binding domain and a transactivation domain located at an appropriate distance from the DNA binding domain must be brought into the correct position in the promoter region of the gene.

25 The traditional transgenic approach utilizes a cell-type specific promoter to drive the expression of a designed transgene. A DNA construct containing the transgene is first incorporated into a host genome. When triggered by a transcriptional activator, expression of the transgene occurs in a given cell type.

Another means to regulate expression of foreign genes in cells is through inducible promoters. Examples of the use of such inducible promoters include the PR1-a promoter, prokaryotic repressor-operator systems, immunosuppressive-immunophilin systems, and higher eukaryotic transcription activation systems such as steroid hormone receptor systems and are described below.

The PR1-a promoter from tobacco is induced during the systemic acquired resistance response following pathogen attack. The use of PR1-a may be limited because it often responds to endogenous

materials and external factors such as pathogens, UV-B radiation, and pollutants. Gene regulation systems based on promoters induced by heat shock, interferon and heavy metals have been described (Wurm et al., 1986, Proc. Natl. Acad. Sci. USA 83: 5414-5418; Arnheiter et al., 1990, Cell 62:51-61; Filmus et al., 1992, Nucleic Acids Research 20: 27550-27560). However, these systems have limitations  
5 due to their effect on expression of non-target genes. These systems are also leaky.

Prokaryotic repressor-operator systems utilize bacterial repressor proteins and the unique operator DNA sequences to which they bind. Both the tetracycline ("Tet") and lactose ("Lac") repressor-operator systems from the bacterium *Escherichia coli* have been used in plants and animals to control gene expression. In the Tet system, tetracycline binds to the TetR repressor protein, resulting in a  
10 conformational change that releases the repressor protein from the operator which as a result allows transcription to occur. In the Lac system, a lac operon is activated in response to the presence of lactose, or synthetic analogs such as isopropyl-b-D-thiogalactoside. Unfortunately, the use of such systems is restricted by unstable chemistry of the ligands, i.e. tetracycline and lactose, their toxicity, their natural presence, or the relatively high levels required for induction or repression. For similar reasons, utility of  
15 such systems in animals is limited.

Immunosuppressive molecules such as FK506, rapamycin and cyclosporine A can bind to immunophilins FKBP12, cyclophilin, etc. Using this information, a general strategy has been devised to bring together any two proteins simply by placing FK506 on each of the two proteins or by placing FK506 on one and cyclosporine A on another one. A synthetic homodimer of FK506 (FK1012) or a  
20 compound resulted from fusion of FK506-cyclosporine (FKCsA) can then be used to induce dimerization of these molecules (Spencer et al., 1993, *Science* 262: 1019-24; Belshaw et al., 1996 *Proc Natl Acad Sci USA* 93: 4604-7). Gal4 DNA binding domain fused to FKBP12 and VP16 activator domain fused to cyclophilin, and FKCsA compound were used to show heterodimerization and activation of a reporter gene under the control of a promoter containing Gal4 binding sites. Unfortunately, this system includes  
25 immunosuppressants that can have unwanted side effects and therefore, limits its use for various mammalian gene switch applications.

Higher eukaryotic transcription activation systems such as steroid hormone receptor systems have also been employed. Steroid hormone receptors are members of the nuclear receptor superfamily and are found in vertebrate and invertebrate cells. Unfortunately, use of steroidal compounds that  
30 activate the receptors for the regulation of gene expression, particularly in plants and mammals, is limited due to their involvement in many other natural biological pathways in such organisms. In order to overcome such difficulties, an alternative system has been developed using insect ecdysone receptors (EcR).

Growth, molting, and development in insects are regulated by the ecdysone steroid hormone  
35 (molting hormone) and the juvenile hormones (Dhadialla, et al., 1998, *Annu. Rev. Entomol.* 43: 545-569). The molecular target for ecdysone in insects consists of at least ecdysone receptor (EcR) and ultraspiracle protein (USP). EcR is a member of the nuclear steroid receptor super family that is

characterized by signature DNA and ligand binding domains, and an activation domain (Koelle et al. 1991, Cell, 67:59-77). EcR receptors are responsive to a number of steroidal compounds such as ponasterone A and muristerone A. Recently, non-steroidal compounds with ecdysteroid agonist activity have been described, including the commercially available insecticides tebufenozide and  
5 methoxyfenozide that are marketed world wide by Rohm and Haas Company (see International Patent Application No. PCT/EP96/00686 and US Patent 5,530,028). Both analogs have exceptional safety profiles to other organisms.

The insect ecdysone receptor (EcR) heterodimerizes with Ultraspiracle (USP), the insect  
homologue of the mammalian RXR, and binds ecdysteroids and ecdysone receptor response elements  
10 and activate transcription of ecdysone responsive genes (Riddiford et al., 2000). The EcR/USP/ligand complexes play important roles during insect development and reproduction. The EcR is a member of the steroid hormone receptor superfamily and has five modular domains, A/B (transactivation), C (DNA binding, heterodimerization), D (Hinge, heterodimerization), E (ligand binding, heterodimerization and transactivation and F (transactivation) domains. Some of these domains such as A/B, C and E retain  
15 their function when they are fused to other proteins.

Tightly regulated inducible gene expression systems or "gene switches" are useful for various applications such as gene therapy, large scale production of proteins in cells, cell based high throughput screening assays, functional genomics and regulation of traits in transgenic plants and animals.

The first version of EcR-based gene switch used *Drosophila melanogaster* EcR (DmEcR) and  
20 *Mus musculus* RXR (MmRXR) and showed that these receptors in the presence of steroid, ponasteroneA, transactivate reporter genes in mammalian cell lines and transgenic mice (Christopherson et al., 1992; No et al., 1996). Later, Suhr et al., 1998 showed that non-steroidal ecdysone agonist, tebufenozide, induced high level of transactivation of reporter genes in mammalian cells through *Bombyx mori* EcR (BmEcR) in the absence of exogenous heterodimer partner.

International Patent Applications No. PCT/US97/05330 (WO 97/38117) and PCT/US99/08381  
25 (WO99/58155) disclose methods for modulating the expression of an exogenous gene in which a DNA construct comprising the exogenous gene and an ecdysone response element is activated by a second DNA construct comprising an ecdysone receptor that, in the presence of a ligand therefor, and optionally in the presence of a receptor capable of acting as a silent partner, binds to the ecdysone response element  
30 to induce gene expression. The ecdysone receptor of choice was isolated from *Drosophila melanogaster*. Typically, such systems require the presence of the silent partner, preferably retinoid X receptor (RXR), in order to provide optimum activation. In mammalian cells, insect ecdysone receptor (EcR) heterodimerizes with retinoid X receptor (RXR) and regulates expression of target genes in a ligand dependent manner. International Patent Application No. PCT/US98/14215 (WO 99/02683) discloses  
35 that the ecdysone receptor isolated from the silk moth *Bombyx mori* is functional in mammalian systems without the need for an exogenous dimer partner.

U.S. Patent No. 6,265,173 B1 discloses that various members of the steroid/thyroid superfamily

of receptors can combine with *Drosophila melanogaster* ultraspiracle receptor (USP) or fragments thereof comprising at least the dimerization domain of USP for use in a gene expression system. U.S. Patent No. 5,880,333 discloses a *Drosophila melanogaster* EcR and ultraspiracle (USP) heterodimer system used in plants in which the transactivation domain and the DNA binding domain are positioned  
5 on two different hybrid proteins. Unfortunately, these USP-based systems are constitutive in animal cells and therefore, are not effective for regulating reporter gene expression.

In each of these cases, the transactivation domain and the DNA binding domain (either as native EcR as in International Patent Application No. PCT/US98/14215 or as modified EcR as in International Patent Application No. PCT/US97/05330) were incorporated into a single molecule and the other  
10 heterodimeric partners, either USP or RXR, were used in their native state.

Drawbacks of the above described EcR-based gene regulation systems include a considerable background activity in the absence of ligands and non-applicability of these systems for use in both plants and animals (see U.S. Patent No. 5,880,333). Therefore, a need exists in the art for improved EcR-based systems to precisely modulate the expression of exogenous genes in both plants and animals.  
15 Such improved systems would be useful for applications such as gene therapy, large-scale production of proteins and antibodies, cell-based high throughput screening assays, functional genomics and regulation of traits in transgenic animals. For certain applications such as gene therapy, it may be desirable to have an inducible gene expression system that responds well to synthetic non-steroid ligands and at the same is insensitive to the natural steroids. Thus, improved systems that are simple, compact, and dependent on  
20 ligands that are relatively inexpensive, readily available, and of low toxicity to the host would prove useful for regulating biological systems.

Recently, Applicants have shown that an ecdysone receptor-based inducible gene expression system in which the transactivation and DNA binding domains are separated from each other by placing them on two different proteins results in greatly reduced background activity in the absence of a ligand  
25 and significantly increased activity over background in the presence of a ligand (pending application PCT/US01/09050).

This two-hybrid system is a significantly improved inducible gene expression modulation system compared to the two systems disclosed in applications PCT/US97/05330 and PCT/US98/14215. The two-hybrid system exploits the ability of a pair of interacting proteins to bring the transcription activation domain into a more favorable  
30 position relative to the DNA binding domain such that when the DNA binding domain binds to the DNA binding site on the gene, the transactivation domain more effectively activates the promoter (see, for example, U.S. Patent No. 5,283,173). Briefly, the two-hybrid gene expression system comprises two gene expression cassettes; the first encoding a DNA binding domain fused to a nuclear receptor polypeptide, and the second encoding a transactivation domain fused to a different nuclear receptor  
35 polypeptide. In the presence of ligand, the interaction of the first polypeptide with the second polypeptide effectively tethers the DNA binding domain to the transactivation domain. Since the DNA binding and transactivation domains reside on two different molecules, the background activity in the

absence of ligand is greatly reduced.

A two-hybrid system also provides improved sensitivity to non-steroidal ligands for example, diacylhydrazines, when compared to steroidal ligands for example, ponasterone A ("PonA") or muristerone A ("MurA"). That is, when compared to steroids, the non-steroidal ligands provide higher activity at a lower concentration. In addition, since transactivation based on EcR gene switches is often cell-line dependent, it is easier to tailor switching systems to obtain maximum transactivation capability for each application. Furthermore, the two-hybrid system avoids some side effects due to overexpression of RXR that often occur when unmodified RXR is used as a switching partner. In a preferred two-hybrid system, native DNA binding and transactivation domains of EcR or RXR are eliminated and as a result, these hybrid molecules have less chance of interacting with other steroid hormone receptors present in the cell resulting in reduced side effects.

The EcR is a member of the nuclear receptor superfamily and classified into subfamily 1, group H (referred to herein as "Group H nuclear receptors"). The members of each group share 40-60% amino acid identity in the E (ligand binding) domain (Laudet et al., A Unified Nomenclature System for the Nuclear Receptor Subfamily, 1999; Cell 97: 161-163). In addition to the ecdysone receptor, other members of this nuclear receptor subfamily 1, group H include: ubiquitous receptor (UR), Orphan receptor 1 (OR-1), steroid hormone nuclear receptor 1 (NER-1), RXR interacting protein-15 (RIP-15), liver x receptor  $\beta$  (LXR $\beta$ ), steroid hormone receptor like protein (RLD-1), liver x receptor (LXR), liver x receptor  $\alpha$  (LXR $\alpha$ ), farnesoid x receptor (FXR), receptor interacting protein 14 (RIP-14), and farnesol receptor (HRR-1).

To develop an improved Group H nuclear receptor-based inducible gene expression system in which ligand binding or ligand specificity is modified, Applicants created several substitution mutant EcRs that comprise substituted amino acid residues in the ligand binding domain (LBD). A homology modeling and docking approach was used to predict critical residues that mediate binding of ecdysteroids and non-ecdysteroids to the EcR LBD. These substitution mutant EcRs were evaluated in ligand binding and transactivation assays. As presented herein, Applicants' novel substitution mutant nuclear receptors and their use in a nuclear receptor-based inducible gene expression system provides an improved inducible gene expression system in both prokaryotic and eukaryotic host cells in which ligand sensitivity and magnitude of transactivation may be selected as desired, depending upon the application.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

**Figure 1:** *In vitro*  $^3\text{H}$ -RH2485 ligand binding of full-length A110P CfEcR mutant while steroid binding is completely disrupted. The ligand binding values are expressed as specific counts (specific dpm).

**Figure 2:** Transactivation of reporter genes through GAL4/CfEcR-A/BCDEF (full length CfEcR) or its GAL4/A110P mutant version constructs transfected into NIH3T3 cells along with VP16LmUSP-EF and pFREcRE by PonA or GS<sup>TM</sup>-E. The numbers on top of the bars indicate fold increase over DMSO

levels.

Figure 3: Transactivation of reporter genes through IE1VP16/CfEcRCDEF (Example 1.5) or its VP16/A110P mutant version constructs (Example 1.6) transfected into L57 cells along with pMK43.2 reporter by 20E or GST<sup>TM</sup>-E. The numbers on top of the bars indicate fold increase over DMSO levels.

5 Figure 4: Transactivation of reporter genes through GAL4/CfEcR-A/BCDEF (full length CfEcR) or its GAL4/A110 mutant versions (A110S, A110P, A110L, and A110M) constructs transfected into NIH3T3 cells along with VP16LmUSP-EF and pFREcRE by PonA or GST<sup>TM</sup>-E. The numbers on top of the bars indicate fold increase over DMSO levels.

Figure 5: *In vitro* <sup>3</sup>H-PonA ligand binding of wild-type CfEcR-A/BCDEF (full length CfEcR) or its A110  
10 mutant versions (A110S, A110P, A110L, and A110M). The ligand binding values are expressed as specific counts (specific dpm).

Figure 6: *In vitro* <sup>3</sup>H-RH2485 ligand binding of wild-type CfEcR-A/BCDEF (full length CfEcR) or its A110 mutant versions (A110S, A110P, A110L, and A110M). These values were expressed as specific counts (specific dpm).

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### DETAILED DESCRIPTION OF THE INVENTION

Applicants describe herein the construction of Group H nuclear receptors that comprise substitution mutations (referred to herein as "substitution mutants") at amino acid residues that are  
20 involved in ligand binding to a Group H nuclear receptor ligand binding domain that affect the ligand sensitivity and magnitude of induction of the Group H nuclear receptor and the demonstration that these substitution mutant nuclear receptors are useful in methods of modulating gene expression.

Specifically, Applicants have developed a novel nuclear receptor-based inducible gene expression system comprising a Group H nuclear receptor ligand binding domain comprising a  
25 substitution mutation. Applicants have shown that the effect of such a substitution mutation may increase or reduce ligand binding activity or ligand sensitivity and the ligand may be steroid or non-steroid specific. Thus, Applicants' invention provides a Group H nuclear receptor-based inducible gene expression system useful for modulating expression of a gene of interest in a host cell. In a particularly desirable embodiment, Applicants' invention provides an ecdysone receptor-based inducible gene  
30 expression system that responds solely to either steroidal ligand or non-steroidal ligand. In addition, the present invention also provides an improved non-steroidal ligand responsive ecdysone receptor-based inducible gene expression system. Thus, Applicants' novel inducible gene expression system and its use in methods of modulating gene expression in a host cell overcome the limitations of currently available inducible expression systems and provide the skilled artisan with an effective means to control gene  
35 expression.

The present invention is useful for applications such as gene therapy, large scale production of proteins and antibodies, cell-based high throughput screening assays, orthogonal ligand screening assays,

functional genomics, proteomics, metabolomics, and regulation of traits in transgenic organisms, where control of gene expression levels is desirable. An advantage of Applicants' invention is that it provides a means to regulate gene expression and to tailor expression levels to suit the user's requirements.

## 5 DEFINITIONS

In this disclosure, a number of terms and abbreviations are used. The following definitions are provided and should be helpful in understanding the scope and practice of the present invention.

In a specific embodiment, the term "about" or "approximately" means within 20%, preferably within 10%, more preferably within 5%, and even more preferably within 1% of a given value or range.

10 The term "substantially free" means that a composition comprising "A" (where "A" is a single protein, DNA molecule, vector, recombinant host cell, etc.) is substantially free of "B" (where "B" comprises one or more contaminating proteins, DNA molecules, vectors, etc.) when at least about 75% by weight of the proteins, DNA, vectors (depending on the category of species to which A and B belong) in the composition is "A". Preferably, "A" comprises at least about 90% by weight of the A + B species  
15 in the composition, most preferably at least about 99% by weight. It is also preferred that a composition, which is substantially free of contamination, contain only a single molecular weight species having the activity or characteristic of the species of interest.

The term "isolated" for the purposes of the present invention designates a biological material (nucleic acid or protein) that has been removed from its original environment (the environment in which  
20 it is naturally present). For example, a polynucleotide present in the natural state in a plant or an animal is not isolated, however the same polynucleotide separated from the adjacent nucleic acids in which it is naturally present, is considered "isolated". The term "purified" does not require the material to be present in a form exhibiting absolute purity, exclusive of the presence of other compounds. It is rather a relative definition.

25 A polynucleotide is in the "purified" state after purification of the starting material or of the natural material by at least one order of magnitude, preferably 2 or 3 and preferably 4 or 5 orders of magnitude.

A "nucleic acid" is a polymeric compound comprised of covalently linked subunits called nucleotides. Nucleic acid includes polyribonucleic acid (RNA) and polydeoxyribonucleic acid (DNA),  
30 both of which may be single-stranded or double-stranded. DNA includes but is not limited to cDNA, genomic DNA, plasmids DNA, synthetic DNA, and semi-synthetic DNA. DNA may be linear, circular, or supercoiled.

A "nucleic acid molecule" refers to the phosphate ester polymeric form of ribonucleosides (adenosine, guanosine, uridine or cytidine; "RNA molecules") or deoxyribonucleosides (deoxyadenosine,  
35 deoxyguanosine, deoxythymidine, or deoxycytidine; "DNA molecules"), or any phosphoester analogs thereof, such as phosphorothioates and thioesters, in either single stranded form, or a double-stranded helix. Double stranded DNA-DNA, DNA-RNA and RNA-RNA helices are possible. The term nucleic

acid molecule, and in particular DNA or RNA molecule, refers only to the primary and secondary structure of the molecule, and does not limit it to any particular tertiary forms. Thus, this term includes double-stranded DNA found, *inter alia*, in linear or circular DNA molecules (e.g., restriction fragments), plasmids, and chromosomes. In discussing the structure of particular double-stranded DNA molecules, sequences may be described herein according to the normal convention of giving only the sequence in the 5' to 3' direction along the non-transcribed strand of DNA (i.e., the strand having a sequence homologous to the mRNA). A "recombinant DNA molecule" is a DNA molecule that has undergone a molecular biological manipulation.

The term "fragment" will be understood to mean a nucleotide sequence of reduced length relative to the reference nucleic acid and comprising, over the common portion, a nucleotide sequence identical to the reference nucleic acid. Such a nucleic acid fragment according to the invention may be, where appropriate, included in a larger polynucleotide of which it is a constituent. Such fragments comprise, or alternatively consist of, oligonucleotides ranging in length from at least 6, 8, 9, 10, 12, 15, 18, 20, 21, 22, 23, 24, 25, 30, 39, 40, 42, 45, 48, 50, 51, 54, 57, 60, 63, 66, 70, 75, 78, 80, 90, 100, 105, 120, 135, 150, 200, 300, 500, 720, 900, 1000 or 1500 consecutive nucleotides of a nucleic acid according to the invention.

As used herein, an "isolated nucleic acid fragment" is a polymer of RNA or DNA that is single- or double-stranded, optionally containing synthetic, non-natural or altered nucleotide bases. An isolated nucleic acid fragment in the form of a polymer of DNA may be comprised of one or more segments of cDNA, genomic DNA or synthetic DNA.

A "gene" refers to an assembly of nucleotides that encode a polypeptide, and includes cDNA and genomic DNA nucleic acids. "Gene" also refers to a nucleic acid fragment that expresses a specific protein or polypeptide, including regulatory sequences preceding (5' non-coding sequences) and following (3' non-coding sequences) the coding sequence. "Native gene" refers to a gene as found in nature with its own regulatory sequences. "Chimeric gene" refers to any gene that is not a native gene, comprising regulatory and/or coding sequences that are not found together in nature. Accordingly, a chimeric gene may comprise regulatory sequences and coding sequences that are derived from different sources, or regulatory sequences and coding sequences derived from the same source, but arranged in a manner different than that found in nature. A chimeric gene may comprise coding sequences derived from different sources and/or regulatory sequences derived from different sources. "Endogenous gene" refers to a native gene in its natural location in the genome of an organism. A "foreign" gene or "heterologous" gene refers to a gene not normally found in the host organism, but that is introduced into the host organism by gene transfer. Foreign genes can comprise native genes inserted into a non-native organism, or chimeric genes. A "transgene" is a gene that has been introduced into the genome by a transformation procedure.

"Heterologous" DNA refers to DNA not naturally located in the cell, or in a chromosomal site of the cell. Preferably, the heterologous DNA includes a gene foreign to the cell.

The term "genome" includes chromosomal as well as mitochondrial, chloroplast and viral DNA or RNA.

A nucleic acid molecule is "hybridizable" to another nucleic acid molecule, such as a cDNA, genomic DNA, or RNA, when a single stranded form of the nucleic acid molecule can anneal to the other  
5 nucleic acid molecule under the appropriate conditions of temperature and solution ionic strength (see Sambrook *et al.*, 1989 *infra*). Hybridization and washing conditions are well known and exemplified in Sambrook, J., Fritsch, E. F. and Maniatis, T. *Molecular Cloning: A Laboratory Manual*, Second Edition, Cold Spring Harbor Laboratory Press, Cold Spring Harbor (1989), particularly Chapter 11 and Table 11.1 therein.

The conditions of temperature and ionic  
10 strength determine the "stringency" of the hybridization.

Stringency conditions can be adjusted to screen for moderately similar fragments, such as homologous sequences from distantly related organisms, to highly similar fragments, such as genes that duplicate functional enzymes from closely related organisms. For preliminary screening for homologous nucleic acids, low stringency hybridization conditions, corresponding to a  $T_m$  of 55°, can be used, *e.g.*, 5x  
15 SSC, 0.1% SDS, 0.25% milk, and no formamide; or 30% formamide, 5x SSC, 0.5% SDS. Moderate stringency hybridization conditions correspond to a higher  $T_m$ , *e.g.*, 40% formamide, with 5x or 6x SCC. High stringency hybridization conditions correspond to the highest  $T_m$ , *e.g.*, 50% formamide, 5x or 6x SCC.

Hybridization requires that the two nucleic acids contain complementary sequences, although  
20 depending on the stringency of the hybridization, mismatches between bases are possible. The term "complementary" is used to describe the relationship between nucleotide bases that are capable of hybridizing to one another. For example, with respect to DNA, adenosine is complementary to thymine and cytosine is complementary to guanine. Accordingly, the instant invention also includes isolated nucleic acid fragments that are complementary to the complete sequences as disclosed or used herein as  
25 well as those substantially similar nucleic acid sequences.

In a specific embodiment of the invention, polynucleotides are detected by employing hybridization conditions comprising a hybridization step at  $T_m$  of 55°C, and utilizing conditions as set forth above. In a preferred embodiment, the  $T_m$  is 60°C; in a more preferred embodiment, the  $T_m$  is 63°C; in an even more preferred embodiment, the  $T_m$  is 65°C.

30 Post-hybridization washes also determine stringency conditions. One set of preferred conditions uses a series of washes starting with 6X SSC, 0.5% SDS at room temperature for 15 minutes (min), then repeated with 2X SSC, 0.5% SDS at 45°C for 30 minutes, and then repeated twice with 0.2X SSC, 0.5% SDS at 50°C for 30 minutes. A more preferred set of stringent conditions uses higher temperatures in which the washes are identical to those above except for the temperature of the final two 30 min washes  
35 in 0.2X SSC, 0.5% SDS was increased to 60°C. Another preferred set of highly stringent conditions uses two final washes in 0.1X SSC, 0.1% SDS at 65°C. Hybridization requires that the two nucleic acids comprise complementary sequences, although depending on the stringency of the hybridization,

mismatches between bases are possible.

The appropriate stringency for hybridizing nucleic acids depends on the length of the nucleic acids and the degree of complementation, variables well known in the art. The greater the degree of similarity or homology between two nucleotide sequences, the greater the value of  $T_m$  for hybrids of nucleic acids having those sequences. The relative stability (corresponding to higher  $T_m$ ) of nucleic acid hybridizations decreases in the following order: RNA:RNA, DNA:RNA, DNA:DNA. For hybrids of greater than 100 nucleotides in length, equations for calculating  $T_m$  have been derived (see Sambrook *et al.*, *supra*, 9.50-0.51). For hybridization with shorter nucleic acids, *i.e.*, oligonucleotides, the position of mismatches becomes more important, and the length of the oligonucleotide determines its specificity (see Sambrook *et al.*, *supra*, 11.7-11.8).

In a specific embodiment of the invention, polynucleotides are detected by employing hybridization conditions comprising a hybridization step in less than 500 mM salt and at least 37 degrees Celsius, and a washing step in 2XSSPE at at least 63 degrees Celsius. In a preferred embodiment, the hybridization conditions comprise less than 200 mM salt and at least 37 degrees Celsius for the hybridization step. In a more preferred embodiment, the hybridization conditions comprise 2XSSPE and 63 degrees Celsius for both the hybridization and washing steps.

In one embodiment, the length for a hybridizable nucleic acid is at least about 10 nucleotides. Preferable a minimum length for a hybridizable nucleic acid is at least about 15 nucleotides; more preferably at least about 20 nucleotides; and most preferably the length is at least 30 nucleotides. Furthermore, the skilled artisan will recognize that the temperature and wash solution salt concentration may be adjusted as necessary according to factors such as length of the probe.

The term "probe" refers to a single-stranded nucleic acid molecule that can base pair with a complementary single stranded target nucleic acid to form a double-stranded molecule.

As used herein, the term "oligonucleotide" refers to a nucleic acid, generally of at least 18 nucleotides, that is hybridizable to a genomic DNA molecule, a cDNA molecule, a plasmid DNA or an mRNA molecule. Oligonucleotides can be labeled, *e.g.*, with  $^{32}\text{P}$ -nucleotides or nucleotides to which a label, such as biotin, has been covalently conjugated. A labeled oligonucleotide can be used as a probe to detect the presence of a nucleic acid. Oligonucleotides (one or both of which may be labeled) can be used as PCR primers, either for cloning full length or a fragment of a nucleic acid, or to detect the presence of a nucleic acid. An oligonucleotide can also be used to form a triple helix with a DNA molecule. Generally, oligonucleotides are prepared synthetically, preferably on a nucleic acid synthesizer. Accordingly, oligonucleotides can be prepared with non-naturally occurring phosphoester analog bonds, such as thioester bonds, etc.

A "primer" is an oligonucleotide that hybridizes to a target nucleic acid sequence to create a double stranded nucleic acid region that can serve as an initiation point for DNA synthesis under suitable conditions. Such primers may be used in a polymerase chain reaction.

"Polymerase chain reaction" is abbreviated PCR and means an *in vitro* method for enzymatically

amplifying specific nucleic acid sequences. PCR involves a repetitive series of temperature cycles with each cycle comprising three stages: denaturation of the template nucleic acid to separate the strands of the target molecule, annealing a single stranded PCR oligonucleotide primer to the template nucleic acid, and extension of the annealed primer(s) by DNA polymerase. PCR provides a means to detect the  
5 presence of the target molecule and, under quantitative or semi-quantitative conditions, to determine the relative amount of that target molecule within the starting pool of nucleic acids.

“Reverse transcription-polymerase chain reaction” is abbreviated RT-PCR and means an *in vitro* method for enzymatically producing a target cDNA molecule or molecules from an RNA molecule or molecules, followed by enzymatic amplification of a specific nucleic acid sequence or sequences within  
10 the target cDNA molecule or molecules as described above. RT-PCR also provides a means to detect the presence of the target molecule and, under quantitative or semi-quantitative conditions, to determine the relative amount of that target molecule within the starting pool of nucleic acids.

A DNA “coding sequence” is a double-stranded DNA sequence that is transcribed and translated into a polypeptide in a cell *in vitro* or *in vivo* when placed under the control of appropriate regulatory  
15 sequences. “Suitable regulatory sequences” refer to nucleotide sequences located upstream (5' non-coding sequences), within, or downstream (3' non-coding sequences) of a coding sequence, and which influence the transcription, RNA processing or stability, or translation of the associated coding sequence. Regulatory sequences may include promoters, translation leader sequences, introns, polyadenylation recognition sequences, RNA processing site, effector binding site and stem-loop structure. The  
20 boundaries of the coding sequence are determined by a start codon at the 5' (amino) terminus and a translation stop codon at the 3' (carboxyl) terminus. A coding sequence can include, but is not limited to, prokaryotic sequences, cDNA from mRNA, genomic DNA sequences, and even synthetic DNA sequences. If the coding sequence is intended for expression in a eukaryotic cell, a polyadenylation signal and transcription termination sequence will usually be located 3' to the coding sequence.

25 “Open reading frame” is abbreviated ORF and means a length of nucleic acid sequence, either DNA, cDNA or RNA, that comprises a translation start signal or initiation codon, such as an ATG or AUG, and a termination codon and can be potentially translated into a polypeptide sequence.

The term “head-to-head” is used herein to describe the orientation of two polynucleotide sequences in relation to each other. Two polynucleotides are positioned in a head-to-head orientation  
30 when the 5' end of the coding strand of one polynucleotide is adjacent to the 5' end of the coding strand of the other polynucleotide, whereby the direction of transcription of each polynucleotide proceeds away from the 5' end of the other polynucleotide. The term “head-to-head” may be abbreviated (5')-to-(5') and may also be indicated by the symbols ( $\leftarrow \rightarrow$ ) or ( $3' \leftarrow 5' 5' \rightarrow 3'$ ).

The term “tail-to-tail” is used herein to describe the orientation of two polynucleotide sequences  
35 in relation to each other. Two polynucleotides are positioned in a tail-to-tail orientation when the 3' end of the coding strand of one polynucleotide is adjacent to the 3' end of the coding strand of the other polynucleotide, whereby the direction of transcription of each polynucleotide proceeds toward the other

polynucleotide. The term "tail-to-tail" may be abbreviated (3')-to-(3') and may also be indicated by the symbols ( $\rightarrow \leftarrow$ ) or ( $5' \rightarrow 3' 3' \leftarrow 5'$ ).

The term "head-to-tail" is used herein to describe the orientation of two polynucleotide sequences in relation to each other. Two polynucleotides are positioned in a head-to-tail orientation  
5 when the 5' end of the coding strand of one polynucleotide is adjacent to the 3' end of the coding strand of the other polynucleotide, whereby the direction of transcription of each polynucleotide proceeds in the same direction as that of the other polynucleotide. The term "head-to-tail" may be abbreviated (5')-to-(3') and may also be indicated by the symbols ( $\rightarrow \rightarrow$ ) or ( $5' \rightarrow 3' 5' \rightarrow 3'$ ).

The term "downstream" refers to a nucleotide sequence that is located 3' to reference nucleotide  
10 sequence. In particular, downstream nucleotide sequences generally relate to sequences that follow the starting point of transcription. For example, the translation initiation codon of a gene is located downstream of the start site of transcription.

The term "upstream" refers to a nucleotide sequence that is located 5' to reference nucleotide sequence. In particular, upstream nucleotide sequences generally relate to sequences that are located on  
15 the 5' side of a coding sequence or starting point of transcription. For example, most promoters are located upstream of the start site of transcription.

The terms "restriction endonuclease" and "restriction enzyme" refer to an enzyme that binds and cuts within a specific nucleotide sequence within double stranded DNA.

"Homologous recombination" refers to the insertion of a foreign DNA sequence into another  
20 DNA molecule, e.g., insertion of a vector in a chromosome. Preferably, the vector targets a specific chromosomal site for homologous recombination. For specific homologous recombination, the vector will contain sufficiently long regions of homology to sequences of the chromosome to allow complementary binding and incorporation of the vector into the chromosome. Longer regions of homology, and greater degrees of sequence similarity, may increase the efficiency of homologous  
25 recombination.

Several methods known in the art may be used to propagate a polynucleotide according to the invention. Once a suitable host system and growth conditions are established, recombinant expression vectors can be propagated and prepared in quantity. As described herein, the expression vectors which can be used include, but are not limited to, the following vectors or their derivatives: human or animal  
30 viruses such as vaccinia virus or adenovirus; insect viruses such as baculovirus; yeast vectors; bacteriophage vectors (e.g., lambda), and plasmid and cosmid DNA vectors, to name but a few.

A "vector" is any means for the cloning of and/or transfer of a nucleic acid into a host cell. A vector may be a replicon to which another DNA segment may be attached so as to bring about the replication of the attached segment. A "replicon" is any genetic element (e.g., plasmid, phage, cosmid,  
35 chromosome, virus) that functions as an autonomous unit of DNA replication *in vivo*, *i.e.*, capable of replication under its own control. The term "vector" includes both viral and nonviral means for introducing the nucleic acid into a cell *in vitro*, *ex vivo* or *in vivo*. A large number of vectors known in

the art may be used to manipulate nucleic acids, incorporate response elements and promoters into genes, etc. Possible vectors include, for example, plasmids or modified viruses including, for example bacteriophages such as lambda derivatives, or plasmids such as pBR322 or pUC plasmid derivatives, or the Bluescript vector. For example, the insertion of the DNA fragments corresponding to response  
5 elements and promoters into a suitable vector can be accomplished by ligating the appropriate DNA fragments into a chosen vector that has complementary cohesive termini. Alternatively, the ends of the DNA molecules may be enzymatically modified or any site may be produced by ligating nucleotide sequences (linkers) into the DNA termini. Such vectors may be engineered to contain selectable marker genes that provide for the selection of cells that have incorporated the marker into the cellular genome.  
10 Such markers allow identification and/or selection of host cells that incorporate and express the proteins encoded by the marker.

Viral vectors, and particularly retroviral vectors, have been used in a wide variety of gene delivery applications in cells, as well as living animal subjects. Viral vectors that can be used include but are not limited to retrovirus, adeno-associated virus, pox, baculovirus, vaccinia, herpes simplex,  
15 Epstein-Barr, adenovirus, geminivirus, and caulimovirus vectors. Non-viral vectors include plasmids, liposomes, electrically charged lipids (cytofectins), DNA-protein complexes, and biopolymers. In addition to a nucleic acid, a vector may also comprise one or more regulatory regions, and/or selectable markers useful in selecting, measuring, and monitoring nucleic acid transfer results (transfer to which tissues, duration of expression, etc.).

20 The term "plasmid" refers to an extra chromosomal element often carrying a gene that is not part of the central metabolism of the cell, and usually in the form of circular double-stranded DNA molecules. Such elements may be autonomously replicating sequences, genome integrating sequences, phage or nucleotide sequences, linear, circular, or supercoiled, of a single- or double-stranded DNA or RNA, derived from any source, in which a number of nucleotide sequences have been joined or recombined  
25 into a unique construction which is capable of introducing a promoter fragment and DNA sequence for a selected gene product along with appropriate 3' untranslated sequence into a cell.

A "cloning vector" is a "replicon", which is a unit length of a nucleic acid, preferably DNA, that replicates sequentially and which comprises an origin of replication, such as a plasmid, phage or cosmid, to which another nucleic acid segment may be attached so as to bring about the replication of the  
30 attached segment. Cloning vectors may be capable of replication in one cell type and expression in another ("shuttle vector").

Vectors may be introduced into the desired host cells by methods known in the art, e.g., transfection, electroporation, microinjection, transduction, cell fusion, DEAE dextran, calcium phosphate precipitation, lipofection (lysosome fusion), use of a gene gun, or a DNA vector transporter (see, e.g.,  
35 Wu et al., 1992, J. Biol. Chem. 267: 963-967; Wu and Wu, 1988, J. Biol. Chem. 263: 14621-14624; and Hartmut et al., Canadian Patent Application No. 2,012,311, filed March 15, 1990).

A polynucleotide according to the invention can also be introduced *in vivo* by lipofection. For the

past decade, there has been increasing use of liposomes for encapsulation and transfection of nucleic acids *in vitro*. Synthetic cationic lipids designed to limit the difficulties and dangers encountered with liposome-mediated transfection can be used to prepare liposomes for *in vivo* transfection of a gene encoding a marker (Felgner et al., 1987, Proc. Natl. Acad. Sci. U.S.A. 84: 7413; Mackey, et al., 1988, Proc. Natl. Acad. Sci. U.S.A. 85:8027-8031; and Ulmer et al., 1993, Science 259: 1745-1748). The use of cationic lipids may promote encapsulation of negatively charged nucleic acids, and also promote fusion with negatively charged cell membranes (Felgner and Ringold, 1989, Science 337:387-388). Particularly useful lipid compounds and compositions for transfer of nucleic acids are described in International Patent Publications WO95/18863 and WO96/17823, and in U.S. Patent No. 5,459,127. The use of lipofection to introduce exogenous genes into the specific organs *in vivo* has certain practical advantages. Molecular targeting of liposomes to specific cells represents one area of benefit. It is clear that directing transfection to particular cell types would be particularly preferred in a tissue with cellular heterogeneity, such as pancreas, liver, kidney, and the brain. Lipids may be chemically coupled to other molecules for the purpose of targeting (Mackey, et al., 1988, *supra*). Targeted peptides, *e.g.*, hormones or neurotransmitters, and proteins such as antibodies, or non-peptide molecules could be coupled to liposomes chemically.

Other molecules are also useful for facilitating transfection of a nucleic acid *in vivo*, such as a cationic oligopeptide (*e.g.*, WO95/21931), peptides derived from DNA binding proteins (*e.g.*, WO96/25508), or a cationic polymer (*e.g.*, WO95/21931).

It is also possible to introduce a vector *in vivo* as a naked DNA plasmid (see U.S. Patents 5,693,622, 5,589,466 and 5,580,859). Receptor-mediated DNA delivery approaches can also be used (Curiel et al., 1992, Hum. Gene Ther. 3: 147-154; and Wu and Wu, 1987, J. Biol. Chem. 262: 4429-4432).

The term "transfection" means the uptake of exogenous or heterologous RNA or DNA by a cell. A cell has been "transfected" by exogenous or heterologous RNA or DNA when such RNA or DNA has been introduced inside the cell. A cell has been "transformed" by exogenous or heterologous RNA or DNA when the transfected RNA or DNA effects a phenotypic change. The transforming RNA or DNA can be integrated (covalently linked) into chromosomal DNA making up the genome of the cell.

"Transformation" refers to the transfer of a nucleic acid fragment into the genome of a host organism, resulting in genetically stable inheritance. Host organisms containing the transformed nucleic acid fragments are referred to as "transgenic" or "recombinant" or "transformed" organisms.

The term "genetic region" will refer to a region of a nucleic acid molecule or a nucleotide sequence that comprises a gene encoding a polypeptide.

In addition, the recombinant vector comprising a polynucleotide according to the invention may include one or more origins for replication in the cellular hosts in which their amplification or their expression is sought, markers or selectable markers.

The term "selectable marker" means an identifying factor, usually an antibiotic or chemical

resistance gene, that is able to be selected for based upon the marker gene's effect, *i.e.*, resistance to an antibiotic, resistance to a herbicide, colorimetric markers, enzymes, fluorescent markers, and the like, wherein the effect is used to track the inheritance of a nucleic acid of interest and/or to identify a cell or organism that has inherited the nucleic acid of interest. Examples of selectable marker genes known and  
5 used in the art include: genes providing resistance to ampicillin, streptomycin, gentamycin, kanamycin, hygromycin, bialaphos herbicide, sulfonamide, and the like; and genes that are used as phenotypic markers, *i.e.*, anthocyanin regulatory genes, isopentanyl transferase gene, and the like.

The term "reporter gene" means a nucleic acid encoding an identifying factor that is able to be identified based upon the reporter gene's effect, wherein the effect is used to track the inheritance of a  
10 nucleic acid of interest, to identify a cell or organism that has inherited the nucleic acid of interest, and/or to measure gene expression induction or transcription. Examples of reporter genes known and used in the art include: luciferase (Luc), green fluorescent protein (GFP), chloramphenicol acetyltransferase (CAT),  $\beta$ -galactosidase (LacZ),  $\beta$ -glucuronidase (Gus), and the like. Selectable marker genes may also be considered reporter genes.

15 "Promoter" refers to a DNA sequence capable of controlling the expression of a coding sequence or functional RNA. In general, a coding sequence is located 3' to a promoter sequence. Promoters may be derived in their entirety from a native gene, or be composed of different elements derived from different promoters found in nature, or even comprise synthetic DNA segments. It is understood by those skilled in the art that different promoters may direct the expression of a gene in different tissues or  
20 cell types, or at different stages of development, or in response to different environmental or physiological conditions. Promoters that cause a gene to be expressed in most cell types at most times are commonly referred to as "constitutive promoters". Promoters that cause a gene to be expressed in a specific cell type are commonly referred to as "cell-specific promoters" or "tissue-specific promoters". Promoters that cause a gene to be expressed at a specific stage of development or cell differentiation are  
25 commonly referred to as "developmentally-specific promoters" or "cell differentiation-specific promoters". Promoters that are induced and cause a gene to be expressed following exposure or treatment of the cell with an agent, biological molecule, chemical, ligand, light, or the like that induces the promoter are commonly referred to as "inducible promoters" or "regulatable promoters". It is further recognized that since in most cases the exact boundaries of regulatory sequences have not been  
30 completely defined, DNA fragments of different lengths may have identical promoter activity.

A "promoter sequence" is a DNA regulatory region capable of binding RNA polymerase in a cell and initiating transcription of a downstream (3' direction) coding sequence. For purposes of defining the present invention, the promoter sequence is bounded at its 3' terminus by the transcription initiation site and extends upstream (5' direction) to include the minimum number of bases or elements necessary to  
35 initiate transcription at levels detectable above background. Within the promoter sequence will be found a transcription initiation site (conveniently defined for example, by mapping with nuclease S1), as well as protein binding domains (consensus sequences) responsible for the binding of RNA polymerase.

A coding sequence is "under the control" of transcriptional and translational control sequences in a cell when RNA polymerase transcribes the coding sequence into mRNA, which is then trans-RNA spliced (if the coding sequence contains introns) and translated into the protein encoded by the coding sequence.

5 "Transcriptional and translational control sequences" are DNA regulatory sequences, such as promoters, enhancers, terminators, and the like, that provide for the expression of a coding sequence in a host cell. In eukaryotic cells, polyadenylation signals are control sequences.

The term "response element" means one or more cis-acting DNA elements which confer responsiveness on a promoter mediated through interaction with the DNA-binding domains of the first  
10 chimeric gene. This DNA element may be either palindromic (perfect or imperfect) in its sequence or composed of sequence motifs or half sites separated by a variable number of nucleotides. The half sites can be similar or identical and arranged as either direct or inverted repeats or as a single half site or multimers of adjacent half sites in tandem. The response element may comprise a minimal promoter isolated from different organisms depending upon the nature of the cell or organism into which the  
15 response element will be incorporated. The DNA binding domain of the first hybrid protein binds, in the presence or absence of a ligand, to the DNA sequence of a response element to initiate or suppress transcription of downstream gene(s) under the regulation of this response element. Examples of DNA sequences for response elements of the natural ecdysone receptor include: RRGG/TTCANTGAC/ACY (see Cherbas L., et. al., (1991), *Genes Dev.* 5, 120-131); AGGTCAN<sub>(n)</sub>AGGTCA, where N<sub>(n)</sub> can be one  
20 or more spacer nucleotides (see D'Avino PP., et. al., (1995), *Mol. Cell. Endocrinol.* 113, 1-9); and GGGTTGAATGAATTT (see Antoniewski C., et. al., (1994). *Mol. Cell Biol.* 14, 4465-4474).

The term "operably linked" refers to the association of nucleic acid sequences on a single nucleic acid fragment so that the function of one is affected by the other. For example, a promoter is operably linked with a coding sequence when it is capable of affecting the expression of that coding sequence (i.e.,  
25 that the coding sequence is under the transcriptional control of the promoter). Coding sequences can be operably linked to regulatory sequences in sense or antisense orientation.

The term "expression", as used herein, refers to the transcription and stable accumulation of sense (mRNA) or antisense RNA derived from a nucleic acid or polynucleotide. Expression may also refer to translation of mRNA into a protein or polypeptide.

30 The terms "cassette", "expression cassette" and "gene expression cassette" refer to a segment of DNA that can be inserted into a nucleic acid or polynucleotide at specific restriction sites or by homologous recombination. The segment of DNA comprises a polynucleotide that encodes a polypeptide of interest, and the cassette and restriction sites are designed to ensure insertion of the cassette in the proper reading frame for transcription and translation. "Transformation cassette" refers to  
35 a specific vector comprising a polynucleotide that encodes a polypeptide of interest and having elements in addition to the polynucleotide that facilitate transformation of a particular host cell. Cassettes, expression cassettes, gene expression cassettes and transformation cassettes of the invention may also

comprise elements that allow for enhanced expression of a polynucleotide encoding a polypeptide of interest in a host cell. These elements may include, but are not limited to: a promoter, a minimal promoter, an enhancer, a response element, a terminator sequence, a polyadenylation sequence, and the like.

5 For purposes of this invention, the term "gene switch" refers to the combination of a response element associated with a promoter, and an EcR based system which, in the presence of one or more ligands, modulates the expression of a gene into which the response element and promoter are incorporated.

The terms "modulate" and "modulates" mean to induce, reduce or inhibit nucleic acid or gene  
10 expression, resulting in the respective induction, reduction or inhibition of protein or polypeptide production.

The plasmids or vectors according to the invention may further comprise at least one promoter suitable for driving expression of a gene in a host cell. The term "expression vector" means a vector, plasmid or vehicle designed to enable the expression of an inserted nucleic acid sequence following  
15 transformation into the host. The cloned gene, i.e., the inserted nucleic acid sequence, is usually placed under the control of control elements such as a promoter, a minimal promoter, an enhancer, or the like. Initiation control regions or promoters, which are useful to drive expression of a nucleic acid in the desired host cell are numerous and familiar to those skilled in the art. Virtually any promoter capable of driving these genes is suitable for the present invention including but not limited to: viral promoters,  
20 bacterial promoters, animal promoters, mammalian promoters, synthetic promoters, constitutive promoters, tissue specific promoter, developmental specific promoters, inducible promoters, light regulated promoters; *CYC1*, *HIS3*, *GAL1*, *GAL4*, *GAL10*, *ADHI*, *PGK*, *PHO5*, *GAPDH*, *ADC1*, *TRP1*, *URA3*, *LEU2*, *ENO*, *TPI*, alkaline phosphatase promoters (useful for expression in *Saccharomyces*); *AOX1* promoter (useful for expression in *Pichia*);  $\beta$ -lactamase, *lac*, *ara*, *tet*, *trp*, *IP<sub>L</sub>*, *IP<sub>R</sub>*, *T7*, *tac*, and  
25 *trc* promoters (useful for expression in *Escherichia coli*); light regulated-, seed specific-, pollen specific-, ovary specific-, pathogenesis or disease related-, cauliflower mosaic virus 35S, CMV 35S minimal, cassava vein mosaic virus (CsVMV), chlorophyll a/b binding protein, ribulose 1, 5-bisphosphate carboxylase, shoot-specific, root specific, chitinase, stress inducible, rice tungro bacilliform virus, plant super-promoter, potato leucine aminopeptidase, nitrate reductase, mannopine synthase, nopaline  
30 synthase, ubiquitin, zein protein, and anthocyanin promoters (useful for expression in plant cells); animal and mammalian promoters known in the art include, but are not limited to, the SV40 early (SV40e) promoter region, the promoter contained in the 3' long terminal repeat (LTR) of Rous sarcoma virus (RSV), the promoters of the E1A or major late promoter (MLP) genes of adenoviruses (Ad), the cytomegalovirus (CMV) early promoter, the herpes simplex virus (HSV) thymidine kinase (TK)  
35 promoter, a baculovirus IE1 promoter, an elongation factor 1 alpha (EF1) promoter, a phosphoglycerate kinase (PGK) promoter, a ubiquitin (Ubc) promoter, an albumin promoter, the regulatory sequences of the mouse metallothionein-L promoter and transcriptional control regions, the ubiquitous promoters

(HPRT, vimentin,  $\alpha$ -actin, tubulin and the like), the promoters of the intermediate filaments (desmin, neurofilaments, keratin, GFAP, and the like), the promoters of therapeutic genes (of the MDR, CFTR or factor VIII type, and the like), pathogenesis or disease related-promoters, and promoters that exhibit tissue specificity and have been utilized in transgenic animals, such as the elastase I gene control region  
5 which is active in pancreatic acinar cells; insulin gene control region active in pancreatic beta cells, immunoglobulin gene control region active in lymphoid cells, mouse mammary tumor virus control region active in testicular, breast, lymphoid and mast cells; albumin gene, Apo AI and Apo AII control regions active in liver, alpha-fetoprotein gene control region active in liver, alpha 1-antitrypsin gene control region active in the liver, beta-globin gene control region active in myeloid cells, myelin basic  
10 protein gene control region active in oligodendrocyte cells in the brain, myosin light chain-2 gene control region active in skeletal muscle, and gonadotropic releasing hormone gene control region active in the hypothalamus, pyruvate kinase promoter, villin promoter, promoter of the fatty acid binding intestinal protein, promoter of the smooth muscle cell  $\alpha$ -actin, and the like. In addition, these expression sequences may be modified by addition of enhancer or regulatory sequences and the like.

15 Enhancers that may be used in embodiments of the invention include but are not limited to: an SV40 enhancer, a cytomegalovirus (CMV) enhancer, an elongation factor 1 (EF1) enhancer, yeast enhancers, viral gene enhancers, and the like.

Termination control regions, *i.e.*, terminator or polyadenylation sequences, may also be derived from various genes native to the preferred hosts. Optionally, a termination site may be unnecessary,  
20 however, it is most preferred if included. In a preferred embodiment of the invention, the termination control region may be comprise or be derived from a synthetic sequence, synthetic polyadenylation signal, an SV40 late polyadenylation signal, an SV40 polyadenylation signal, a bovine growth hormone (BGH) polyadenylation signal, viral terminator sequences, or the like.

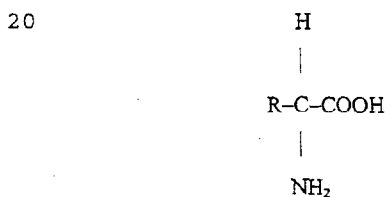
The terms "3' non-coding sequences" or "3' untranslated region (UTR)" refer to DNA sequences  
25 located downstream (3') of a coding sequence and may comprise polyadenylation [poly(A)] recognition sequences and other sequences encoding regulatory signals capable of affecting mRNA processing or gene expression. The polyadenylation signal is usually characterized by affecting the addition of polyadenylic acid tracts to the 3' end of the mRNA precursor.

"Regulatory region" means a nucleic acid sequence that regulates the expression of a second  
30 nucleic acid sequence. A regulatory region may include sequences which are naturally responsible for expressing a particular nucleic acid (a homologous region) or may include sequences of a different origin that are responsible for expressing different proteins or even synthetic proteins (a heterologous region). In particular, the sequences can be sequences of prokaryotic, eukaryotic, or viral genes or derived sequences that stimulate or repress transcription of a gene in a specific or non-specific manner and in an  
35 inducible or non-inducible manner. Regulatory regions include origins of replication, RNA splice sites, promoters, enhancers, transcriptional termination sequences, and signal sequences which direct the polypeptide into the secretory pathways of the target cell.

A regulatory region from a "heterologous source" is a regulatory region that is not naturally associated with the expressed nucleic acid. Included among the heterologous regulatory regions are regulatory regions from a different species, regulatory regions from a different gene, hybrid regulatory sequences, and regulatory sequences which do not occur in nature, but which are designed by one having  
5 ordinary skill in the art.

"RNA transcript" refers to the product resulting from RNA polymerase-catalyzed transcription of a DNA sequence. When the RNA transcript is a perfect complementary copy of the DNA sequence, it is referred to as the primary transcript or it may be a RNA sequence derived from post-transcriptional processing of the primary transcript and is referred to as the mature RNA. "Messenger RNA (mRNA)"  
10 refers to the RNA that is without introns and that can be translated into protein by the cell. "cDNA" refers to a double-stranded DNA that is complementary to and derived from mRNA. "Sense" RNA refers to RNA transcript that includes the mRNA and so can be translated into protein by the cell. "Antisense RNA" refers to a RNA transcript that is complementary to all or part of a target primary transcript or mRNA and that blocks the expression of a target gene. The complementarity of an antisense  
15 RNA may be with any part of the specific gene transcript, i.e., at the 5' non-coding sequence, 3' non-coding sequence, or the coding sequence. "Functional RNA" refers to antisense RNA, ribozyme RNA, or other RNA that is not translated yet has an effect on cellular processes.

A "polypeptide" is a polymeric compound comprised of covalently linked amino acid residues. Amino acids have the following general structure:



25 Amino acids are classified into seven groups on the basis of the side chain R: (1) aliphatic side chains, (2) side chains containing a hydroxylic (OH) group, (3) side chains containing sulfur atoms, (4) side chains containing an acidic or amide group, (5) side chains containing a basic group, (6) side chains containing an aromatic ring, and (7) proline, an imino acid in which the side chain is fused to the amino group. A polypeptide of the invention preferably comprises at least about 14 amino acids.

30 A "protein" is a polypeptide that performs a structural or functional role in a living cell.

An "isolated polypeptide" or "isolated protein" is a polypeptide or protein that is substantially free of those compounds that are normally associated therewith in its natural state (e.g., other proteins or polypeptides, nucleic acids, carbohydrates, lipids). "Isolated" is not meant to exclude artificial or synthetic mixtures with other compounds, or the presence of impurities which do not interfere with  
35 biological activity, and which may be present, for example, due to incomplete purification, addition of stabilizers, or compounding into a pharmaceutically acceptable preparation.

A "substitution mutant polypeptide" or a "substitution mutant" will be understood to mean a

mutant polypeptide comprising a substitution of at least one (1) wild-type or naturally occurring amino acid with a different amino acid relative to the wild-type or naturally occurring polypeptide. A substitution mutant polypeptide may comprise only one (1) wild-type or naturally occurring amino acid substitution and may be referred to as a "point mutant" or a "single point mutant" polypeptide.

5 Alternatively, a substitution mutant polypeptide may comprise a substitution of two (2) or more wild-type or naturally occurring amino acids with 2 or more amino acids relative to the wild-type or naturally occurring polypeptide. According to the invention, a Group H nuclear receptor ligand binding domain polypeptide comprising a substitution mutation comprises a substitution of at least one (1) wild-type or naturally occurring amino acid with a different amino acid relative to the wild-type or naturally occurring  
10 Group H nuclear receptor ligand binding domain polypeptide.

Wherein the substitution mutant polypeptide comprises a substitution of two (2) or more wild-type or naturally occurring amino acids, this substitution may comprise either an equivalent number of wild-type or naturally occurring amino acids deleted for the substitution, i.e., 2 wild-type or naturally occurring amino acids replaced with 2 non-wild-type or non-naturally occurring amino acids, or a non-  
15 equivalent number of wild-type amino acids deleted for the substitution, i.e., 2 wild-type amino acids replaced with 1 non-wild-type amino acid (a substitution+deletion mutation), or 2 wild-type amino acids replaced with 3 non-wild-type amino acids (a substitution+insertion mutation). Substitution mutants may be described using an abbreviated nomenclature system to indicate the amino acid residue and number replaced within the reference polypeptide sequence and the new substituted amino acid residue. For  
20 example, a substitution mutant in which the twentieth (20<sup>th</sup>) amino acid residue of a polypeptide is substituted may be abbreviated as "x20z", wherein "x" is the amino acid to be replaced, "20" is the amino acid residue position or number within the polypeptide, and "z" is the new substituted amino acid. Therefore, a substitution mutant abbreviated interchangeably as "E20A" or "Glu20Ala" indicates that the mutant comprises an alanine residue (commonly abbreviated in the art as "A" or "Ala") in place of  
25 the glutamic acid (commonly abbreviated in the art as "E" or "Glu") at position 20 of the polypeptide.

A substitution mutation may be made by any technique for mutagenesis known in the art, including but not limited to, *in vitro* site-directed mutagenesis (Hutchinson, C., et al., 1978, J. Biol. Chem. 253: 6551; Zoller and Smith, 1984, DNA 3: 479-488; Oliphant et al., 1986, Gene 44: 177; Hutchinson et al., 1986, Proc. Natl. Acad. Sci. U.S.A. 83: 710), use of TAB® linkers (Pharmacia),  
30 restriction endonuclease digestion/fragment deletion and substitution, PCR-mediated/oligonucleotide-directed mutagenesis, and the like. PCR-based techniques are preferred for site-directed mutagenesis (see Higuchi, 1989, "Using PCR to Engineer DNA", in *PCR Technology: Principles and Applications for DNA Amplification*, H. Erlich, ed., Stockton Press, Chapter 6, pp. 61-70).

"Fragment" of a polypeptide according to the invention will be understood to mean a polypeptide  
35 whose amino acid sequence is shorter than that of the reference polypeptide and which comprises, over the entire portion with these reference polypeptides, an identical amino acid sequence. Such fragments may, where appropriate, be included in a larger polypeptide of which they are a part. Such fragments of

a polypeptide according to the invention may have a length of at least 2, 3, 4, 5, 6, 8, 10, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 25, 26, 30, 35, 40, 45, 50, 100, 200, 240, or 300 amino acids.

A "variant" of a polypeptide or protein is any analogue, fragment, derivative, or mutant which is derived from a polypeptide or protein and which retains at least one biological property of the polypeptide or protein. Different variants of the polypeptide or protein may exist in nature. These variants may be allelic variations characterized by differences in the nucleotide sequences of the structural gene coding for the protein, or may involve differential splicing or post-translational modification. The skilled artisan can produce variants having single or multiple amino acid substitutions, deletions, additions, or replacements. These variants may include, *inter alia*: (a) variants in which one or more amino acid residues are substituted with conservative or non-conservative amino acids, (b) variants in which one or more amino acids are added to the polypeptide or protein, (c) variants in which one or more of the amino acids includes a substituent group, and (d) variants in which the polypeptide or protein is fused with another polypeptide such as serum albumin. The techniques for obtaining these variants, including genetic (suppressions, deletions, mutations, etc.), chemical, and enzymatic techniques, are known to persons having ordinary skill in the art. A variant polypeptide preferably comprises at least about 14 amino acids.

A "heterologous protein" refers to a protein not naturally produced in the cell.

A "mature protein" refers to a post-translationally processed polypeptide; i.e., one from which any pre- or propeptides present in the primary translation product have been removed. "Precursor" protein refers to the primary product of translation of mRNA; i.e., with pre- and propeptides still present. Pre- and propeptides may be but are not limited to intracellular localization signals.

The term "signal peptide" refers to an amino terminal polypeptide preceding the secreted mature protein. The signal peptide is cleaved from and is therefore not present in the mature protein. Signal peptides have the function of directing and translocating secreted proteins across cell membranes. Signal peptide is also referred to as signal protein.

A "signal sequence" is included at the beginning of the coding sequence of a protein to be expressed on the surface of a cell. This sequence encodes a signal peptide, N-terminal to the mature polypeptide, that directs the host cell to translocate the polypeptide. The term "translocation signal sequence" is used herein to refer to this sort of signal sequence. Translocation signal sequences can be found associated with a variety of proteins native to eukaryotes and prokaryotes, and are often functional in both types of organisms.

The term "homology" refers to the percent of identity between two polynucleotide or two polypeptide moieties. The correspondence between the sequence from one moiety to another can be determined by techniques known to the art. For example, homology can be determined by a direct comparison of the sequence information between two polypeptide molecules by aligning the sequence information and using readily available computer programs. Alternatively, homology can be determined by hybridization of polynucleotides under conditions that form stable duplexes between homologous

regions, followed by digestion with single-stranded-specific nuclease(s) and size determination of the digested fragments.

As used herein, the term "homologous" in all its grammatical forms and spelling variations refers to the relationship between proteins that possess a "common evolutionary origin," including proteins from superfamilies (e.g., the immunoglobulin superfamily) and homologous proteins from different species (e.g., myosin light chain, etc.) (Reeck et al., 1987, Cell 50: 667.). Such proteins (and their encoding genes) have sequence homology, as reflected by their high degree of sequence similarity. However, in common usage and in the instant application, the term "homologous," when modified with an adverb such as "highly," may refer to sequence similarity and not a common evolutionary origin.

Accordingly, the term "sequence similarity" in all its grammatical forms refers to the degree of identity or correspondence between nucleic acid or amino acid sequences of proteins that may or may not share a common evolutionary origin (see Reeck et al., 1987, Cell 50:667).

In a specific embodiment, two DNA sequences are "substantially homologous" or "substantially similar" when at least about 50% (preferably at least about 75%, and most preferably at least about 90 or 95%) of the nucleotides match over the defined length of the DNA sequences. Sequences that are substantially homologous can be identified by comparing the sequences using standard software available in sequence data banks, or in a Southern hybridization experiment under, for example, stringent conditions as defined for that particular system. Defining appropriate hybridization conditions is within the skill of the art. See, e.g., Sambrook *et al.*, 1989, *supra*.

As used herein, "substantially similar" refers to nucleic acid fragments wherein changes in one or more nucleotide bases results in substitution of one or more amino acids, but do not affect the functional properties of the protein encoded by the DNA sequence. "Substantially similar" also refers to nucleic acid fragments wherein changes in one or more nucleotide bases does not affect the ability of the nucleic acid fragment to mediate alteration of gene expression by antisense or co-suppression technology. "Substantially similar" also refers to modifications of the nucleic acid fragments of the instant invention such as deletion or insertion of one or more nucleotide bases that do not substantially affect the functional properties of the resulting transcript. It is therefore understood that the invention encompasses more than the specific exemplary sequences. Each of the proposed modifications is well within the routine skill in the art, as is determination of retention of biological activity of the encoded products.

Moreover, the skilled artisan recognizes that substantially similar sequences encompassed by this invention are also defined by their ability to hybridize, under stringent conditions (0.1X SSC, 0.1% SDS, 65°C and washed with 2X SSC, 0.1% SDS followed by 0.1X SSC, 0.1% SDS), with the sequences exemplified herein. Substantially similar nucleic acid fragments of the instant invention are those nucleic acid fragments whose DNA sequences are at least 70% identical to the DNA sequence of the nucleic acid fragments reported herein. Preferred substantially nucleic acid fragments of the instant invention are those nucleic acid fragments whose DNA sequences are at least 80% identical to the DNA

sequence of the nucleic acid fragments reported herein. More preferred nucleic acid fragments are at least 90% identical to the DNA sequence of the nucleic acid fragments reported herein. Even more preferred are nucleic acid fragments that are at least 95% identical to the DNA sequence of the nucleic acid fragments reported herein.

5 Two amino acid sequences are "substantially homologous" or "substantially similar" when greater than about 40% of the amino acids are identical, or greater than 60% are similar (functionally identical). Preferably, the similar or homologous sequences are identified by alignment using, for example, the GCG (Genetics Computer Group, Program Manual for the GCG Package, *Version 7*, Madison, Wisconsin) pileup program.

10 The term "corresponding to" is used herein to refer to similar or homologous sequences, whether the exact position is identical or different from the molecule to which the similarity or homology is measured. A nucleic acid or amino acid sequence alignment may include spaces. Thus, the term "corresponding to" refers to the sequence similarity, and not the numbering of the amino acid residues or nucleotide bases.

15 A "substantial portion" of an amino acid or nucleotide sequence comprises enough of the amino acid sequence of a polypeptide or the nucleotide sequence of a gene to putatively identify that polypeptide or gene, either by manual evaluation of the sequence by one skilled in the art, or by computer-automated sequence comparison and identification using algorithms such as BLAST (Basic Local Alignment Search Tool; Altschul, S. F., et al., (1993) *J. Mol. Biol.* 215: 403-410).

20 In general, a sequence of ten or more contiguous amino acids or thirty or more nucleotides is necessary in order to putatively identify a polypeptide or nucleic acid sequence as homologous to a known protein or gene. Moreover, with respect to nucleotide sequences, gene specific oligonucleotide probes comprising 20-30 contiguous nucleotides may be used in sequence-dependent methods of gene identification (e.g., Southern hybridization) and isolation (e.g., *in situ* hybridization of  
25 bacterial colonies or bacteriophage plaques). In addition, short oligonucleotides of 12-15 bases may be used as amplification primers in PCR in order to obtain a particular nucleic acid fragment comprising the primers. Accordingly, a "substantial portion" of a nucleotide sequence comprises enough of the sequence to specifically identify and/or isolate a nucleic acid fragment comprising the sequence.

The term "percent identity", as known in the art, is a relationship between two or more  
30 polypeptide sequences or two or more polynucleotide sequences, as determined by comparing the sequences. In the art, "identity" also means the degree of sequence relatedness between polypeptide or polynucleotide sequences, as the case may be, as determined by the match between strings of such sequences. "Identity" and "similarity" can be readily calculated by known methods, including but not limited to those described in: *Computational Molecular Biology* (Lesk, A. M., ed.) Oxford University  
35 Press, New York (1988); *Biocomputing: Informatics and Genome Projects* (Smith, D. W., ed.) Academic Press, New York (1993); *Computer Analysis of Sequence Data, Part I* (Griffin, A. M., and Griffin, H. G., eds.) Humana Press, New Jersey (1994); *Sequence Analysis in Molecular Biology* (von

Heinje, G., ed.) Academic Press (1987); and *Sequence Analysis Primer* (Gribskov, M. and Devereux, J., eds.) Stockton Press, New York (1991). Preferred methods to determine identity are designed to give the best match between the sequences tested. Methods to determine identity and similarity are codified in publicly available computer programs. Sequence alignments and percent identity calculations may be performed using the Megalign program of the LASERGENE bioinformatics computing suite (DNASTAR Inc., Madison, WI). Multiple alignment of the sequences may be performed using the Clustal method of alignment (Higgins and Sharp (1989) *CABIOS*. 5:151-153) with the default parameters (GAP PENALTY=10, GAP LENGTH PENALTY=10). Default parameters for pairwise alignments using the Clustal method may be selected: KTUPLE 1, GAP PENALTY=3, WINDOW=5 and  
10 DIAGONALS SAVED=5.

The term "sequence analysis software" refers to any computer algorithm or software program that is useful for the analysis of nucleotide or amino acid sequences. "Sequence analysis software" may be commercially available or independently developed. Typical sequence analysis software will include but is not limited to the GCG suite of programs (Wisconsin Package Version 9.0, Genetics Computer Group (GCG), Madison, WI), BLASTP, BLASTN, BLASTX (Altschul et al., *J. Mol. Biol.* 215: 403-410 (1990), and DNASTAR (DNASTAR, Inc. 1228 S. Park St. Madison, WI 53715 USA). Within the context of this application it will be understood that where sequence analysis software is used for analysis, that the results of the analysis will be based on the "default values" of the program referenced, unless otherwise specified. As used herein "default values" will mean any set of values or parameters  
20 which originally load with the software when first initialized.

"Synthetic genes" can be assembled from oligonucleotide building blocks that are chemically synthesized using procedures known to those skilled in the art. These building blocks are ligated and annealed to form gene segments that are then enzymatically assembled to construct the entire gene. "Chemically synthesized", as related to a sequence of DNA, means that the component nucleotides were assembled *in vitro*. Manual chemical synthesis of DNA may be accomplished using well-established  
25 procedures, or automated chemical synthesis can be performed using one of a number of commercially available machines. Accordingly, the genes can be tailored for optimal gene expression based on optimization of nucleotide sequence to reflect the codon bias of the host cell. The skilled artisan appreciates the likelihood of successful gene expression if codon usage is biased towards those codons  
30 favored by the host. Determination of preferred codons can be based on a survey of genes derived from the host cell where sequence information is available.

As used herein, two or more individually operable gene regulation systems are said to be "orthogonal" when; a) modulation of each of the given systems by its respective ligand, at a chosen concentration, results in a measurable change in the magnitude of expression of the gene of that system,  
35 and b) the change is statistically significantly different than the change in expression of all other systems simultaneously operable in the cell, tissue, or organism, regardless of the simultaneity or sequentially of the actual modulation. Preferably, modulation of each individually operable gene regulation system

effects a change in gene expression at least 2-fold greater than all other operable systems in the cell, tissue, or organism. More preferably, the change is at least 5-fold greater. Even more preferably, the change is at least 10-fold greater. Still more preferably, the change is at least 100 fold greater. Even still more preferably, the change is at least 500-fold greater. Ideally, modulation of each of the given systems by its respective ligand at a chosen concentration results in a measurable change in the magnitude of expression of the gene of that system and no measurable change in expression of all other systems operable in the cell, tissue, or organism. In such cases the multiple inducible gene regulation system is said to be "fully orthogonal". The present invention is useful to search for orthogonal ligands and orthogonal receptor-based gene expression systems such as those described in

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10 WO 2002/029075.

#### GENE EXPRESSION MODULATION SYSTEM OF THE INVENTION

Applicants have identified herein amino acid residues that are involved in ligand binding to a Group H nuclear receptor ligand binding domain that affect the ligand sensitivity and magnitude of induction in an ecdysone receptor-based inducible gene expression system. Applicants describe herein the construction of Group H nuclear receptors that comprise substitution mutations (referred to herein as "substitution mutants") at these critical residues and the demonstration that these substitution mutant nuclear receptors are useful in methods of modulating gene expression. As presented herein, Applicants' novel substitution mutant nuclear receptors and their use in a nuclear receptor-based inducible gene expression system provides an improved inducible gene expression system in both prokaryotic and eukaryotic host cells in which ligand sensitivity and magnitude of transactivation may be selected as desired, depending upon the application.

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Thus, the present invention relates to novel substitution mutant Group H nuclear receptor polynucleotides and polypeptides, a nuclear receptor-based inducible gene expression system comprising such mutated Group H nuclear receptor polynucleotides and polypeptides, and methods of modulating the expression of a gene within a host cell using such a nuclear receptor-based inducible gene expression system.

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In particular, the present invention relates to a gene expression modulation system comprising at least one gene expression cassette that is capable of being expressed in a host cell comprising a polynucleotide that encodes a polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation. Preferably, the Group H nuclear receptor ligand binding domain comprising a substitution mutation is from an ecdysone receptor, a ubiquitous receptor, an orphan receptor 1, a NER-1, a steroid hormone nuclear receptor 1, a retinoid X receptor interacting protein -15, a liver X receptor  $\beta$ , a steroid hormone receptor like protein, a liver X receptor, a liver X receptor  $\alpha$ , a farnesoid X receptor, a receptor interacting protein 14, and a farnesol receptor. More preferably, the Group H nuclear receptor ligand binding domain comprising a substitution mutation is from an ecdysone receptor.

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In a specific embodiment, the gene expression modulation system comprises a gene expression cassette comprising a polynucleotide that encodes a polypeptide comprising a transactivation domain, a DNA-binding domain that recognizes a response element associated with a gene whose expression is to be modulated; and a Group H nuclear receptor ligand binding domain comprising a substitution  
5 mutation. The gene expression modulation system may further comprise a second gene expression cassette comprising: i) a response element recognized by the DNA-binding domain of the encoded polypeptide of the first gene expression cassette; ii) a promoter that is activated by the transactivation domain of the encoded polypeptide of the first gene expression cassette; and iii) a gene whose expression is to be modulated.

10 In another specific embodiment, the gene expression modulation system comprises a gene expression cassette comprising a) a polynucleotide that encodes a polypeptide comprising a transactivation domain, a DNA-binding domain that recognizes a response element associated with a gene whose expression is to be modulated; and a Group H nuclear receptor ligand binding domain comprising a substitution mutation, and b) a second nuclear receptor ligand binding domain selected  
15 from the group consisting of a vertebrate retinoid X receptor ligand binding domain, an invertebrate retinoid X receptor ligand binding domain, an ultraspiracle protein ligand binding domain, and a chimeric ligand binding domain comprising two polypeptide fragments, wherein the first polypeptide fragment is from a vertebrate retinoid X receptor ligand binding domain, an invertebrate retinoid X receptor ligand binding domain, or an ultraspiracle protein ligand binding domain, and the second  
20 polypeptide fragment is from a different vertebrate retinoid X receptor ligand binding domain, invertebrate retinoid X receptor ligand binding domain, or ultraspiracle protein ligand binding domain. The gene expression modulation system may further comprise a second gene expression cassette comprising: i) a response element recognized by the DNA-binding domain of the encoded polypeptide of the first gene expression cassette; ii) a promoter that is activated by the transactivation domain of the  
25 encoded polypeptide of the first gene expression cassette; and iii) a gene whose expression is to be modulated.

In another specific embodiment, the gene expression modulation system comprises a first gene expression cassette comprising a polynucleotide that encodes a first polypeptide comprising a DNA-binding domain that recognizes a response element associated with a gene whose expression is to  
30 be modulated and a nuclear receptor ligand binding domain, and a second gene expression cassette comprising a polynucleotide that encodes a second polypeptide comprising a transactivation domain and a nuclear receptor ligand binding domain, wherein one of the nuclear receptor ligand binding domains is a Group H nuclear receptor ligand binding domain comprising a substitution mutation. In a preferred embodiment, the first polypeptide is substantially free of a transactivation domain and the second  
35 polypeptide is substantially free of a DNA binding domain. For purposes of the invention, "substantially free" means that the protein in question does not contain a sufficient sequence of the domain in question to provide activation or binding activity. The gene expression modulation system may further comprise a



one vertebrate species RXR polypeptide fragment and one non-Dipteran/non-Lepidopteran invertebrate species RXR homolog polypeptide fragment.

In a specific embodiment, the gene whose expression is to be modulated is a homologous gene with respect to the host cell. In another specific embodiment, the gene whose expression is to be  
5 modulated is a heterologous gene with respect to the host cell.

The ligands for use in the present invention as described below, when combined with the ligand binding domain of the nuclear receptor(s), which in turn are bound to the response element linked to a gene, provide the means for external temporal regulation of expression of the gene. The binding mechanism or the order in which the various components of this invention bind to each other, that is, for  
10 example, ligand to ligand binding domain, DNA-binding domain to response element, transactivation domain to promoter, etc., is not critical.

In a specific example, binding of the ligand to the ligand binding domain of a Group H nuclear receptor and its nuclear receptor ligand binding domain partner enables expression or suppression of the gene. This mechanism does not exclude the potential for ligand binding to the Group H nuclear receptor  
15 (GHNR) or its partner, and the resulting formation of active homodimer complexes (e.g. GHNR + GHNR or partner+partner). Preferably, one or more of the receptor domains is varied producing a hybrid gene switch. Typically, one or more of the three domains, DBD, LBD, and transactivation domain, may be chosen from a source different than the source of the other domains so that the hybrid genes and the resulting hybrid proteins are optimized in the chosen host cell or organism for  
20 transactivating activity, complementary binding of the ligand, and recognition of a specific response element. In addition, the response element itself can be modified or substituted with response elements for other DNA binding protein domains such as the GAL-4 protein from yeast (see Sadowski, et al. (1988), *Nature*, 335: 563-564) or LexA protein from *Escherichia coli* (see Brent and Ptashne (1985), *Cell*, 43: 729-736), or synthetic response elements specific for targeted interactions with proteins  
25 designed, modified, and selected for such specific interactions (see, for example, Kim, et al. (1997), *Proc. Natl. Acad. Sci., USA*, 94:3 616-3620) to accommodate hybrid receptors. Another advantage of two-hybrid systems is that they allow choice of a promoter used to drive the gene expression according to a desired end result. Such double control can be particularly important in areas of gene therapy, especially when cytotoxic proteins are produced, because both the timing of expression as well as the  
30 cells wherein expression occurs can be controlled. When genes, operably linked to a suitable promoter, are introduced into the cells of the subject, expression of the exogenous genes is controlled by the presence of the system of this invention. Promoters may be constitutively or inducibly regulated or may be tissue-specific (that is, expressed only in a particular type of cells) or specific to certain developmental stages of the organism.

35 The ecdysone receptor is a member of the nuclear receptor superfamily and classified into subfamily 1, group H (referred to herein as "Group H nuclear receptors"). The members of each group share 40-60% amino acid identity in the E (ligand binding) domain (Laudet et al., A Unified

Nomenclature System for the Nuclear Receptor Subfamily, 1999; Cell 97: 161-163). In addition to the ecdysone receptor, other members of this nuclear receptor subfamily 1, group H include: ubiquitous receptor (UR), orphan receptor 1 (OR-1), steroid hormone nuclear receptor 1 (NER-1), retinoid X receptor interacting protein -15 (RIP-15), liver X receptor  $\beta$  (LXR $\beta$ ), steroid hormone receptor like protein (RLD-1), liver X receptor (LXR), liver X receptor  $\alpha$  (LXR $\alpha$ ), farnesoid X receptor (FXR), receptor interacting protein 14 (RIP-14), and farnesol receptor (HRR-1).

Applicants have developed a CfEcR homology model and have used this homology model together with a published *Chironomus tentans* ecdysone receptor ("CtEcR") homology model (Wurtz et al., 2000) to identify critical residues involved in binding to steroids and non-steroids. The synthetic non-steroids, diacylhydrazines, have been shown to bind lepidopteran EcRs with high affinity and induce precocious incomplete molt in these insects (Wing et al., 1988) and several of these compounds are currently marketed as insecticides. The ligand binding cavity or "pocket" of EcRs has evolved to fit the long backbone structures of ecdysteroids such as 20-hydroxyecdysone (20E). The diacylhydrazines have a compact structure compared to steroids and occupy only the bottom part of the EcR binding pocket. This leaves a few critical residues at the top part of the binding pocket that make contact with steroids but not with non-steroids such as bisacylhydrazines. Applicants describe herein the construction of mutant ecdysone receptors comprising a substitution mutation at these binding pocket residues and have identified several classes of substitution mutant ecdysone receptors with modified ligand binding and transactivation characteristics.

Given the close relatedness of ecdysone receptor to other Group H nuclear receptors, Applicants' identified ecdysone receptor ligand binding domain substitution mutations are also expected to work when introduced into the analogous position of the ligand binding domains of other Group H nuclear receptors to modify their ligand binding or ligand sensitivity. Applicants' novel substitution mutated Group H nuclear receptor polynucleotides and polypeptides are useful in a nuclear receptor-based inducible gene modulation system for various applications including gene therapy, expression of proteins of interest in host cells, production of transgenic organisms, and cell-based assays.

In particular, Applicants describe herein a novel gene expression modulation system comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation. This gene expression system may be a "single switch"-based gene expression system in which the transactivation domain, DNA-binding domain and ligand binding domain are on one encoded polypeptide. Alternatively, the gene expression modulation system may be a "dual switch"- or "two-hybrid"-based gene expression modulation system in which the transactivation domain and DNA-binding domain are located on two different encoded polypeptides. Applicants have demonstrated for the first time that a substitution mutated nuclear receptor can be used as a component of a nuclear receptor-based inducible gene expression system to modify ligand binding activity and/or ligand specificity in both prokaryotic and eukaryotic cells. As discussed herein, Applicants' findings are both unexpected and surprising.

An ecdysone receptor-based gene expression modulation system of the present invention may be

either heterodimeric and homodimeric. A functional EcR complex generally refers to a heterodimeric protein complex consisting of two members of the steroid receptor family, an ecdysone receptor protein obtained from various insects, and an ultraspiracle (USP) protein or the vertebrate homolog of USP, retinoid X receptor protein (see Yao, et al. (1993) Nature 366: 476-479; Yao, et al., (1992) Cell 71: 63-72). However, the complex may also be a homodimer as detailed below. The functional ecdysteroid receptor complex may also include additional protein(s) such as immunophilins. Additional members of the steroid receptor family of proteins, known as transcriptional factors (such as DHR38 or *betaFTZ-1*), may also be ligand dependent or independent partners for EcR, USP, and/or RXR. Additionally, other cofactors may be required such as proteins generally known as coactivators (also termed adapters or mediators). These proteins do not bind sequence-specifically to DNA and are not involved in basal transcription. They may exert their effect on transcription activation through various mechanisms, including stimulation of DNA-binding of activators, by affecting chromatin structure, or by mediating activator-initiation complex interactions. Examples of such coactivators include RIP140, TIF1, RAP46/Bag-1, ARA70, SRC-1/NCoA-1, TIF2/GRIP/NCoA-2, ACTR/AIB1/RAC3/pCIP as well as the promiscuous coactivator C response element B binding protein, CBP/p300 (for review see Glass et al., Curr. Opin. Cell Biol. 9: 222-232, 1997). Also, protein cofactors generally known as corepressors (also known as repressors, silencers, or silencing mediators) may be required to effectively inhibit transcriptional activation in the absence of ligand. These corepressors may interact with the unliganded ecdysone receptor to silence the activity at the response element. Current evidence suggests that the binding of ligand changes the conformation of the receptor, which results in release of the corepressor and recruitment of the above described coactivators, thereby abolishing their silencing activity. Examples of corepressors include N-CoR and SMRT (for review, see Horwitz et al. Mol Endocrinol. 10: 1167-1177, 1996). These cofactors may either be endogenous within the cell or organism, or may be added exogenously as transgenes to be expressed in either a regulated or unregulated fashion. Homodimer complexes of the ecdysone receptor protein, USP, or RXR may also be functional under some circumstances.

The ecdysone receptor complex typically includes proteins that are members of the nuclear receptor superfamily wherein all members are generally characterized by the presence of an amino-terminal transactivation domain, a DNA binding domain ("DBD"), and a ligand binding domain ("LBD") separated from the DBD by a hinge region. As used herein, the term "DNA binding domain" comprises a minimal polypeptide sequence of a DNA binding protein, up to the entire length of a DNA binding protein, so long as the DNA binding domain functions to associate with a particular response element. Members of the nuclear receptor superfamily are also characterized by the presence of four or five domains: A/B, C, D, E, and in some members F (see US patent 4,981,784 and Evans, *Science* 240:889-895 (1988)). The "A/B" domain corresponds to the transactivation domain, "C" corresponds to the DNA binding domain, "D" corresponds to the hinge region, and "E" corresponds to the ligand binding domain. Some members of the family may also have another transactivation domain on the

carboxy-terminal side of the LBD corresponding to "F".

The DBD is characterized by the presence of two cysteine zinc fingers between which are two amino acid motifs, the P-box and the D-box, which confer specificity for ecdysone response elements. These domains may be either native, modified, or chimeras of different domains of heterologous receptor proteins. The EcR receptor, like a subset of the steroid receptor family, also possesses less well-defined regions responsible for heterodimerization properties. Because the domains of nuclear receptors are modular in nature, the LBD, DBD, and transactivation domains may be interchanged.

Gene switch systems are known that incorporate components from the ecdysone receptor complex. However, in these known systems, whenever EcR is used it is associated with native or modified DNA binding domains and transactivation domains on the same molecule. USP or RXR are typically used as silent partners. Applicants have previously shown that when DNA binding domains and transactivation domains are on the same molecule the background activity in the absence of ligand is high and that such activity is dramatically reduced when DNA binding domains and transactivation domains are on different molecules, that is, on each of two partners of a heterodimeric or homodimeric complex (see PCT/US01/09050).

#### GENE EXPRESSION CASSETTES OF THE INVENTION

The novel nuclear receptor-based inducible gene expression system of the invention comprises at least one gene expression cassette that is capable of being expressed in a host cell, wherein the gene expression cassette comprises a polynucleotide that encodes a polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation. Thus, Applicants' invention also provides novel gene expression cassettes for use in the gene expression system of the invention.

In a specific embodiment, the gene expression cassette that is capable of being expressed in a host cell comprises a polynucleotide that encodes a polypeptide selected from the group consisting of a) a polypeptide comprising a transactivation domain, a DNA-binding domain, and a Group H nuclear receptor ligand binding domain comprising a substitution mutation; b) a polypeptide comprising a DNA-binding domain and a Group H nuclear receptor ligand binding domain comprising a substitution mutation; and c) a polypeptide comprising a transactivation domain and a Group H nuclear receptor ligand binding domain comprising a substitution mutation.

In another specific embodiment, the present invention provides a gene expression cassette that is capable of being expressed in a host cell, wherein the gene expression cassette comprises a polynucleotide that encodes a hybrid polypeptide selected from the group consisting of a) a hybrid polypeptide comprising a transactivation domain, a DNA-binding domain, and a Group H nuclear receptor ligand binding domain comprising a substitution mutation; b) a hybrid polypeptide comprising a DNA-binding domain and a Group H nuclear receptor ligand binding domain comprising a substitution mutation; and c) a hybrid polypeptide comprising a transactivation domain and a Group H nuclear receptor ligand binding domain comprising a substitution mutation. A hybrid polypeptide according to

the invention comprises at least two polypeptide fragments, wherein each polypeptide fragment is from a different source, i.e., a different polypeptide, a different nuclear receptor, a different species, *etc.* The hybrid polypeptide according to the invention may comprise at least two polypeptide domains, wherein each polypeptide domain is from a different source.

5 In a specific embodiment, the Group H nuclear receptor ligand binding domain comprising a substitution mutation is from an ecdysone receptor, a ubiquitous receptor, an orphan receptor 1, a NER-1, a steroid hormone nuclear receptor 1, a retinoid X receptor interacting protein -15, a liver X receptor  $\beta$ , a steroid hormone receptor like protein, a liver X receptor, a liver X receptor  $\alpha$ , a farnesoid X receptor, a receptor interacting protein 14, and a farnesol receptor. In a preferred embodiment, the Group H nuclear  
10 receptor ligand binding domain is from an ecdysone receptor.

Thus, the present invention also provides a gene expression cassette comprising a polynucleotide that encodes a polypeptide selected from the group consisting of a) a polypeptide comprising a transactivation domain, a DNA-binding domain, and an ecdysone receptor ligand binding domain comprising a substitution mutation; b) a polypeptide comprising a DNA-binding domain and an ecdysone  
15 receptor ligand binding domain comprising a substitution mutation; and c) a polypeptide comprising a transactivation domain and an ecdysone receptor ligand binding domain comprising a substitution mutation. Preferably, the gene expression cassette comprises a polynucleotide that encodes a hybrid polypeptide selected from the group consisting of a) a hybrid polypeptide comprising a transactivation domain, a DNA-binding domain, and an ecdysone receptor ligand binding domain comprising a  
20 substitution mutation; b) a hybrid polypeptide comprising a DNA-binding domain and an ecdysone receptor ligand binding domain comprising a substitution mutation; and c) a hybrid polypeptide comprising a transactivation domain and an ecdysone receptor ligand binding domain comprising a substitution mutation; wherein the encoded hybrid polypeptide comprises at least two polypeptide fragments, wherein each polypeptide fragment is from a different source.

25 The ecdysone receptor (EcR) ligand binding domain (LBD) may be from an invertebrate EcR, preferably selected from the class Arthropod EcR. Preferably the EcR is selected from the group consisting of a Lepidopteran EcR, a Dipteran EcR, an Orthopteran EcR, a Homopteran EcR and a Hemipteran EcR. More preferably, the EcR ligand binding domain for use in the present invention is from a spruce budworm *Choristoneura fumiferana* EcR ("CfEcR"), a beetle *Tenebrio molitor* EcR  
30 ("TmEcR"), a *Manduca sexta* EcR ("MsEcR"), a *Heliothies virescens* EcR ("HvEcR"), a midge *Chironomus tentans* EcR ("CtEcR"), a silk moth *Bombyx mori* EcR ("BmEcR"), a squinting bush brown *Bicyclus anynana* EcR ("BanEcR"), a buckeye *Junonia coenia* EcR ("JcEcR"), a fruit fly *Drosophila melanogaster* EcR ("DmEcR"), a mosquito *Aedes aegypti* EcR ("AaEcR"), a blowfly *Lucilia capitata* ("LcEcR"), a blowfly *Lucilia cuprina* EcR ("LucEcR"), a blowfly *Calliphora vicina* EcR ("CvEcR"), a  
35 Mediterranean fruit fly *Ceratitis capitata* EcR ("CcEcR"), a locust *Locusta migratoria* EcR ("LmEcR"), an aphid *Myzus persicae* EcR ("MpEcR"), a fiddler crab *Celuca pugilator* EcR ("CpEcR"), an ixodid tick *Amblyomma americanum* EcR ("AmaEcR"), a whitefly *Bemisia argentifoli* EcR ("BaEcR", SEQ ID

NO: 112) or a leafhopper *Nephotrix cincticeps* EcR ("NcEcR", SEQ ID NO: 113). More preferably, the LBD is from a CfEcR, a DmEcR, or an ArmaEcR.

In a specific embodiment, the LBD is from a truncated EcR polypeptide. The EcR polypeptide truncation results in a deletion of at least 1, 2, 3, 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 105, 110, 115, 120, 125, 130, 135, 140, 145, 150, 155, 160, 165, 170, 175, 180, 185, 190, 195, 200, 205, 210, 215, 220, 225, 230, 235, 240, 245, 250, 255, 260, or 265 amino acids. Preferably, the EcR polypeptide truncation results in a deletion of at least a partial polypeptide domain. More preferably, the EcR polypeptide truncation results in a deletion of at least an entire polypeptide domain. In a specific embodiment, the EcR polypeptide truncation results in a deletion of at least an A/B-domain, a C-domain, a D-domain, an F-domain, an A/B/C-domains, an A/B1/2-C-domains, an A/B/C/D-domains, an A/B/C/D/F-domains, an A/B/F-domains, an A/B/C/F-domains, a partial E domain, or a partial F domain. A combination of several complete and/or partial domain deletions may also be performed.

In a specific embodiment, the Group H nuclear receptor ligand binding domain is encoded by a polynucleotide comprising a codon mutation that results in a substitution of a) amino acid residue 20, 21, 48, 51, 52, 55, 58, 59, 61, 62, 92, 93, 95, 96, 107, 109, 110, 120, 123, 125, 175, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) amino acid residues 95 and 110 of SEQ ID NO: 1, c) amino acid residues 218 and 219 of SEQ ID NO: 1, d) amino acid residues 107 and 175 of SEQ ID NO: 1, e) amino acid residues 127 and 175 of SEQ ID NO: 1, f) amino acid residues 107 and 127 of SEQ ID NO: 1, g) amino acid residues 107, 127 and 175 of SEQ ID NO: 1, h) amino acid residues 52, 107 and 175 of SEQ ID NO: 1, i) amino acid residues 96, 107, and 175 of SEQ ID NO: 1, j) amino acid residues 107, 110, and 175 of SEQ ID NO: 1, k) amino acid residue 107, 121, 213, or 217 of SEQ ID NO: 2, or l) amino acid residue 99 or 113 of SEQ ID NO: 3. In a preferred embodiment, the Group H nuclear receptor ligand binding domain is from an ecdysone receptor.

In another specific embodiment, the Group H nuclear receptor ligand binding domain is encoded by a polynucleotide comprising a codon mutation that results in a substitution of a) an alanine residue at a position equivalent or analogous to amino acid residue 20, 21, 48, 51, 55, 58, 59, 61, 62, 92, 93, 95, 109, 120, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) an alanine, valine, isoleucine, or leucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, c) an alanine, threonine, aspartic acid, or methionine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, d) a proline, serine, methionine, or leucine residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, e) a phenylalanine residue at a position equivalent or analogous to amino acid residue 123 of SEQ ID NO: 1, f) an alanine residue at a position equivalent or analogous to amino acid residue 95 of SEQ ID NO: 1 and a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, g) an alanine residue at a position equivalent or analogous to amino acid residues 218 and 219 of SEQ ID NO: 1, h) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, i) a glutamine

residue at a position equivalent or analogous to amino acid residues 175 of SEQ ID NO: 1, j) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, k) a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, l) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 127 of SEQ ID NO: 1, m) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, n) a valine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, o) an alanine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, p) an alanine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, q) a threonine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, r) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, a proline residue at a position equivalent or analogous to amino acid 110 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid 175 of SEQ ID NO: 1, s) a proline at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 2, t) an arginine or a leucine at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, u) an alanine at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, v) an alanine or a serine at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, w) an alanine at a position equivalent or analogous to amino acid residue 99 of SEQ ID NO: 3, or x) a proline at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3.

30 In a preferred embodiment, the Group H nuclear receptor ligand binding domain is from an ecdysone receptor.

In another specific embodiment, the Group H nuclear receptor ligand binding domain comprising a substitution mutation is an ecdysone receptor ligand binding domain comprising a substitution mutation encoded by a polynucleotide comprising a codon mutation that results in a substitution mutation selected

35 from the group consisting of a) E20A, Q21A, F48A, I51A, T52A, T52V, T52I, T52L, T55A, T58A, V59A, L61A, I62A, M92A, M93A, R95A, V96A, V96T, V96D, V96M, V107I, F109A, A110P, A110S, A110M, A110L, Y120A, A123F, M125A, R175E, M218A, C219A, L223A, L230A, L234A, W238A,

R95A/A110P, M218A/C219A, V107I/R175E, Y127E/R175E, V107I/Y127E, V107I/Y127E/R175E, T52V/V107I/R175E, V96A/V107I/R175E, T52A/V107I/R175E, V96T/V107I/R175E or V107I/A110P/R175E substitution mutation of SEQ ID NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S substitution mutation of SEQ ID NO: 2, and c) G99A or A113P substitution mutation  
5 of SEQ ID NO: 3.

In another specific embodiment, the Group H nuclear receptor ligand binding domain comprising a substitution mutation is an ecdysone receptor ligand binding domain polypeptide comprising a substitution mutation encoded by a polynucleotide that hybridizes to a polynucleotide comprising a codon mutation that results in a substitution mutation selected from the group consisting of a) T58A,  
10 A110P, A110L, A110S, or A110M of SEQ ID NO: 1, b) A107P of SEQ ID NO: 2, and c) A113P of SEQ ID NO: 3 under hybridization conditions comprising a hybridization step in less than 500 mM salt and at least 37 degrees Celsius, and a washing step in 2XSSPE at least 63 degrees Celsius. In a preferred embodiment, the hybridization conditions comprise less than 200 mM salt and at least 37 degrees Celsius for the hybridization step. In another preferred embodiment, the hybridization conditions comprise  
15 2XSSPE and 63 degrees Celsius for both the hybridization and washing steps. In another preferred embodiment, the ecdysone receptor ligand binding domain lacks steroid binding activity, such as 20-hydroxyecdysone binding activity, ponasterone A binding activity, or muristerone A binding activity.

In another specific embodiment, the Group H nuclear receptor ligand binding domain comprises a substitution mutation at a position equivalent or analogous to a) amino acid residue 20, 21, 48, 51, 52,  
20 55, 58, 59, 61, 62, 92, 93, 95, 96, 107, 109, 110, 120, 123, 125, 175, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) amino acid residues 95 and 110 of SEQ ID NO: 1, c) amino acid residues 218 and 219 of SEQ ID NO: 1, d) amino acid residues 107 and 175 of SEQ ID NO: 1, e) amino acid residues 127 and 175 of SEQ ID NO: 1, f) amino acid residues 107 and 127 of SEQ ID NO: 1, g) amino acid residues 107, 127 and 175 of SEQ ID NO: 1, h) amino acid residues 52, 107 and 175 of SEQ ID NO: 1, i) amino acid  
25 residues 96, 107 and 175 of SEQ ID NO: 1, j) amino acid residues 107, 110, and 175 of SEQ ID NO: 1, k) amino acid residue 107, 121, 213, or 217 of SEQ ID NO: 2, or l) amino acid residue 99 or 113 of SEQ ID NO: 3. In a preferred embodiment, the Group H nuclear receptor ligand binding domain is from an ecdysone receptor.

Preferably, the Group H nuclear receptor ligand binding domain comprises a substitution of a) an  
30 alanine residue at a position equivalent or analogous to amino acid residue 20, 21, 48, 51, 55, 58, 59, 61, 62, 92, 93, 95, 109, 120, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) an alanine, valine, isoleucine, or leucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, c) an alanine, threonine, aspartic acid, or methionine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, d) a proline, serine, methionine, or leucine residue at a  
35 position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, e) a phenylalanine residue at a position equivalent or analogous to amino acid residue 123 of SEQ ID NO: 1, f) an alanine residue at a position equivalent or analogous to amino acid residue 95 of SEQ ID NO: 1 and a proline residue at a

position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, g) an alanine residue at a position equivalent or analogous to amino acid residues 218 and 219 of SEQ ID NO: 1, h) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, i) a glutamine residue at a position equivalent or analogous to amino acid residues 175, j) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, k) a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, l) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 127 of SEQ ID NO: 1, m) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, n) a valine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, o) an alanine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, p) an alanine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, q) a threonine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, r) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, a proline residue at a position equivalent or analogous to amino acid 110 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid 175 of SEQ ID NO: 1, s) a proline at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 2, t) an arginine or a leucine at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, u) an alanine at a position equivalent or analogous to amino acid residue 215 of SEQ ID NO: 2, v) an alanine or a serine at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, w) an alanine at a position equivalent or analogous to amino acid residue 99 of SEQ ID NO: 3, or x) a proline at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. In a preferred embodiment, the Group H nuclear receptor ligand binding domain is from an ecdysone receptor.

In another specific embodiment, the Group H nuclear receptor ligand binding domain comprising a substitution mutation is an ecdysone receptor ligand binding domain polypeptide comprising a substitution mutation, wherein the substitution mutation is selected from the group consisting of a) E20A, Q21A, F48A, I51A, T52A, T52V, T52I, T52L, T55A, T58A, V59A, L61A, I62A, M92A, M93A,

R95A, V96A, V96T, V96D, V96M, V107I, F109A, A110P, A110S, A110M, A110L, Y120A, A123F, M125A, R175E, M218A, C219A, L223A, L230A, L234A, W238A, R95A/A110P, M218A/C219A, V107I/R175E, Y127E/R175E, V107I/Y127E, V107I/Y127E/R175E, T52V/V107I/R175E, V96A/V107I/R175E, T52A/V107I/R175E, V96T/V107I/R175E, or V107I/A110P/R175E substitution mutation of SEQ ID NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S substitution mutation of SEQ ID NO: 2, and c) G99A or A113P substitution mutation of SEQ ID NO: 3.

The DNA binding domain can be any DNA binding domain with a known response element, including synthetic and chimeric DNA binding domains, or analogs, combinations, or modifications thereof. Preferably, the DBD is a GAL4 DBD, a LexA DBD, a transcription factor DBD, a Group H nuclear receptor member DBD, a steroid/thyroid hormone nuclear receptor superfamily member DBD, or a bacterial LacZ DBD. More preferably, the DBD is an EcR DBD [SEQ ID NO: 4 (polynucleotide) or SEQ ID NO: 5 (polypeptide)], a GAL4 DBD [SEQ ID NO: 6 (polynucleotide) or SEQ ID NO: 7 (polypeptide)], or a LexA DBD [(SEQ ID NO: 8 (polynucleotide) or SEQ ID NO: 9 (polypeptide))].

The transactivation domain (abbreviated "AD" or "TA") may be any Group H nuclear receptor member AD, steroid/thyroid hormone nuclear receptor AD, synthetic or chimeric AD, polyglutamine AD, basic or acidic amino acid AD, a VP16 AD, a GAL4 AD, an NF- $\kappa$ B AD, a BP64 AD, a B42 acidic activation domain (B42AD), a p65 transactivation domain (p65AD), or an analog, combination, or modification thereof. In a specific embodiment, the AD is a synthetic or chimeric AD, or is obtained from an EcR, a glucocorticoid receptor, VP16, GAL4, NF- $\kappa$ B, or B42 acidic activation domain AD. Preferably, the AD is an EcR AD [SEQ ID NO: 10 (polynucleotide) or SEQ ID NO: 11 (polypeptide)], a VP16 AD [SEQ ID NO: 12 (polynucleotide) or SEQ ID NO: 13 (polypeptide)], a B42 AD [SEQ ID NO: 14 (polynucleotide) or SEQ ID NO: 15 (polypeptide)], or a p65 AD [SEQ ID NO: 16 (polynucleotide) or SEQ ID NO: 17 (polypeptide)].

In a specific embodiment, the gene expression cassette encodes a hybrid polypeptide comprising either a) a DNA-binding domain encoded by a polynucleotide comprising a nucleic acid sequence of SEQ ID NO: 4, SEQ ID NO: 6, or SEQ ID NO: 8, or b) a transactivation domain encoded by a polynucleotide comprising a nucleic acid sequence of SEQ ID NO: 10, SEQ ID NO: 12, SEQ ID NO: 14, or SEQ ID NO: 16; and a Group H nuclear receptor ligand binding domain comprising a substitution mutation encoded by a polynucleotide according to the invention. Preferably, the Group H nuclear receptor ligand binding domain comprising a substitution mutation is an ecdysone receptor ligand binding domain comprising a substitution mutation encoded by a polynucleotide according to the invention.

In another specific embodiment, the gene expression cassette encodes a hybrid polypeptide comprising either a) a DNA-binding domain comprising an amino acid sequence of SEQ ID NO: 5, SEQ ID NO: 7, or SEQ ID NO: 9, or b) a transactivation domain comprising an amino acid sequence of SEQ ID NO: 11, SEQ ID NO: 13, SEQ ID NO: 15, or SEQ ID NO: 17; and a Group H nuclear receptor ligand binding domain comprising a substitution mutation according to the invention. Preferably, the Group H

nuclear receptor ligand binding domain comprising a substitution mutation is an ecdysone receptor ligand binding domain comprising a substitution mutation according to the invention.

The present invention also provides a gene expression cassette comprising: i) a response element comprising a domain recognized by a polypeptide comprising a DNA binding domain; ii) a promoter that  
5 is activated by a polypeptide comprising a transactivation domain; and iii) a gene whose expression is to be modulated.

The response element ("RE") may be any response element with a known DNA binding domain, or an analog, combination, or modification thereof. A single RE may be employed or multiple REs, either multiple copies of the same RE or two or more different REs, may be used in the present  
10 invention. In a specific embodiment, the RE is an RE from GAL4 ("GAL4RE"), LexA, a Group H nuclear receptor RE, a steroid/thyroid hormone nuclear receptor RE, or a synthetic RE that recognizes a synthetic DNA binding domain. Preferably, the RE is an ecdysone response element (EcRE) comprising a polynucleotide sequence of SEQ ID NO: 18, a GAL4RE comprising a polynucleotide sequence of SEQ ID NO: 19, or a LexA RE (operon, "op") comprising a polynucleotide sequence of SEQ ID NO: 20  
15 ("2XLexAopRE").

A steroid/thyroid hormone nuclear receptor DNA binding domain, activation domain or response element according to the invention may be obtained from a steroid/thyroid hormone nuclear receptor selected from the group consisting of thyroid hormone receptor  $\alpha$  (TR $\alpha$ ), thyroid receptor 1 (c-erbA-1), thyroid hormone receptor  $\beta$  (TR $\beta$ ), retinoic acid receptor  $\alpha$  (RAR $\alpha$ ), retinoic acid receptor  $\beta$  (RAR $\beta$ ,  
20 HAP), retinoic acid receptor  $\gamma$  (RAR $\gamma$ ), retinoic acid receptor gamma-like (RARD), peroxisome proliferator-activated receptor  $\alpha$  (PPAR $\alpha$ ), peroxisome proliferator-activated receptor  $\beta$  (PPAR $\beta$ ), peroxisome proliferator-activated receptor  $\delta$  (PPAR $\delta$ , NUC-1), peroxisome proliferator-activator related receptor (FFAR), peroxisome proliferator-activated receptor  $\gamma$  (PPAR $\gamma$ ), orphan receptor encoded by non-encoding strand of thyroid hormone receptor  $\alpha$  (REVERB $\alpha$ ), v-erb A related receptor (EAR-1), v-  
25 erb related receptor (EAR-1A),  $\gamma$ ), orphan receptor encoded by non-encoding strand of thyroid hormone receptor  $\beta$  (REVERB $\beta$ ), v-erb related receptor (EAR-1 $\beta$ ), orphan nuclear receptor BD73 (BD73), rev-erbA-related receptor (RVR), zinc finger protein 126 (HZF2), ecdysone-inducible protein E75 (E75), ecdysone-inducible protein E78 (E78), *Drosophila* receptor 78 (DR-78), retinoid-related orphan receptor  $\alpha$  (ROR $\alpha$ ), retinoid Z receptor  $\alpha$  (RZR $\alpha$ ), retinoid related orphan receptor  $\beta$  (ROR $\beta$ ), retinoid Z receptor  
30  $\beta$  (RZR $\beta$ ), retinoid-related orphan receptor  $\gamma$  (ROR $\gamma$ ), retinoid Z receptor  $\gamma$  (RZR $\gamma$ ), retinoid-related orphan receptor (TOR), hormone receptor 3 (HR-3), *Drosophila* hormone receptor 3 (DHR-3), *Manduca* hormone receptor (MHR-3), *Galleria* hormone receptor 3 (GHR-3), *C. elegans* nuclear receptor 3 (CNR-3), *Choristoneura* hormone receptor 3 (CHR-3), *C. elegans* nuclear receptor 14 (CNR-14), ecdysone receptor (ECR), ubiquitous receptor (UR), orphan nuclear receptor (OR-1), NER-1, receptor-interacting  
35 protein 15 (RIP-15), liver X receptor  $\beta$  (LXR $\beta$ ), steroid hormone receptor like protein (RLD-1), liver X receptor (LXR), liver X receptor  $\alpha$  (LXR $\alpha$ ), farnesoid X receptor (FXR), receptor-interacting protein 14

(RIP-14), HRR-1, vitamin D receptor (VDR), orphan nuclear receptor (ONR-1), pregnane X receptor (PXR), steroid and xenobiotic receptor (SXR), benzoate X receptor (BXR), nuclear receptor (MB-67), constitutive androstane receptor 1 (CAR-1), constitutive androstane receptor  $\alpha$  (CAR $\alpha$ ), constitutive androstane receptor 2 (CAR-2), constitutive androstane receptor  $\beta$  (CAR $\beta$ ), *Drosophila* hormone receptor 96 (DHR-96), nuclear hormone receptor 1 (NHR-1), hepatocyte nuclear factor 4 (HNF-4), hepatocyte nuclear factor 4G (HNF-4G), hepatocyte nuclear factor 4B (HNF-4B), hepatocyte nuclear factor 4D (HNF-4D, DHNF-4), retinoid X receptor  $\alpha$  (RXR $\alpha$ ), retinoid X receptor  $\beta$  (RXR $\beta$ ), H-2 region II binding protein (H-2RIIBP), nuclear receptor co-regulator-1 (RCOR-1), retinoid X receptor  $\gamma$  (RXR $\gamma$ ), Ultraspiracle (USP), 2C1 nuclear receptor, chorion factor 1 (CF-1), testicular receptor 2 (TR-2),

10 testicular receptor 2-11 (TR2-11), testicular receptor 4 (TR4), TAK-1, *Drosophila* hormone receptor (DHR78), Tailless (TLL), tailless homolog (TLX), XTLL, chicken ovalbumin upstream promoter transcription factor I (COUP-TFI), chicken ovalbumin upstream promoter transcription factor A (COUP-TFA), EAR-3, SVP-44, chicken ovalbumin upstream promoter transcription factor II (COUP-TFII), chicken ovalbumin upstream promoter transcription factor B (COUP-TFB), ARP-1, SVP-40, SVP,

15 chicken ovalbumin upstream promoter transcription factor III (COUP-TFIII), chicken ovalbumin upstream promoter transcription factor G (COUP-TFG), SVP-46, EAR-2, estrogen receptor  $\alpha$  (ER $\alpha$ ), estrogen receptor  $\beta$  (ER $\beta$ ), estrogen related receptor 1 (ERR1), estrogen related receptor  $\alpha$  (ERR $\alpha$ ), estrogen related receptor 2 (ERR2), estrogen related receptor  $\beta$  (ERR $\beta$ ), glucocorticoid receptor (GR), mineralocorticoid receptor (MR), progesterone receptor (PR), androgen receptor (AR), nerve growth

20 factor induced gene B (NGFI-B), nuclear receptor similar to Nur-77 (TRS), N10, Orphan receptor (NUR-77), Human early response gene (NAK-1), Nur related factor 1 (NURR-1), a human immediate-early response gene (NOT), regenerating liver nuclear receptor 1 (RNR-1), hematopoietic zinc finger 3 (HZF-3), Nur related protein -1 (TINOR), Nuclear orphan receptor 1 (NOR-1), NOR1 related receptor (MINOR), *Drosophila* hormone receptor 38 (DHR-38), *C. elegans* nuclear receptor 8 (CNR-8), C48D5,

25 steroidogenic factor 1 (SF1), endozepine-like peptide (ELP), fushi tarazu factor 1 (FTZ-F1), adrenal 4 binding protein (AD4BP), liver receptor homolog (LRH-1), Ftz-F1-related orphan receptor A (xFFrA), Ftz-F1-related orphan receptor B (xFFrB), nuclear receptor related to LRH-1 (FFLR), nuclear receptor related to LRH-1 (PHR), fetoprotein transcriptin factor (FTF), germ cell nuclear factor (GCNFM), retinoid receptor-related testis-associated receptor (RTR), knirps (KNI), knirps related (KNRL),

30 Embryonic gonad (EGON), *Drosophila* gene for ligand dependent nuclear receptor (EAGLE), nuclear receptor similar to trithorax (ODR7), Trithorax, dosage sensitive sex reversal adrenal hypoplasia congenita critical region chromosome X gene (DAX-1), adrenal hypoplasia congenita and hypogonadotropic hypogonadism (AHCH), and short heterodimer partner (SHP).

For purposes of this invention, nuclear receptors and Group H nuclear receptors also include

35 synthetic and chimeric nuclear receptors and Group H nuclear receptors and their homologs.

Genes of interest for use in Applicants' gene expression cassettes may be endogenous genes or heterologous genes. Nucleic acid or amino acid sequence information for a desired gene or protein can be

located in one of many public access databases, for example, GENBANK, EMBL, Swiss-Prot, and PIR, or in many biology related journal publications. Thus, those skilled in the art have access to nucleic acid sequence information for virtually all known genes. Such information can then be used to construct the desired constructs for the insertion of the gene of interest within the gene expression cassettes used in

5 Applicants' methods described herein.

Examples of genes of interest for use in Applicants' gene expression cassettes include, but are not limited to: genes encoding therapeutically desirable polypeptides or products that may be used to treat a condition, a disease, a disorder, a dysfunction, a genetic defect, such as monoclonal antibodies, enzymes, proteases, cytokines, interferons, insulin, erythropoietin, clotting factors, other blood factors or  
10 components, viral vectors for gene therapy, virus for vaccines, targets for drug discovery, functional genomics, and proteomics analyses and applications, and the like.

#### POLYNUCLEOTIDES OF THE INVENTION

The novel nuclear receptor-based inducible gene expression system of the invention comprises at  
15 least one gene expression cassette comprising a polynucleotide that encodes a Group H nuclear receptor ligand binding domain comprising a substitution mutation. These gene expression cassettes, the polynucleotides they comprise, and the polypeptides they encode are useful as components of a nuclear receptor-based gene expression system to modulate the expression of a gene within a host cell.

Thus, the present invention provides an isolated polynucleotide that encodes a Group H nuclear  
20 receptor ligand binding domain comprising a substitution mutation.

In a specific embodiment, the Group H nuclear receptor ligand binding domain is encoded by a polynucleotide comprising a codon mutation that results in a substitution of an amino acid residue at a position equivalent or analogous to a) amino acid residue 20, 21, 48, 51, 52, 55, 58, 59, 61, 62, 92, 93, 95, 96, 107, 109, 110, 120, 123, 125, 175, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) amino  
25 acid residues 95 and 110 of SEQ ID NO: 1, c) amino acid residues 218 and 219 of SEQ ID NO: 1, d) amino acid residues 107 and 175 of SEQ ID NO: 1, e) amino acid residues 127 and 175 of SEQ ID NO: 1, f) amino acid residues 107 and 127 of SEQ ID NO: 1, g) amino acid residues 107, 127 and 175 of SEQ ID NO: 1, h) amino acid residues 52, 107 and 175 of SEQ ID NO: 1, i) amino acid residues 96, 107 and 175 of SEQ ID NO: 1, j) amino acid residues 107, 110, and 175 of SEQ ID NO: 1, k) amino acid residue  
30 107, 121, 213, or 217 of SEQ ID NO: 2, or l) amino acid residue 99 or 113 of SEQ ID NO: 3. In a preferred embodiment, the Group H nuclear receptor ligand binding domain is from an ecdysone receptor.

In another specific embodiment, the Group H nuclear receptor ligand binding domain is encoded by a polynucleotide comprising a codon mutation that results in a substitution of a) an alanine residue at  
35 a position equivalent or analogous to amino acid residue 20, 21, 48, 51, 55, 58, 59, 61, 62, 92, 93, 95, 109, 120, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) an alanine, valine, isoleucine, or leucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, c) an

alanine, threonine, aspartic acid, or methionine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, d) a proline, serine, methionine, or leucine residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, e) a phenylalanine residue at a position equivalent or analogous to amino acid residue 123 of SEQ ID NO: 1, f) an alanine residue at a position equivalent or analogous to amino acid residue 95 of SEQ ID NO: 1 and a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, g) an alanine residue at a position equivalent or analogous to amino acid residues 218 and 219 of SEQ ID NO: 1, h) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, i) a glutamine residue at a position equivalent or analogous to amino acid residues 175, j) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, k) a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, l) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 127 of SEQ ID NO: 1, m) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, n) a valine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, o) an alanine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, p) an alanine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, q) a threonine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, r) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, s) a proline at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 2, t) an arginine or a leucine at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, u) an alanine at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, v) an alanine or a serine at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, w) an alanine at a position equivalent or analogous to amino acid residue 99 of SEQ ID NO: 3, or x) a proline at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. In a preferred

embodiment, the Group H nuclear receptor ligand binding domain is from an ecdysone receptor.

In another specific embodiment, the Group H nuclear receptor ligand binding domain comprising a substitution mutation is an ecdysone receptor ligand binding domain comprising a substitution mutation encoded by a polynucleotide comprising a codon mutation that results in a substitution mutation selected  
5 from the group consisting of a) E20A, Q21A, F48A, I51A, T52A, T52V, T52I, T52L, T55A, T58A, V59A, L61A, I62A, M92A, M93A, R95A, V96A, V96T, V96D, V96M, V107I, F109A, A110P, A110S, A110M, A110L, Y120A, A123F, M125A, R175E, M218A, C219A, L223A, L230A, L234A, W238A, R95A/A110P, M218A/C219A, V107I/R175E, Y127E/R175E, V107I/Y127E, V107I/Y127E/R175E, T52V/V107I/R175E, V96A/V107I/R175E, T52A/V107I/R175E, V96T/V107I/R175E or  
10 V107I/A110P/R175E substitution mutation of SEQ ID NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S substitution mutation of SEQ ID NO: 2, and c) G99A or A113P substitution mutation of SEQ ID NO: 3.

In another specific embodiment, the Group H nuclear receptor ligand binding domain comprising a substitution mutation is an ecdysone receptor ligand binding domain comprising a substitution mutation  
15 encoded by a polynucleotide that hybridizes to a polynucleotide comprising a codon mutation that results in a substitution mutation selected from the group consisting of a) T58A, A110P, A110L, A110S, or A110M of SEQ ID NO: 1, b) A107P of SEQ ID NO: 2, and c) A113P of SEQ ID NO: 3 under hybridization conditions comprising a hybridization step in less than 500 mM salt and at least 37 degrees  
20 Celsius, and a washing step in 2XSSPE at least 63 degrees Celsius. In a preferred embodiment, the hybridization conditions comprise less than 200 mM salt and at least 37 degrees Celsius for the hybridization step. In another preferred embodiment, the hybridization conditions comprise 2XSSPE and 63 degrees Celsius for both the hybridization and washing steps. In another preferred embodiment, the ecdysone receptor ligand binding domain lacks binding activity to a steroid such as 20-hydroxyecdysone, ponasterone A, or muristerone A.

25 The present invention also provides an isolated polynucleotide that encodes a polypeptide selected from the group consisting of a) a polypeptide comprising a transactivation domain, a DNA-binding domain, and a Group H nuclear receptor ligand binding domain comprising a substitution mutation according to the invention; b) a polypeptide comprising a DNA-binding domain and a Group H nuclear receptor ligand binding domain comprising a substitution mutation according to the invention;  
30 and c) a polypeptide comprising a transactivation domain and a Group H nuclear receptor ligand binding domain comprising a substitution mutation according to the invention.

In a specific embodiment, the isolated polynucleotide encodes a hybrid polypeptide selected from the group consisting of a) a hybrid polypeptide comprising a transactivation domain, a DNA-binding domain, and a Group H nuclear receptor ligand binding domain comprising a substitution  
35 mutation according to the invention; b) a hybrid polypeptide comprising a DNA-binding domain and a Group H nuclear receptor ligand binding domain comprising a substitution mutation according to the invention; and c) a hybrid polypeptide comprising a transactivation domain and a Group H nuclear

receptor ligand binding domain comprising a substitution mutation according to the invention.

The present invention also relates to an isolated polynucleotide encoding a Group H nuclear receptor ligand binding domain comprising a substitution mutation, wherein the substitution mutation affects ligand binding activity or ligand sensitivity of the Group H nuclear receptor ligand binding domain.

In particular, the present invention relates to an isolated polynucleotide encoding a Group H nuclear receptor ligand binding domain comprising a substitution mutation, wherein the substitution mutation reduces ligand binding activity or ligand sensitivity of the Group H nuclear receptor ligand binding domain.

10 In a specific embodiment, the present invention relates to an isolated polynucleotide encoding a Group H nuclear receptor ligand binding domain comprising a substitution mutation, wherein the substitution mutation reduces steroid binding activity or steroid sensitivity of the Group H nuclear receptor ligand binding domain. Preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of an amino acid residue at a position equivalent or analogous to a) amino acid  
15 residue 20, 21, 48, 51, 52, 55, 58, 59, 62, 92, 93, 95, 109, 110, 120, 123, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) amino acid residues 95 and 110 of SEQ ID NO: 1, c) amino acid residues 218 and 219 of SEQ ID NO: 1, d) amino acid residue 107, 121, 213, or 217 of SEQ ID NO: 2, or e) amino acid residue 113 of SEQ ID NO: 3. More preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of a) an alanine residue at a position equivalent or analogous to  
20 amino acid residue 20, 21, 48, 51, 52, 55, 58, 59, 62, 92, 93, 95, 109, 120, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, c) a phenylalanine residue at a position equivalent or analogous to amino acid residue 123 of SEQ ID NO: 1, d) an alanine residue at a position equivalent or analogous to amino acid residue 95 of SEQ ID NO: 1 and a proline residue at a position equivalent or analogous to amino acid  
25 residue 110 of SEQ ID NO: 1, e) an alanine residue at a position equivalent or analogous to amino acid residues 218 and 219 of SEQ ID NO: 1, f) a proline residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 2, g) an arginine or leucine residue at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, h) an alanine residue at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, i) an alanine or a serine residue at a position  
30 equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, or j) a proline residue at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. Even more preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution mutation of a) E20A, Q21A, F48A, I51A, T52A, T55A, T58A, V59A, I62A, M92A, M93A, R95A, F109A, A110P, Y120A, A123F, M125A, M218A, C219A, L223A, L230A, L234A, W238A, R95A/A110P, or M218A/C219A of SEQ ID  
35 NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S of SEQ ID NO: 2, or c) A113P of SEQ ID NO: 3.

In another specific embodiment, the present invention relates to an isolated polynucleotide

encoding a Group H nuclear receptor ligand binding domain comprising a substitution mutation, wherein the substitution mutation eliminates steroid binding activity or steroid sensitivity of the Group H ligand binding domain. Preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of an amino acid residue at a position equivalent or analogous to a) amino acid residue 58 or  
5 110 of SEQ ID NO: 1, b) amino acid residues 107, 110 and 175 of SEQ ID NO: 1, c) amino acid residue 107, 121, 213, or 217 of SEQ ID NO: 2, or d) amino acid residue 113 of SEQ ID NO: 3. More preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of a) an alanine at a position equivalent or analogous to amino acid residue 58 of SEQ ID NO: 1, b) a proline, leucine, serine, or methionine residue at a position equivalent or analogous to amino acid residue 110 of  
10 SEQ ID NO: 1, c) an isoleucine at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, a proline at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, and a glutamine at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, d) a proline at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 2, e) an arginine or a leucine at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, f) an  
15 alanine at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, g) an alanine or a serine at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, or h) a proline at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. Even more preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution mutation selected from the group consisting of a) T58A, A110P, A110L, A110S, A110M, or V107/A110P/R175E  
20 substitution mutation of SEQ ID NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S substitution mutation of SEQ ID NO: 2, and c) A113P substitution mutation of SEQ ID NO: 3.

The present invention also relates to an isolated polynucleotide encoding a polypeptide comprising an ecdysone receptor ligand binding domain comprising a substitution mutation, wherein the ecdysone receptor ligand binding domain lacks steroid binding activity. Preferably, the ecdysone  
25 receptor ligand binding domain comprises a codon mutation that results in a substitution mutation at an equivalent or analogous amino acid residue to a) amino acid residue 58 or 110 of SEQ ID NO: 1, b) amino acid residues 107, 110 and 175 of SEQ ID NO: 1, b) amino acid residue 107, 121, 213, or 217 of SEQ ID NO: 2, or d) amino acid residue 113 of SEQ ID NO: 3. More preferably, the ecdysone receptor ligand binding domain comprises a codon mutation that results in a substitution of a) an alanine at a  
30 position equivalent or analogous to amino acid residue 58 of SEQ ID NO: 1, b) a proline, leucine, serine, or methionine residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, c) an isoleucine at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, a proline at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, a glutamine at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, d) a proline at a position  
35 equivalent or analogous to amino acid residue 107 of SEQ ID NO: 2, e) an arginine or a leucine at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, f) an alanine at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, g) an alanine or a serine at a

position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, or h) a proline at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. Even more preferably, the isolated the ecdysone receptor ligand binding domain comprises a codon mutation that results in a substitution mutation selected from the group consisting of a) T58A, A110P, A110L, A110S, A110M, or

5 V1071/A110P/R175E substitution mutation of SEQ ID NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S substitution mutation of SEQ ID NO: 2, and c) A113P substitution mutation of SEQ ID NO: 3. In a specific embodiment, the ecdysone receptor ligand binding domain lacks steroid binding activity selected from the group consisting of ecdysone binding activity, 20-hydroxyecdysone binding activity, ponasterone A binding activity, and muristerone A binding activity.

10 In another specific embodiment, the isolated polynucleotide encoding an ecdysone receptor ligand binding domain comprising a substitution mutation, wherein the ecdysone receptor ligand binding domain lacks steroid binding activity, hybridizes to a polynucleotide comprising a codon mutation that results in a substitution mutation selected from the group consisting of a) T58A, A110P, A110L, A110S, A110M, or V1071/A110P/R175E substitution mutation of SEQ ID NO: 1, b) A107P, G121R, G121L,

15 N213A, C217A, or C217S substitution mutation of SEQ ID NO: 2, and c) A113P substitution mutation of SEQ ID NO: 3 under hybridization conditions comprising a hybridization step in less than 500 mM salt and at least 37 degrees Celsius, and a washing step in 2XSSPE at at least 63 degrees Celsius. In a preferred embodiment, the hybridization conditions comprise less than 200 mM salt and at least 37 degrees Celsius for the hybridization step. In another preferred embodiment, the hybridization

20 conditions comprise 2XSSPE and 63 degrees Celsius for both the hybridization and washing steps. In another preferred embodiment, the ecdysone receptor ligand binding domain lacks steroid binding activity selected from the group consisting of ecdysone binding activity, 20-hydroxyecdysone binding activity, ponasterone A binding activity, and muristerone A binding activity.

In another specific embodiment, the present invention relates to an isolated polynucleotide

25 encoding a Group H nuclear receptor ligand binding domain comprising a substitution mutation, wherein the substitution mutation reduces non-steroid binding activity or non-steroid sensitivity of the Group H nuclear receptor ligand binding domain. Preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of an amino acid residue at a position equivalent or analogous to amino acid residue a) 21, 48, 51, 52, 59, 62, 93, 95, 96, 109, 120, 123, 125, 218, 219, 223, 230, 234, or

30 238 of SEQ ID NO: 1, b) 121, 213, or 217 of SEQ ID NO: 2, or c) 113 of SEQ ID NO: 3. More preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of a) an alanine residue at a position equivalent or analogous to amino acid residue 21, 48, 51, 59, 62, 93, 95, 96, 109, 120, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) a leucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, c) a threonine residue at a position

35 equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, d) a phenylalanine residue at a position equivalent or analogous to amino acid residue 123 of SEQ ID NO: 1, e) an alanine residue at a position equivalent or analogous to amino acid residue 95 of SEQ ID NO: 1 and a proline residue at a

position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, f) an alanine residue at a position equivalent or analogous to amino acid residues 218 and 219 of SEQ ID NO: 1, g) an arginine or a leucine residue at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, h) an alanine residue at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, i) an alanine or a serine residue at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, or j) a proline residue at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. Even more preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution mutation of a) Q21A, F48A, I51A, T52L, V59A, I62A, M93A, R95A, V96A, V96T, F109A, Y120A, A123F, M125A, M218A, C219A, L223A, L230A, L234A, W238A, R95A/A110P, or M218/C219A of SEQ ID NO: 1, b) G121R, G121L, N213A, C217A, or C217S of SEQ ID NO: 2, or c) A113P of SEQ ID NO: 3.

In another specific embodiment, the present invention relates to an isolated polynucleotide encoding a Group H nuclear receptor polypeptide ligand binding domain comprising a substitution mutation, wherein the substitution mutation eliminates non-steroid binding activity or non-steroid sensitivity of the Group H ligand binding domain.

In another specific embodiment, the present invention relates to an isolated polynucleotide encoding a Group H nuclear receptor polypeptide ligand binding domain comprising a substitution mutation, wherein the substitution mutation reduces both steroid binding activity or steroid sensitivity and non-steroid binding activity or non-steroid sensitivity of the Group H ligand binding domain.

Preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of an amino acid residue at a position equivalent or analogous to a) amino acid residue 21, 48, 51, 59, 62, 93, 95, 109, 120, 123, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) amino acid residues 95 and 110 of SEQ ID NO: 1, c) amino acid residues 218 and 219 of SEQ ID NO: 1, d) amino acid residue 121, 213, or 217 of SEQ ID NO: 2, or e) amino acid residue 113 of SEQ ID NO: 3. More preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of a) an alanine residue at a position equivalent or analogous to amino acid residue 21, 48, 51, 59, 62, 93, 95, 109, 120, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) a phenylalanine residue at a position equivalent or analogous to amino acid residue 123 of SEQ ID NO: 1, c) an alanine residue at a position equivalent or analogous to amino acid residue 95 of SEQ ID NO: 1 and a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, d) an alanine residue at a position equivalent or analogous to amino acid residues 218 and 219 of SEQ ID NO: 1, e) an arginine or a leucine residue at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, f) an alanine residue at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, g) an alanine or a serine residue at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, or h) a proline residue at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. Even more preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution mutation of Q21A, F48A, I51A, V59A, I62A, M93A, R95A, F109A, Y120A, A123F, M125A, M218A, C219A,

L223A, L230A, L234A, W238A, R95A/A110P, or M218A/C219A of SEQ ID NO: 1, b) G121R, G121L, N213A, C217A, or C217S of SEQ ID NO: 2, or c) A113P of SEQ ID NO: 3.

In addition, the present invention also relates to an isolated polynucleotide encoding a Group H nuclear receptor ligand binding domain comprising a substitution mutation, wherein the substitution  
5 mutation enhances ligand binding activity or ligand sensitivity of the Group H nuclear receptor ligand binding domain.

In a specific embodiment, the present invention relates to an isolated polynucleotide encoding a Group H nuclear receptor ligand binding domain comprising a substitution mutation, wherein the substitution mutation enhances steroid binding activity or steroid sensitivity of the Group H nuclear  
10 receptor ligand binding domain. Preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of an amino acid residue at a position equivalent or analogous to a) amino acid residue 52 or 96 of SEQ ID NO: 1 or b) amino acid residue 99 of SEQ ID NO: 3. More preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of a) a leucine, valine, or isoleucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, b)  
15 an alanine, threonine, aspartic acid, or methionine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, c) a threonine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, or d) an alanine residue at a position equivalent or analogous  
20 to amino acid residue 99 of SEQ ID NO: 3. Even more preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution mutation of a) T52L, T52V, T52I, V96A, V96T, V96D, or V96M of SEQ ID NO: 1 or b) G99A of SEQ ID NO: 3.

In another specific embodiment, the present invention relates to an isolated polynucleotide encoding a Group H nuclear receptor ligand binding domain comprising a substitution mutation, wherein  
25 the substitution mutation enhances non-steroid binding activity or non-steroid sensitivity of the Group H nuclear receptor ligand binding domain. Preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of an amino acid residue at a position equivalent or analogous to amino acid residue 52, 53, or 96 of SEQ ID NO: 1 or b) amino acid residue 99 of SEQ ID NO: 3. More preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of a) an  
30 alanine, valine, or isoleucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, b) an alanine residue at a position equivalent or analogous to amino acid residue 53 of SEQ ID NO: 1, c) an aspartic acid or methionine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, or d) an alanine residue at a position equivalent or analogous to amino acid residue 99 of SEQ ID NO: 3. Even more preferably, the isolated polynucleotide comprises a codon  
35 mutation that results in a substitution mutation of a) T52A, T52V, T52I, T55A, V96D, or V96M of SEQ ID NO: 1 or b) G99A of SEQ ID NO: 3.

In another specific embodiment, the present invention relates to an isolated polynucleotide

encoding a Group H nuclear receptor ligand binding domain comprising a substitution mutation, wherein the substitution mutation enhances both steroid binding activity or steroid sensitivity and non-steroid binding activity or non-steroid sensitivity of the Group H ligand binding domain. Preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of an amino acid residue at a

5 position equivalent or analogous to a) amino acid residue 52, 96, 107 or 175 of SEQ ID NO: 1, b) amino acid residues 107 and 175 of SEQ ID NO: 1, c) amino acid residues 127 and 175 of SEQ ID NO: 1, d) amino acid residues 107 and 127 of SEQ ID NO: 1, e) amino acid residues 107, 127 and 175 of SEQ ID NO: 1, f) amino acid residues 52, 107 and 175 of SEQ ID NO: 1, g) amino acid residues 96, 107 and 175 of SEQ ID NO: 1, or h) amino acid residue 99 of SEQ ID NO: 3. More preferably, the isolated

10 polynucleotide comprises a codon mutation that results in a substitution of a) a valine or isoleucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, b) an aspartic acid or methionine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, c) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, d) a glutamine residue at a position equivalent or analogous to amino acid residues 175, e) an

15 isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, f) a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, g) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 127 of SEQ

20 ID NO: 1, h) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, i) a valine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue

25 175 of SEQ ID NO: 1, j) an alanine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, k) an alanine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue

30 107 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, or l) an alanine residue at a position equivalent or analogous to amino acid residue 99 of SEQ ID NO: 3. Even more preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution mutation of a) T52V, T52I, V96D, V96M, V107I, R175E, V107I/R175E, Y127E/R175E, V107I/Y127E, V107I/Y127E/R175E, T52V/V107I/R175E,

35 V96A/V107I/R175E or T52A/V107I/R175E of SEQ ID NO: 1 or b) G99A of SEQ ID NO: 3.

In addition, the present invention relates to an expression vector comprising a polynucleotide according to the invention, operatively linked to a transcription regulatory element. Preferably, the

polynucleotide encoding a nuclear receptor ligand binding domain comprising a substitution mutation is operatively linked with an expression control sequence permitting expression of the nuclear receptor ligand binding domain in an expression competent host cell. The expression control sequence may comprise a promoter that is functional in the host cell in which expression is desired. The vector may be a plasmid DNA molecule or a viral vector. Preferred viral vectors include retrovirus, adenovirus, adeno-associated virus, herpes virus, and vaccinia virus. The invention further relates to a replication defective recombinant virus comprising in its genome, the polynucleotide encoding a nuclear receptor ligand binding domain comprising a substitution mutation as described above. Thus, the present invention also relates to an isolated host cell comprising such an expression vector, wherein the transcription regulatory element is operative in the host cell.

The present invention also relates to an isolated polypeptide encoded by a polynucleotide according to the invention.

#### POLYPEPTIDES OF THE INVENTION

The novel nuclear receptor-based inducible gene expression system of the invention comprises at least one gene expression cassette comprising a polynucleotide that encodes a polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation. Thus, the present invention also provides an isolated polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation according to the invention.

In another specific embodiment, the Group H nuclear receptor ligand binding domain comprises a substitution mutation at a position equivalent or analogous to a) amino acid residue 20, 21, 48, 51, 52, 55, 58, 59, 61, 62, 92, 93, 95, 96, 107, 109, 110, 120, 123, 125, 175, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) amino acid residues 95 and 110 of SEQ ID NO: 1, c) amino acid residues 218 and 219 of SEQ ID NO: 1, d) amino acid residues 107 and 175 of SEQ ID NO: 1, e) amino acid residues 127 and 175 of SEQ ID NO: 1, f) amino acid residues 107 and 127 of SEQ ID NO: 1, g) amino acid residues 107, 127 and 175 of SEQ ID NO: 1, h) amino acid residues 52, 107 and 175 of SEQ ID NO: 1, i) amino acid residues 96, 107 and 175 of SEQ ID NO: 1, j) amino acid residues 107, 110 and 175 of SEQ ID NO: 1, k) amino acid residue 107, 121, 213, or 217 of SEQ ID NO: 2, or l) amino acid residue 99 or 113 of SEQ ID NO: 3. In a preferred embodiment, the Group H nuclear receptor ligand binding domain is from an ecdysone receptor.

Preferably, the Group H nuclear receptor ligand binding domain comprises a substitution of a) an alanine residue at a position equivalent or analogous to amino acid residue 20, 21, 48, 51, 55, 58, 59, 61, 62, 92, 93, 95, 109, 120, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) an alanine, valine, isoleucine, or leucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, c) an alanine, threonine, aspartic acid, or methionine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, d) a proline, serine, methionine, or leucine residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, e) a phenylalanine residue

at a position equivalent or analogous to amino acid residue 123 of SEQ ID NO: 1, f) an alanine residue at a position equivalent or analogous to amino acid residue 95 of SEQ ID NO: 1 and a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, g) an alanine residue at a position equivalent or analogous to amino acid residues 218 and 219 of SEQ ID NO: 1, h) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, i) a glutamine residue at a position equivalent or analogous to amino acid residues 175, j) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, k) a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, l) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 127 of SEQ ID NO: 1, m) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, n) a valine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, o) an alanine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, p) an alanine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, q) a threonine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, r) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, a proline at a position equivalent or analogous to amino acid 110 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, s) a proline at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 2, t) an arginine or a leucine at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, u) an alanine at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, v) an alanine or a serine at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, w) an alanine at a position equivalent or analogous to amino acid residue 99 of SEQ ID NO: 3, or x) a proline at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. In a preferred embodiment, the Group H nuclear receptor ligand binding domain is from an ecdysone receptor.

In another specific embodiment, the Group H nuclear receptor ligand binding domain comprising a substitution mutation is an ecdysone receptor ligand binding domain polypeptide comprising a

substitution mutation, wherein the substitution mutation is selected from the group consisting of a) E20A, Q21A, F48A, I51A, T52A, T52V, T52I, T52L, T56A, T58A, V59A, L61A, I62A, M92A, M93A, R95A, V96A, V96T, V96D, V96M, V107I, F109A, A110P, A110S, A110M, A110L, Y120A, A123F, M125A, R175E, M218A, C219A, L223A, L230A, L234A, W238A, R95A/A110P, M218A/C219A, 5 V107I/R175E, Y127E/R175E, V107I/Y127E, V107I/Y127E/R175E, T52V/V107I/R175E, V96A/V107I/R175E, T52A/V107I/R175E V96T/V107I/R175E, or V107I/A110P/R175E substitution mutation of SEQ ID NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S substitution mutation of SEQ ID NO: 2, and c) G99A or A113P substitution mutation of SEQ ID NO: 3.

The present invention also provides an isolated polypeptide selected from the group consisting of 10 a) an isolated polypeptide comprising a transactivation domain, a DNA-binding domain, and a Group H nuclear receptor ligand binding domain comprising a substitution mutation according to the invention; b) an isolated polypeptide comprising a DNA-binding domain and a Group H nuclear receptor ligand binding domain comprising a substitution mutation according to the invention; and c) an isolated polypeptide comprising a transactivation domain and a Group H nuclear receptor ligand binding domain 15 comprising a substitution mutation according to the invention. In a preferred embodiment, the Group H nuclear receptor ligand binding domain is from an ecdysone receptor.

The present invention also provides an isolated hybrid polypeptide selected from the group consisting of a) an isolated hybrid polypeptide comprising a transactivation domain, a DNA-binding domain, and a Group H nuclear receptor ligand binding domain comprising a substitution mutation 20 according to the invention; b) an isolated hybrid polypeptide comprising a DNA-binding domain and a Group H nuclear receptor ligand binding domain comprising a substitution mutation according to the invention; and c) an isolated hybrid polypeptide comprising a transactivation domain and a Group H nuclear receptor ligand binding domain comprising a substitution mutation according to the invention. In a preferred embodiment, the Group H nuclear receptor ligand binding domain is from an ecdysone 25 receptor.

The present invention also provides an isolated polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation that affects ligand binding activity or ligand sensitivity of the Group H nuclear receptor ligand binding domain.

In particular, the present invention relates to an isolated Group H nuclear receptor polypeptide 30 comprising a ligand binding domain comprising a substitution mutation that reduces ligand binding activity or ligand sensitivity of the Group H nuclear receptor ligand binding domain.

In a specific embodiment, the present invention relates to an isolated polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation that reduces steroid binding activity or steroid sensitivity of the Group H nuclear receptor ligand binding domain. Preferably, 35 the isolated polypeptide comprises a substitution of an amino acid residue at a position equivalent or analogous to a) amino acid residue 20, 21, 48, 51, 52, 55, 58, 59, 62, 92, 93, 95, 109, 110, 120, 123, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) amino acid residue 107, 121, 213, or 217 of SEQ ID

NO: 2, or c) amino acid residue 113 of SEQ ID NO: 3. More preferably, the isolated polypeptide comprises a substitution of a) an alanine residue at a position equivalent or analogous to amino acid residue 20, 21, 48, 51, 52, 55, 58, 59, 62, 92, 93, 95, 109, 120, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, c) a phenylalanine residue at a position equivalent or analogous to amino acid residue 123 of SEQ ID NO: 1, d) an alanine residue at a position equivalent or analogous to amino acid residue 95 of SEQ ID NO: 1 and a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, e) an alanine residue at a position equivalent or analogous to amino acid residues 218 and 219 of SEQ ID NO: 1, f) a proline residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 2, g) an arginine or leucine residue at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, h) an alanine residue at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, i) an alanine or a serine residue at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, or j) a proline residue at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. Even more preferably, the isolated polypeptide comprises a substitution mutation of a) E20A, Q21A, F48A, I51A, T52A, T55A, T58A, V59A, I62A, M92A, M93A, R95A, F109A, A110P, Y120A, A123F, M125A, M218A, C219A, L223A, L230A, L234A, W238A, R95A/A110P, or M218A/C219A of SEQ ID NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S of SEQ ID NO: 2, or c) A113P of SEQ ID NO: 3.

In another specific embodiment, the present invention relates to an isolated polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation that eliminates steroid binding activity or steroid sensitivity of the Group H ligand binding domain. Preferably, the isolated polypeptide comprises a substitution of an amino acid residue at a position equivalent or analogous to a) amino acid residue 58 or 110 of SEQ ID NO: 1, b) amino acid residues 107, 110 and 175 of SEQ ID NO: 1, c) amino acid residue 107, 121, 213, or 217 of SEQ ID NO: 2, or d) amino acid residue 113 of SEQ ID NO: 3. More preferably, the isolated polynucleotide comprises a codon mutation that results in a substitution of a) an alanine at a position equivalent or analogous to amino acid residue 58 of SEQ ID NO: 1, b) a proline, leucine, serine, or methionine residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, c) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, a proline residue at a position equivalent or analogous to amino acid 110 of SEQ ID NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, d) a proline at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 2, e) an arginine or a leucine at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, f) an alanine at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, g) an alanine or a serine at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, or h) a proline at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. Even more preferably, the isolated polypeptide comprises a substitution mutation selected from the group consisting of a) T58A, A110P,

A110L, A110S, A110M, or V107/A110P/R175E substitution mutation of SEQ ID NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S substitution mutation of SEQ ID NO: 2, and c) A113P substitution mutation of SEQ ID NO: 3.

The present invention also relates to an isolated polypeptide comprising an ecdysone receptor  
5 ligand binding domain comprising a substitution mutation, wherein the ecdysone receptor ligand binding domain lacks steroid binding activity. Preferably, the ecdysone receptor ligand binding domain comprises a substitution mutation at an equivalent or analogous amino acid residue to a) amino acid residue 58 or 110 of SEQ ID NO: 1, b) amino acid residues 107, 110 and 175 of SEQ ID NO: 1, c) amino acid residue 107, 121, 213, or 217 of SEQ ID NO: 2, or d) amino acid residue 113 of SEQ ID NO: 3.  
10 More preferably, the ecdysone receptor ligand binding domain comprises a substitution of a) an alanine at a position equivalent or analogous to amino acid residue 58 of SEQ ID NO: 1, b) a proline, leucine, serine, or methionine residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, c) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID  
15 NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, d) a proline at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 2, e) an arginine or a leucine at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, f) an alanine at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, g) an alanine or a serine at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2,  
20 or h) a proline at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. Even more preferably, the ecdysone receptor ligand binding domain comprises a substitution mutation selected from the group consisting of a) T58A, A110P, A110L, A110S, A110M, or V107/A110P/R175E substitution mutation of SEQ ID NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S substitution mutation of SEQ ID NO: 2, and c) A113P substitution mutation of SEQ ID NO: 3. In a  
25 specific embodiment, the ecdysone receptor ligand binding domain lacks steroid binding activity selected from the group consisting of ecdysone binding activity, 20-hydroxyecdysone binding activity, ponasterone A binding activity, and muristerone A binding activity.

In another specific embodiment, the isolated polypeptide comprising an ecdysone receptor ligand binding domain comprising a substitution mutation, wherein the ecdysone receptor ligand binding  
30 domain lacks steroid binding activity and is encoded by a polynucleotide that hybridizes to a polynucleotide comprising a codon mutation that results in a substitution mutation selected from the group consisting of a) T58A, A110P, A110L, A110S, A110M, or V107/A110P/R175E substitution mutation of SEQ ID NO: 1, b) A107P, G121R, G121L, N213A, C217A, or C217S substitution mutation of SEQ ID NO: 2, and c) A113P substitution mutation of SEQ ID NO: 3 under hybridization conditions  
35 comprising a hybridization step in less than 500 mM salt and at least 37 degrees Celsius, and a washing step in 2XSSPE at at least 63 degrees Celsius. In a preferred embodiment, the hybridization conditions comprise less than 200 mM salt and at least 37 degrees Celsius for the hybridization step. In another

preferred embodiment, the hybridization conditions comprise 2XSSPE and 63 degrees Celsius for both the hybridization and washing steps. In another preferred embodiment, the ecdysone receptor ligand binding domain lacks steroid binding activity selected from the group consisting of ecdysone binding activity, 20-hydroxyecdysone binding activity, ponasterone A binding activity, and muristerone A

5 binding activity.

In another specific embodiment, the present invention relates to an isolated polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation that reduces non-steroid binding activity or non-steroid sensitivity of the Group H nuclear receptor ligand binding domain. Preferably, the isolated polypeptide comprises a substitution of an amino acid residue at  
10 a position equivalent or analogous to amino acid residue a) 21, 48, 51, 52, 59, 62, 93, 95, 96, 109, 120, 123, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) 121, 213, or 217 of SEQ ID NO: 2, or c) 105 of SEQ ID NO: 3. More preferably, the isolated polypeptide comprises a substitution of a) an alanine residue at a position equivalent or analogous to amino acid residue 21, 48, 51, 59, 62, 93, 95, 96, 109, 120, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) a leucine residue at a position  
15 equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, c) a threonine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, d) a phenylalanine residue at a position equivalent or analogous to amino acid residue 123 of SEQ ID NO: 1, e) an alanine residue at a position equivalent or analogous to amino acid residue 95 of SEQ ID NO: 1 and a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, f) an alanine residue at a  
20 position equivalent or analogous to amino acid residues 218 and 219 of SEQ ID NO: 1, g) an arginine or a leucine residue at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, b) an alanine residue at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, i) an alanine or a serine residue at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, or j) a proline residue at a position equivalent or analogous to amino acid residue 113 of SEQ ID  
25 NO: 3. Even more preferably, the isolated polypeptide comprises a substitution mutation of a) Q21A, F48A, I51A, T52L, V59A, I62A, M93A, R95A, V96A, V96T, F109A, Y120A, A123F, M125A, M218A, C219A, L223A, L230A, L234A, W238A, R95A/A110P, or M218/C219A of SEQ ID NO: 1, b) G121R, G121L, N213A, C217A, or C217S of SEQ ID NO: 2, or c) A113P of SEQ ID NO: 3.

In another specific embodiment, the present invention relates to an isolated polypeptide  
30 comprising a Group H nuclear receptor polypeptide ligand binding domain comprising a substitution mutation that eliminates non-steroid binding activity or non-steroid sensitivity of the Group H ligand binding domain.

In another specific embodiment, the present invention relates to an isolated polypeptide comprising a Group H nuclear receptor polypeptide ligand binding domain comprising a substitution  
35 mutation that reduces both steroid binding activity or steroid sensitivity and non-steroid binding activity or non-steroid sensitivity of the Group H ligand binding domain. Preferably, the isolated polypeptide comprises a substitution of an amino acid residue at a position equivalent or analogous to a) amino acid

residue 21, 48, 51, 59, 62, 93, 95, 109, 120, 123, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) amino acid residues 95 and 110 of SEQ ID NO: 1, c) amino acid residues 218 and 219 of SEQ ID NO: 1, d) amino acid residue 121, 213, or 217 of SEQ ID NO: 2, or c) amino acid residue 113 of SEQ ID NO: 3. More preferably, the isolated polypeptide comprises a substitution of a) an alanine residue at a position equivalent or analogous to amino acid residue 21, 48, 51, 59, 62, 93, 95, 109, 120, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1, b) a phenylalanine residue at a position equivalent or analogous to amino acid residue 123 of SEQ ID NO: 1, c) an alanine residue at a position equivalent or analogous to amino acid residue 95 of SEQ ID NO: 1 and a proline residue at a position equivalent or analogous to amino acid residue 110 of SEQ ID NO: 1, d) an alanine residue at a position equivalent or analogous to amino acid residues 218 and 219 of SEQ ID NO: 1, e) an arginine or leucine residue at a position equivalent or analogous to amino acid residue 121 of SEQ ID NO: 2, f) an alanine residue at a position equivalent or analogous to amino acid residue 213 of SEQ ID NO: 2, g) an alanine or serine residue at a position equivalent or analogous to amino acid residue 217 of SEQ ID NO: 2, or h) a proline residue at a position equivalent or analogous to amino acid residue 113 of SEQ ID NO: 3. Even more preferably, the isolated polypeptide comprises a substitution mutation of Q21A, F48A, I51A, V59A, I62A, M93A, R95A, F109A, Y120A, A123F, M125A, M218A, C219A, L223A, L230A, L234A, W238A, R95A/A110P, or M218A/C219A of SEQ ID NO: 1, b) G121R, G121L, N213A, C217A, or C217S of SEQ ID NO: 2, or c) A113P of SEQ ID NO: 3.

In addition, the present invention also relates to an isolated polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation that enhances ligand binding activity or ligand sensitivity of the Group H nuclear receptor ligand binding domain.

In a specific embodiment, the present invention relates to an isolated polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation that enhances steroid binding activity or steroid sensitivity of the Group H nuclear receptor ligand binding domain. Preferably, the isolated polypeptide comprises a substitution of an amino acid residue at a position equivalent or analogous to a) amino acid residue 52 or 96 of SEQ ID NO: 1, b) amino acid residues 96, 107 and 175 of SEQ ID NO: 1, or c) amino acid residue 99 of SEQ ID NO: 3. More preferably, the isolated polypeptide comprises a substitution of a) a leucine, valine, or isoleucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, b) an alanine, threonine, aspartic acid, or methionine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, c) a threonine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, or d) an alanine residue at a position equivalent or analogous to amino acid residue 99 of SEQ ID NO: 3. Even more preferably, the isolated polypeptide comprises a substitution mutation of a) T52L, T52V, T52I, V96A, V96T, V96D, V96M, or V96T/V107L/R175E of SEQ ID NO: 1 or b) G99A of SEQ ID NO: 3.

In another specific embodiment, the present invention relates to an isolated polypeptide comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation that enhances non-steroid binding activity or non-steroid sensitivity of the Group H nuclear receptor ligand binding domain. Preferably, the isolated polypeptide comprises a substitution of an amino acid residue at 5 a position equivalent or analogous to amino acid residue 52, 55, or 96 of SEQ ID NO: 1 or b) amino acid residue 99 of SEQ ID NO: 3. More preferably, the isolated polypeptide comprises a substitution of a) an alanine, valine, or isoleucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, b) an alanine residue at a position equivalent or analogous to amino acid residue 55 of SEQ ID NO: 1, c) an aspartic acid or methionine residue at a position equivalent or analogous to amino 10 acid residue 96 of SEQ ID NO: 1, or d) an alanine residue at a position equivalent or analogous to amino acid residue 99 of SEQ ID NO: 3. Even more preferably, the isolated polypeptide comprises a substitution mutation of a) T52A, T52V, T52I, T55A, V96D, or V96M of SEQ ID NO: 1 or b) G99A of SEQ ID NO: 3.

In another specific embodiment, the present invention relates to an isolated polypeptide 15 comprising a Group H nuclear receptor ligand binding domain comprising a substitution mutation that enhances both steroid binding activity or steroid sensitivity and non-steroid binding activity or non-steroid sensitivity of the Group H ligand binding domain. Preferably, the isolated polypeptide comprises a substitution of an amino acid residue at a position equivalent or analogous to a) amino acid residue 52, 96, 107 or 175 of SEQ ID NO: 1, b) amino acid residues 107 and 175 of SEQ ID NO: 1, c) amino acid 20 residues 127 and 175 of SEQ ID NO: 1, d) amino acid residues 107 and 127 of SEQ ID NO: 1, e) amino acid residues 107, 127 and 175 of SEQ ID NO: 1, f) amino acid residues 52, 107 and 175 of SEQ ID NO: 1, g) amino acid residues 96, 107 and 175 of SEQ ID NO: 1, or h) amino acid residue 99 of SEQ ID NO: 3. More preferably, the isolated polypeptide comprises a substitution of a) a valine or isoleucine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID NO: 1, b) an aspartic acid or 25 methionine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID NO: 1, c) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1, d) a glutamine residue at a position equivalent or analogous to amino acid residues 175, e) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID NO: 1, f) a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, g) an 30 isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 127 of SEQ ID NO: 1, h) an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residues 127 and 175 of SEQ ID NO: 1, i) a valine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID 35 NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID

NO: 1, j) an alanine residue at a position equivalent or analogous to amino acid residue 96 of SEQ ID  
NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID  
NO: 1 and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ ID  
NO: 1, k) an alanine residue at a position equivalent or analogous to amino acid residue 52 of SEQ ID  
5 NO: 1, an isoleucine residue at a position equivalent or analogous to amino acid residue 107 of SEQ ID  
NO: 1, and a glutamine residue at a position equivalent or analogous to amino acid residue 175 of SEQ  
ID NO: 1, or l) an alanine residue at a position equivalent or analogous to amino acid residue 99 of SEQ  
ID NO: 3. Even more preferably, the isolated polypeptide comprises a substitution mutation of a) T52V,  
T52I, V96D, V96M, V107I, R175E, V107I/R175E, Y127E/R175E, V107I/Y127E,  
10 V107I/Y127E/R175E, T52V/V107I/R175E, V96A/V107I/R175E, or T52A/V107I/R175E of SEQ ID  
NO: 1 or b) G99A of SEQ ID NO: 3.

The present invention also relates to compositions comprising an isolated polypeptide according  
to the invention.

#### 15 METHOD OF MODULATING GENE EXPRESSION OF THE INVENTION

Applicants' invention also relates to methods of modulating gene expression in a host  
cell using a gene expression modulation system according to the invention. Specifically, Applicants'  
invention provides a method of modulating the expression of a gene in a host cell comprising the steps  
of: a) introducing into the host cell a gene expression modulation system according to the invention; and  
20 b) introducing into the host cell a ligand; wherein the gene to be modulated is a component of a gene  
expression cassette comprising: i) a response element comprising a domain recognized by the DNA  
binding domain of the gene expression system; ii) a promoter that is activated by the transactivation  
domain of the gene expression system; and iii) a gene whose expression is to be modulated, whereby  
upon introduction of the ligand into the host cell, expression of the gene is modulated.

25 The invention also provides a method of modulating the expression of a gene in a host cell  
comprising the steps of: a) introducing into the host cell a gene expression modulation system according  
to the invention; b) introducing into the host cell a gene expression cassette according to the invention,  
wherein the gene expression cassette comprises i) a response element comprising a domain recognized  
by the DNA binding domain from the gene expression system; ii) a promoter that is activated by the  
30 transactivation domain of the gene expression system; and iii) a gene whose expression is to be  
modulated; and c) introducing into the host cell a ligand; whereby upon introduction of the ligand into  
the host cell, expression of the gene is modulated.

Applicants' invention also provides a method of modulating the expression of a gene in a host  
cell comprising a gene expression cassette comprising a response element comprising a domain to which  
35 the DNA binding domain from the first hybrid polypeptide of the gene expression modulation system  
binds; a promoter that is activated by the transactivation domain of the second hybrid polypeptide of the  
gene expression modulation system; and a gene whose expression is to be modulated; wherein the

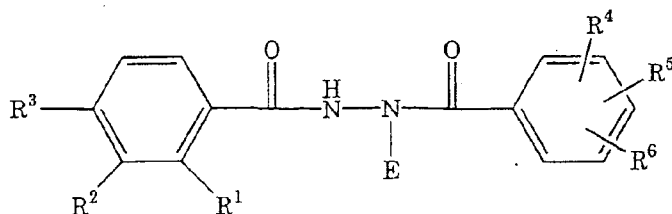
method comprises the steps of: a) introducing into the host cell a gene expression modulation system according to the invention; and b) introducing into the host cell a ligand; whereby upon introduction of the ligand into the host, expression of the gene is modulated.

Genes of interest for expression in a host cell using Applicants' methods may be endogenous  
5 genes or heterologous genes. Nucleic acid or amino acid sequence information for a desired gene or protein can be located in one of many public access databases, for example, GENBANK, EMBL, Swiss-Prot, and PIR, or in many biology related journal publications. Thus, those skilled in the art have access to nucleic acid sequence information for virtually all known genes. Such information can then be used to construct the desired constructs for the insertion of the gene of interest within the gene expression  
10 cassettes used in Applicants' methods described herein.

Examples of genes of interest for expression in a host cell using Applicants' methods include, but are not limited to: antigens produced in plants as vaccines, enzymes like alpha-amylase, phytase, glucanase, xylase and xylanase, genes for resistance against insects, nematodes, fungi, bacteria, viruses, and abiotic stresses, nutraceuticals, pharmaceuticals, vitamins, genes for modifying amino acid content,  
15 herbicide resistance, cold, drought, and heat tolerance, industrial products, oils, protein, carbohydrates, antioxidants, male sterile plants, flowers, fuels, other output traits, genes encoding therapeutically desirable polypeptides or products that may be used to treat a condition, a disease, a disorder, a dysfunction, a genetic defect, such as monoclonal antibodies, enzymes, proteases, cytokines, interferons, insulin, erythropoietin, clotting factors, other blood factors or components, viral vectors for gene therapy,  
20 virus for vaccines, targets for drug discovery, functional genomics, and proteomics analyses and applications, and the like.

Acceptable ligands are any that modulate expression of the gene when binding of the DNA binding domain of the gene expression system according to the invention to the response element in the presence of the ligand results in activation or suppression of expression of the genes. Preferred ligands  
25 include an ecdysteroid, such as ecdysone, 20-hydroxyecdysone, ponasterone A, muristerone A, and the like, 9-cis-retinoic acid, synthetic analogs of retinoic acid, N,N'-diacylhydrazines such as those disclosed in U. S. Patents No. 6,013,836; 5,117,057; 5,530,028; and 5,378,726; dibenzoylalkyl cyanohydrazines such as those disclosed in European Application No. 461,809; N-alkyl-N,N'-diaroylhydrazines such as those disclosed in U. S. Patent No. 5,225,443; N-acyl-N-alkylcarbonylhydrazines such as those disclosed  
30 in European Application No. 234,994; N-aroyl-N-alkyl-N'-aroylhydrazines such as those described in U. S. Patent No. 4,985,461; and other similar materials including 3,5-di-tert-butyl-4-hydroxy-N-isobutyl-benzamide, 8-O-acetylharpagide, oxysterols, 22(R) hydroxycholesterol, 24(S) hydroxycholesterol, 25-epoxycholesterol, T0901317, 5-alpha-6-alpha-epoxycholesterol-3-sulfate (ECHS), 7-ketocholesterol-3-sulfate, farnesol, bile acids, 1,1-biphosphonate  
35 esters, Juvenile hormone III, and the like.

In a preferred embodiment, the ligand for use in Applicants' method of modulating expression of gene is a compound of the formula:



wherein:

E is a (C<sub>4</sub>-C<sub>6</sub>)alkyl containing a tertiary carbon or a cyano(C<sub>3</sub>-C<sub>5</sub>)alkyl containing a tertiary carbon;  
 R<sup>1</sup> is H, Me, Et, i-Pr, F, formyl, CF<sub>3</sub>, CHF<sub>2</sub>, CHCl<sub>2</sub>, CH<sub>2</sub>F, CH<sub>2</sub>Cl, CH<sub>2</sub>OH, CH<sub>2</sub>OMe, CH<sub>2</sub>CN, CN,  
 5 C<sup>o</sup>CH, 1-propynyl, 2-propynyl, vinyl, OH, OMe, OEt, cyclopropyl, CF<sub>2</sub>CF<sub>3</sub>, CH=CHCN, allyl,  
 azido, SCN, or SCHF<sub>2</sub>;

R<sup>2</sup> is H, Me, Et, n-Pr, i-Pr, formyl, CF<sub>3</sub>, CHF<sub>2</sub>, CHCl<sub>2</sub>, CH<sub>2</sub>F, CH<sub>2</sub>Cl, CH<sub>2</sub>OH, CH<sub>2</sub>OMe, CH<sub>2</sub>CN,  
 CN, C<sup>o</sup>CH, 1-propynyl, 2-propynyl, vinyl, Ac, F, Cl, OH, OMe, OEt, O-n-Pr, OAc, NMe<sub>2</sub>, NEt<sub>2</sub>,  
 SMe, SEt, SOCF<sub>3</sub>, OCF<sub>2</sub>CF<sub>2</sub>H, COEt, cyclopropyl, CF<sub>2</sub>CF<sub>3</sub>, CH=CHCN, allyl, azido, OCF<sub>3</sub>,  
 10 OCHF<sub>2</sub>, O-i-Pr, SCN, SCHF<sub>2</sub>, SOMe, NH-CN, or joined with R<sup>3</sup> and the phenyl carbons to  
 which R<sup>2</sup> and R<sup>3</sup> are attached to form an ethylenedioxy, a dihydrofuryl ring with the oxygen  
 adjacent to a phenyl carbon, or a dihydropyryl ring with the oxygen adjacent to a phenyl carbon;

R<sup>3</sup> is H, Et, or joined with R<sup>2</sup> and the phenyl carbons to which R<sup>2</sup> and R<sup>3</sup> are attached to form an  
 ethylenedioxy, a dihydrofuryl ring with the oxygen adjacent to a phenyl carbon, or a  
 15 dihydropyryl ring with the oxygen adjacent to a phenyl carbon;

R<sup>4</sup>, R<sup>5</sup>, and R<sup>6</sup> are independently H, Me, Et, F, Cl, Br, formyl, CF<sub>3</sub>, CHF<sub>2</sub>, CHCl<sub>2</sub>, CH<sub>2</sub>F, CH<sub>2</sub>Cl,  
 CH<sub>2</sub>OH, CN, C<sup>o</sup>CH, 1-propynyl, 2-propynyl, vinyl, OMe, OEt, SMe, or SEt.

In another preferred embodiment, the ligand for use in Applicants' method of modulating  
 expression of gene is an ecdysone, 20-hydroxyecdysone, ponasterone A, muristerone A, an oxysterol, a  
 20 22(R) hydroxycholesterol, 24(S) hydroxycholesterol, 25-epoxycholesterol, T0901317, 5-alpha-6-alpha-  
 epoxycholesterol-3-sulfate (ECHS), 7-ketocholesterol-3-sulfate, farnesol, bile acids, 1,1-biphosphonate  
 esters, or Juvenile hormone III.

In another preferred embodiment, a second ligand may be used in addition to the first ligand  
 discussed above in Applicants' method of modulating expression of a gene. Preferably, this second  
 25 ligand is 9-cis-retinoic acid or a synthetic analog of retinoic acid.

#### HOST CELLS AND NON-HUMAN ORGANISMS OF THE INVENTION

As described above, the gene expression modulation system of the present invention may be used  
 to modulate gene expression in a host cell. Expression in transgenic host cells may be useful for the  
 30 expression of various genes of interest. Applicants' invention provides for modulation of gene  
 expression in prokaryotic and eukaryotic host cells. Expression in transgenic host cells is useful for the  
 expression of various polypeptides of interest including but not limited to antigens produced in plants as

vaccines, enzymes like alpha-amylase, phytase, glucanase, xylase and xylanase, genes for resistance against insects, nematodes, fungi, bacteria, viruses, and abiotic stresses, antigens, nutraceuticals, pharmaceuticals, vitamins, genes for modifying amino acid content, herbicide resistance, cold, drought, and heat tolerance, industrial products, oils, protein, carbohydrates, antioxidants, male sterile plants, flowers, fuels, other output traits, therapeutic polypeptides, pathway intermediates; for the modulation of pathways already existing in the host for the synthesis of new products heretofore not possible using the host; cell based assays; functional genomics assays, biotherapeutic protein production, proteomics assays, and the like. Additionally the gene products may be useful for conferring higher growth yields of the host or for enabling an alternative growth mode to be utilized.

10 Thus, Applicants' invention provides an isolated host cell comprising a gene expression system according to the invention. The present invention also provides an isolated host cell comprising a gene expression cassette according to the invention. Applicants' invention also provides an isolated host cell comprising a polynucleotide or a polypeptide according to the invention. The present invention also relates to a host cell transfected with an expression vector according to the invention. The host cell may  
15 be a bacterial cell, a fungal cell, a nematode cell, an insect cell, a fish cell, a plant cell, an avian cell, an animal cell, or a mammalian cell. In still another embodiment, the invention relates to a method for producing a nuclear receptor ligand binding domain comprising a substitution mutation, wherein the method comprises culturing the host cell as described above in culture medium under conditions permitting expression of a polynucleotide encoding the nuclear receptor ligand binding domain  
20 comprising a substitution mutation, and isolating the nuclear receptor ligand binding domain comprising a substitution mutation from the culture.

In a specific embodiment, the isolated host cell is a prokaryotic host cell or a eukaryotic host cell. In another specific embodiment, the isolated host cell is an invertebrate host cell or a vertebrate host cell. Preferably, the host cell is selected from the group consisting of a bacterial cell, a fungal cell, a  
25 yeast cell, a nematode cell, an insect cell, a fish cell, a plant cell, an avian cell, an animal cell, and a mammalian cell. More preferably, the host cell is a yeast cell, a nematode cell, an insect cell, a plant cell, a zebrafish cell, a chicken cell, a hamster cell, a mouse cell, a rat cell, a rabbit cell, a cat cell, a dog cell, a bovine cell, a goat cell, a cow cell, a pig cell, a horse cell, a sheep cell, a simian cell, a monkey cell, a chimpanzee cell, or a human cell. Examples of preferred host cells include, but are not limited to,  
30 fungal or yeast species such as *Aspergillus*, *Trichoderma*, *Saccharomyces*, *Pichia*, *Candida*, *Hansenula*, or bacterial species such as those in the genera *Synechocystis*, *Synechococcus*, *Salmonella*, *Bacillus*, *Acinetobacter*, *Rhodococcus*, *Streptomyces*, *Escherichia*, *Pseudomonas*, *Methylomonas*, *Methylobacter*, *Alcaligenes*, *Synechocystis*, *Anabaena*, *Thiobacillus*, *Methanobacterium* and *Klebsiella*; plant species selected from the group consisting of an apple, *Arabidopsis*, bajra, banana, barley, beans, beet,  
35 blackgram, chickpea, chili, cucumber, eggplant, favabean, maize, melon, millet, mungbean, oat, okra, *Panicum*, papaya, peanut, pea, pepper, pigeonpea, pineapple, *Phaseolus*, potato, pumpkin, rice, sorghum, soybean, squash, sugarcane, sugarbeet, sunflower, sweet potato, tea, tomato, tobacco, watermelon, and

wheat; animal; and mammalian host cells.

In a specific embodiment, the host cell is a yeast cell selected from the group consisting of a *Saccharomyces*, a *Pichia*, and a *Candida* host cell.

In another specific embodiment, the host cell is a *Caenorhabditis elegans* nematode cell.

5 In another specific embodiment, the host cell is an insect cell.

In another specific embodiment, the host cell is a plant cell selected from the group consisting of an apple, *Arabidopsis*, bajra, banana, barley, beans, beet, blackgram, chickpea, chili, cucumber, eggplant, favabean, maize, melon, millet, mungbean, oat, okra, *Panicum*, papaya, peanut, pea, pepper, pigeonpea, pineapple, *Phaseolus*, potato, pumpkin, rice, sorghum, soybean, squash, sugarcane, sugarbeet, sunflower,

10 sweet potato, tea, tomato, tobacco, watermelon, and wheat cell.

In another specific embodiment, the host cell is a zebrafish cell.

In another specific embodiment, the host cell is a chicken cell.

In another specific embodiment, the host cell is a mammalian cell selected from the group consisting of a hamster cell, a mouse cell, a rat cell, a rabbit cell, a cat cell, a dog cell, a bovine cell, a

15 goat cell, a cow cell, a pig cell, a horse cell, a sheep cell, a monkey cell, a chimpanzee cell, and a human cell.

Host cell transformation is well known in the art and may be achieved by a variety of methods including but not limited to electroporation, viral infection, plasmid/vector transfection, non-viral vector mediated transfection, *Agrobacterium*-mediated transformation, particle bombardment, and the like.

20 Expression of desired gene products involves culturing the transformed host cells under suitable conditions and inducing expression of the transformed gene. Culture conditions and gene expression protocols in prokaryotic and eukaryotic cells are well known in the art (see General Methods section of Examples). Cells may be harvested and the gene products isolated according to protocols specific for the gene product.

25 In addition, a host cell may be chosen which modulates the expression of the inserted polynucleotide, or modifies and processes the polypeptide product in the specific fashion desired. Different host cells have characteristic and specific mechanisms for the translational and post-translational processing and modification [*e.g.*, glycosylation, cleavage (*e.g.*, of signal sequence)] of proteins. Appropriate cell lines or host systems can be chosen to ensure the desired modification and  
30 processing of the foreign protein expressed. For example, expression in a bacterial system can be used to produce a non-glycosylated core protein product. However, a polypeptide expressed in bacteria may not be properly folded. Expression in yeast can produce a glycosylated product. Expression in eukaryotic cells can increase the likelihood of "native" glycosylation and folding of a heterologous protein. Moreover, expression in mammalian cells can provide a tool for reconstituting, or constituting, the  
35 polypeptide's activity. Furthermore, different vector/host expression systems may affect processing reactions, such as proteolytic cleavages, to a different extent.

Applicants' invention also relates to a non-human organism comprising an isolated host cell

according to the invention. In a specific embodiment, the non-human organism is a prokaryotic organism or a eukaryotic organism. In another specific embodiment, the non-human organism is an invertebrate organism or a vertebrate organism.

Preferably, the non-human organism is selected from the group consisting of a bacterium, a  
5 fungus, a yeast, a nematode, an insect, a fish, a plant, a bird, an animal, and a mammal. More preferably, the non-human organism is a yeast, a nematode, an insect, a plant, a zebrafish, a chicken, a hamster, a mouse, a rat, a rabbit, a cat, a dog, a bovine, a goat, a cow, a pig, a horse, a sheep, a simian, a monkey, or a chimpanzee.

In a specific embodiment, the non-human organism is a yeast selected from the group consisting  
10 of *Saccharomyces*, *Pichia*, and *Candida*.

In another specific embodiment, the non-human organism is a *Caenorhabdus elegans* nematode.

In another specific embodiment, the non-human organism is a plant selected from the group  
consisting of an apple, *Arabidopsis*, bajra, banana, barley, beans, beet, blackgram, chickpea, chili,  
cucumber, eggplant, favabean, maize, melon, millet, mungbean, oat, okra, *Panicum*, papaya, peanut, pea,  
15 pepper, pigeonpea, pineapple, *Phaseolus*, potato, pumpkin, rice, sorghum, soybean, squash, sugarcane,  
sugarbeet, sunflower, sweet potato, tea, tomato, tobacco, watermelon, and wheat.

In another specific embodiment, the non-human organism is a *Mus musculus* mouse.

#### MEASURING GENE EXPRESSION/TRANSCRIPTION

20 One useful measurement of Applicants' methods of the invention is that of the transcriptional state of the cell including the identities and abundances of RNA, preferably mRNA species. Such measurements are conveniently conducted by measuring cDNA abundances by any of several existing gene expression technologies.

Nucleic acid array technology is a useful technique for determining differential mRNA  
25 expression. Such technology includes, for example, oligonucleotide chips and DNA microarrays. These techniques rely on DNA fragments or oligonucleotides which correspond to different genes or cDNAs which are immobilized on a solid support and hybridized to probes prepared from total mRNA pools extracted from cells, tissues, or whole organisms and converted to cDNA. Oligonucleotide chips are arrays of oligonucleotides synthesized on a substrate using photolithographic techniques. Chips have  
30 been produced which can analyze for up to 1700 genes. DNA microarrays are arrays of DNA samples, typically PCR products, that are robotically printed onto a microscope slide. Each gene is analyzed by a full or partial-length target DNA sequence. Microarrays with up to 10,000 genes are now routinely prepared commercially. The primary difference between these two techniques is that oligonucleotide chips typically utilize 25-mer oligonucleotides which allow fractionation of short DNA molecules  
35 whereas the larger DNA targets of microarrays, approximately 1000 base pairs, may provide more sensitivity in fractionating complex DNA mixtures.

Another useful measurement of Applicants' methods of the invention is that of determining the

translation state of the cell by measuring the abundances of the constituent protein species present in the cell using processes well known in the art.

Where identification of genes associated with various physiological functions is desired, an assay may be employed in which changes in such functions as cell growth, apoptosis, senescence, 5 differentiation, adhesion, binding to a specific molecules, binding to another cell, cellular organization, organogenesis, intracellular transport, transport facilitation, energy conversion, metabolism, myogenesis, neurogenesis, and/or hematopoiesis is measured.

In addition, selectable marker or reporter gene expression may be used to measure gene expression modulation using Applicants' invention.

10 Other methods to detect the products of gene expression are well known in the art and include Southern blots (DNA detection), dot or slot blots (DNA, RNA), northern blots (RNA), RT-PCR (RNA), western blots (polypeptide detection), and ELISA (polypeptide) analyses. Although less preferred, labeled proteins can be used to detect a particular nucleic acid sequence to which it hybridizes.

In some cases it is necessary to amplify the amount of a nucleic acid sequence. This may be 15 carried out using one or more of a number of suitable methods including, for example, polymerase chain reaction ("PCR"), ligase chain reaction ("LCR"), strand displacement amplification ("SDA"), transcription-based amplification, and the like. PCR is carried out in accordance with known techniques in which, for example, a nucleic acid sample is treated in the presence of a heat stable DNA polymerase, under hybridizing conditions, with one pair of oligonucleotide primers, with one primer hybridizing to 20 one strand (template) of the specific sequence to be detected. The primers are sufficiently complementary to each template strand of the specific sequence to hybridize therewith. An extension product of each primer is synthesized and is complementary to the nucleic acid template strand to which it hybridized. The extension product synthesized from each primer can also serve as a template for further synthesis of extension products using the same primers. Following a sufficient number of rounds 25 of synthesis of extension products, the sample may be analyzed as described above to assess whether the sequence or sequences to be detected are present.

#### LIGAND SCREENING ASSAYS

The present invention also relates to methods of screening for a compound that induces or 30 represses transactivation of a nuclear receptor ligand binding domain comprising a substitution mutation in a cell by contacting a nuclear receptor ligand binding domain with a candidate molecule and detecting reporter gene activity in the presence of the ligand. Candidate compounds may be either agonists or antagonists of the nuclear receptor ligand binding domain. In a preferred embodiment, the nuclear receptor ligand binding domain is expressed from a polynucleotide in the cell and the transactivation 35 activity (i.e., expression or repression of a reporter gene) or compound binding activity is measured.

Accordingly, in addition to rational design of agonists and antagonists based on the structure of a nuclear receptor ligand binding domain, the present invention contemplates an alternative method for

identifying specific ligands of a nuclear receptor ligand binding domain using various screening assays known in the art.

Any screening technique known in the art can be used to screen for Group H nuclear receptor ligand binding domain agonists or antagonists. For example, a suitable cell line comprising a nuclear receptor-based gene expression system according to the invention can be transfected with a gene  
5 expression cassette encoding a marker gene operatively linked to an inducible or repressible promoter. The transfected cells are then exposed to a test solution comprising a candidate agonist or antagonist compound, and then assayed for marker gene expression or repression. The presence of more marker gene expression relative to control cells not exposed to the test solution is an indication of the presence  
10 of an agonist compound in the test solution. Conversely, the presence of less marker gene expression relative to control cells not exposed to the test solution is an indication of the presence of an antagonist compound in the test solution.

The present invention contemplates screens for small molecule ligands or ligand analogs and mimics, as well as screens for natural ligands that bind to and agonize or antagonize a Group H nuclear  
15 receptor ligand binding domain according to the invention *in vivo*. For example, natural products libraries can be screened using assays of the invention for molecules that agonize or antagonize nuclear receptor-based gene expression system activity.

Identification and screening of antagonists is further facilitated by determining structural features of the protein, *e.g.*, using X-ray crystallography, neutron diffraction, nuclear magnetic resonance  
20 spectrometry, and other techniques for structure determination. These techniques provide for the rational design or identification of agonists and antagonists.

Another approach uses recombinant bacteriophage to produce large libraries. Using the "phage method" [Scott and Smith, 1990, *Science* 249: 386-390 (1990); Cwirla, et al., *Proc. Natl. Acad. Sci.*, 87: 6378-6382 (1990); Devlin et al., *Science*, 249: 404-406 (1990)], very large libraries can be constructed  
25 ( $10^6$ - $10^8$  chemical entities). A second approach uses primarily chemical methods, of which the Geysen method [Geysen et al., *Molecular Immunology* 23: 709-715 (1986); Geysen et al. *J. Immunologic Method* 102: 259-274 (1987)] and the method of Fodor et al. [*Science* 251: 767-773 (1991)] are examples. Furka et al. [*14th International Congress of Biochemistry, Volume 5*, Abstract FR:013 (1988); Furka, *Int. J. Peptide Protein Res.* 37:487-493 (1991)], Houghton [U.S. Patent No. 4,631,211, issued December 1986]  
30 and Rutter et al. [U.S. Patent No. 5,010,175, issued April 23, 1991] describe methods to produce a mixture of peptides that can be tested as agonists or antagonists.

In another aspect, synthetic libraries [Needels et al., *Proc. Natl. Acad. Sci. USA* 90: 10700-4 (1993); Ohlmeyer et al., *Proc. Natl. Acad. Sci. USA* 90: 10922-10926 (1993); Lam et al., International Patent Publication No. WO 92/00252; Kocis et al., International Patent Publication No. WO 9428028].  
35 and the like can be used to screen for candidate ligands according to the present invention.

The screening can be performed with recombinant cells that express a nuclear receptor ligand

binding domain according to the invention, or alternatively, using purified protein, *e.g.*, produced recombinantly, as described above. For example, labeled, soluble nuclear receptor ligand binding domains can be used to screen libraries, as described in the foregoing references.

In one embodiment, a Group H nuclear receptor ligand binding domain according to the invention may be directly labeled. In another embodiment, a labeled secondary reagent may be used to detect binding of a nuclear receptor ligand binding domain of the invention to a molecule of interest, *e.g.*, a molecule attached to a solid phase support. Binding may be detected by *in situ* formation of a chromophore by an enzyme label. Suitable enzymes include, but are not limited to, alkaline phosphatase and horseradish peroxidase. In a further embodiment, a two-color assay, using two chromogenic substrates with two enzyme labels on different acceptor molecules of interest, may be used. Cross-reactive and singly-reactive ligands may be identified with a two-color assay.

Other labels for use in the invention include colored latex beads, magnetic beads, fluorescent labels (*e.g.*, fluorescein isothiocyanate (FITC), phycoerythrin (PE), Texas red (TR), rhodamine, free or chelated lanthanide series salts, especially  $\text{Eu}^{3+}$ , to name a few fluorophores), chemiluminescent molecules, radio-isotopes, or magnetic resonance imaging labels. Two-color assays may be performed with two or more colored latex beads, or fluorophores that emit at different wavelengths. Labeled molecules or cells may be detected visually or by mechanical/optical means. Mechanical/optical means include fluorescence activated sorting, *i.e.*, analogous to FACS, and micromanipulator removal means.

The present invention may be better understood by reference to the following non-limiting Examples, which are provided as exemplary of the invention.

## EXAMPLES

Applicants have developed a CfEcR homology model and have used this homology model together with a published *Chironomus tentans* ecdysone receptor ("CtEcR") homology model (Wurtz et al., 2000) to identify critical residues involved in binding to steroids and non-steroids. The synthetic non-steroids, diacylhydrazines, have been shown to bind lepidopteran EcRs with high affinity and induce precocious incomplete molt in these insects (Wing et al., 1988) and several of these compounds are currently marketed as insecticides. The ligand binding cavity of EcRs has evolved to fit the long backbone structures of ecdysteroids such as 20E. The diacylhydrazines have a compact structure compared to steroids and occupy only the bottom part of the EcR binding pocket. This leaves a few critical residues at the top part of the binding pocket that make contact with steroids but not with non-steroids such as diacylhydrazines. Applicants made substitution mutations of the residues that make contact with steroids and/or non-steroids and determined the mutational effect on ligand binding. Applicants describe herein substitution mutations at several of these residues and have identified several classes of substitution mutant receptors based upon their binding and transactivation characteristics. Applicants' novel substitution mutated nuclear receptor polynucleotides and polypeptides are useful in a nuclear receptor-based inducible gene modulation system for various applications including gene therapy, expression of proteins of interest in host cells, production of transgenic organisms, and cell-based assays.

### GENERAL METHODS

Standard recombinant DNA and molecular cloning techniques used herein are well known in the art and are described by Sambrook, J., Fritsch, E. F. and Maniatis, T. *Molecular Cloning: A Laboratory Manual*; Cold Spring Harbor Laboratory Press: Cold Spring Harbor, N.Y. (1989) (Maniatis) and by T. J. Silhavy, M. L. Bannan, and L. W. Enquist, *Experiments with Gene Fusions*, Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y. (1984) and by Ausubel, F. M. et al., *Current Protocols in Molecular Biology*, Greene Publishing Assoc. and Wiley-Interscience (1987).

Materials and methods suitable for the maintenance and growth of bacterial cultures are well known in the art. Techniques suitable for use in the following examples may be found as set out in *Manual of Methods for General Bacteriology* (Phillipp Gerhardt, R. G. E. Murray, Ralph N. Costilow, Eugene W. Nester, Willis A. Wood, Noel R. Krieg and G. Briggs Phillips, eds), American Society for Microbiology, Washington, DC. (1994) or by Thomas D. Brock in *Biotechnology: A Textbook of Industrial Microbiology*, Second Edition, Sinauer Associates, Inc., Sunderland, MA (1989). All reagents, restriction enzymes and materials used for the growth and maintenance of host cells were obtained from Aldrich Chemicals (Milwaukee, WI), DIFCO Laboratories (Detroit, MI), GIBCO/BRL (Gaithersburg, MD), or Sigma Chemical Company (St. Louis, MO) unless otherwise specified.

Manipulations of genetic sequences may be accomplished using the suite of programs available from the Genetics Computer Group Inc. (Wisconsin Package Version 9.0, Genetics Computer Group (GCG), Madison, WI). Where the GCG program "Pileup" is used the gap creation default value of 12,

and the gap extension default value of 4 may be used. Where the CGC "Gap" or "Bestfit" program is used the default gap creation penalty of 50 and the default gap extension penalty of 3 may be used. In any case where GCG program parameters are not prompted for, in these or any other GCG program, default values may be used.

- 5           The meaning of abbreviations is as follows: "h" means hour(s), "min" means minute(s), "sec" means second(s), "d" means day(s), "μl" means microliter(s), "ml" means milliliter(s), "L" means liter(s), "μM" means micromolar, "mM" means millimolar, "μg" means microgram(s), "mg" means milligram(s), "A" means adenine or adenosine, "T" means thymine or thymidine, "G" means guanine or guanosine, "C" means cytidine or cytosine, "xg" means times gravity, "nt" means nucleotide(s), "aa" means amino acid(s), "bp" means base pair(s), "kb" means kilobase(s), "k" means kilo, "μ" means micro, and "°C" means degrees Celsius.

#### EXAMPLE 1

- 15           This Example describes the construction of several gene expression cassettes comprising novel substitution mutated Group H nuclear receptor polynucleotides and polypeptides of the invention for use in a nuclear receptor-based inducible gene expression system. Applicants constructed several gene expression cassettes based on the spruce budworm *Choristoneura fumiferana* EcR ("CfEcR"), fruit fly *Drosophila melanogaster* EcR ("DmEcR"), ixodid tick *Amblyomma americanum* EcR ("AmaEcR"), locust *Locusta migratoria* ultraspiracle protein ("LmUSP"), an invertebrate RXR homolog of vertebrate RXR, and *C. fumiferana* USP ("CfUSP"). The prepared receptor constructs comprise a ligand binding domain of either an EcR, an invertebrate USP, or an invertebrate RXR; and a GAL4 DNA binding domain (DBD) or a VP16 transactivation domain (AD). The reporter constructs include a reporter gene, luciferase or LacZ (β-galactosidase), operably linked to a synthetic promoter construct that comprises a GAL4 response element to which the Gal4 DBD binds. Various combinations of these receptor and reporter constructs were cotransfected into mammalian cells as described in Examples 2-10 *infra*.

- Gene Expression Cassettes:** Ecdysone receptor-based gene expression cassettes (switches) were constructed as followed, using standard cloning methods available in the art. The following is a brief description of preparation and composition of each switch used in the Examples described herein.
- 1.1 - GAL4CfEcR-DEF/VP16LmUSP-EF: The wild-type D, E, and F domains from spruce budworm *Choristoneura fumiferana* EcR ("CfEcR-DEF"; SEQ ID NO: 21) were fused to a GAL4 DNA binding domain ("Gal4DNABD" or "Gal4DBD"; SEQ ID NO: 6) and placed under the control of an SV40e promoter (SEQ ID NO: 22). The E and F domains from locust *Locusta migratoria* ultraspiracle protein ("LmUSP-EF"; SEQ ID NO: 23) were fused to the transactivation domain from VP16 ("VP16AD"; SEQ ID NO: 12) and placed under the control of an SV40e promoter (SEQ ID NO: 22). Five consensus GAL4 response element binding sites ("5XGAL4RE"; comprising 5 copies of a GAL4RE comprising

SEQ ID NO: 19) were fused to a synthetic E1b minimal promoter (SEQ ID NO: 24) and placed upstream of the luciferase gene (SEQ ID NO: 25).

1.2 - GAL4/mutantCfEcR-DEF/VP16LmUSP-EF: This construct was prepared in the same way as in switch 1.1 above except wild-type CfEcR-DEF was replaced with mutant CfEcR-DEF comprising a 5 ligand binding domain comprising a substitution mutation selected from Table 1 below.

**Table 1.** Substitution Mutants of *Choristoneura fumiferana* Ecdysone Receptor (“CfEcR”) Ligand Binding Domain (LBD).

CfEcR-DEF LBD Mutation	Resulting “WT to Mutant” Amino Acid Substitution	Corresponding amino acid in full length CfEcR (SEQ ID NO: 26)
E20A	Glutamic Acid (E) to Alanine (A)	303
Q21A	Glutamine (Q) to Alanine (A)	304
F48A	Phenylalanine (F) to Alanine (A)	331
I51A	Isoleucine (I) to Alanine (A)	334
T52A	Threonine (T) to Alanine (A)	335
T52L	Threonine (T) to Leucine (L)	335
T52V	Threonine (T) to Valine (V)	335
T52I	Threonine (T) to Isoleucine (I)	335
T55A	Threonine (T) to Alanine (A)	338
T58A	Threonine (T) to Alanine (A)	341
V59A	Valine (V) to Alanine (A)	342
L61A	Leucine (L) to Alanine (A)	344
I62A	Isoleucine (I) to Alanine (A)	345
M92A	Methionine (M) to Alanine (A)	375
M93A	Methionine (M) to Alanine (A)	376
R95A	Arginine (R) to Alanine (A)	378
V96A	Valine (V) to Alanine (A)	379
V96T	Valine (V) to Threonine (T)	379
V96D	Valine (V) to Aspartic Acid (D)	379
V96M	Valine (V) to Methionine (M)	379
V107I	Valine (V) to Isoleucine	390
F109A	Phenylalanine (F) to Alanine (A)	392
A110P	Alanine (A) to Proline (P)	393
A110S	Alanine (A) to Serine (S)	393
A110L	Alanine (A) to Leucine (L)	393
A110M	Alanine (A) to Methionine (M)	393
Y120A	Tyrosine (Y) to Alanine (A)	403
A123F	Alanine (A) to Phenylalanine (F)	406
M125A	Methionine (M) to Alanine (A)	408
R175E	Arginine (R) to Glutamine (E)	458
M218A	Methionine (M) to Alanine (A)	501
C219A	Cysteine (C) to Alanine (A)	502
L223A	Leucine (L) to Alanine (A)	506
L230A	Leucine (L) to Alanine (A)	513
L234A	Leucine (L) to Alanine (A)	517
W238A	Tryptophan (W) to Alanine (A)	521
R95A and A110P double	Arginine (R) to Alanine (A) and Alanine (A) to Proline (P),	378 and 393, respectively

mutant	respectively	
V107I and R175E double mutant	Valine (V) to Isoleucine (I) and Arginine (R) to Glutamine (E), respectively	390 and 458, respectively
V107E and Y127E double mutant	Valine (V) to Isoleucine (I) and Tyrosine (Y) to Glutamine (E), respectively	390 and 410, respectively
Y127E and R175E double mutant	Tyrosine (Y) to Glutamine (E) and Arginine (R) to Glutamine (E), respectively	410 and 458, respectively
M218A and C219A double mutant	Methionine (M) to Alanine (A) and Cysteine (C) to Alanine (A), respectively	501 and 502, respectively
T52V, V107I and R175E triple mutant	Threonine (T) to Valine (V), Valine (V) to Isoleucine (I) and Arginine (R) to Glutamine (E), respectively	335, 390 and 458, respectively
T52A, V107I and R175E triple mutant	Threonine (T) to Alanine (A), Valine (V) to Isoleucine (I) and Arginine (R) to Glutamine (E), respectively	335, 390 and 458, respectively
V96A, V107I and R175E triple mutant	Valine (V) to Alanine (A), Valine (V) to Isoleucine (I) and Arginine (R) to Glutamine (E), respectively	379, 390 and 458, respectively
V96T, V107I and R175E triple mutant	Valine (V) to Threonine (T), Valine (V) to Isoleucine (I) and Arginine (R) to Glutamine (E), respectively	379, 390 and 458, respectively
V107I, Y127E and R175E triple mutant	Valine (V) to Isoleucine (I), Tyrosine (Y) to Glutamine (E) and Arginine (R) to Glutamine (E), respectively	390, 410 and 458, respectively
V107I, A110P and R175E triple mutant	Valine (V) to Isoleucine (I), Alanine (A) to Proline (P) and Arginine (R) to Glutamine (E), respectively	390, 393, and 458, respectively

1.3 - GAL4CfEcR-A/BCDEF/VP16LmUSP-EF: The full-length spruce budworm *Choristoneura fumiferana* EcR ("CfEcR-A/BCDEF"; SEQ ID NO: 27) was fused to a GAL4 DNA binding domain ("Gal4DNABD" or "Gal4DBD"; SEQ ID NO: 6) and placed under the control of an SV40e promoter (SEQ ID NO: 22). The E and F domains from *Locusta migratoria* ultraspiracle ("LmUSP-EF"; SEQ ID NO: 23) were fused to the transactivation domain from VP16 ("VP16AD"; SEQ ID NO: 12) and placed under the control of an SV40e promoter (SEQ ID NO: 22). Five consensus GAL4 response element binding sites ("5XGAL4RE"; comprising 5 copies of a GAL4RE comprising SEQ ID NO: 19) were fused to a synthetic E1b minimal promoter (SEQ ID NO: 24) and placed upstream of the luciferase gene (SEQ ID NO: 25).

1.4 - GAL4/A110PmutantCfEcR-A/BCDEF/VP16LmUSP-EF: This construct was prepared in the same way as in switch 1.3 above except wild-type CfEcR-A/BCDEF was replaced with a mutant CfEcR-

A/BCDEF comprising a ligand binding domain comprising an A110P substitution mutation as described in Table 1 above.

1.5 - VP16/CfEcR-CDEF: This construct was prepared in the same way as switch 1.1 except the GAL4 DNA binding domain was replaced with the transactivation domain from VP16 ("VP16AD"; SEQ ID NO: 12) and placed under the control of a baculovirus IE1 promoter (SEQ ID NO: 28). Six consensus ecdysone response element binding sites ("6XEcRE"; comprising 6 copies of an ecdysone RE comprising SEQ ID NO: 18) were fused to a synthetic E1b minimal promoter (SEQ ID NO: 24) and placed upstream of the  $\beta$ -galactosidase gene (SEQ ID NO: 29). This construct uses endogenous ultraspiracle protein as a heterodimerization partner.

1.6 - VP16/A110PmutantCfEcR-CDEF: This construct was prepared in the same way as in switch 1.5 above except wild-type CfEcR-CDEF was replaced with a mutant CfEcR-CDEF comprising a ligand binding domain comprising an A110P substitution mutation as described in Table 1 above.

1.7 - Bacterially expressed CfUSP-A/BCDEF: This construct was prepared with the A/BCDEF domains from spruce budworm *C. fumiferana* USP ("CfUSP-A/BCDEF"; SEQ ID NO: 30).

1.8 - GAL4/DmEcR-CDEF/VP16LmUSP-EF: The wild-type C, D, E, and F domains from fruit fly *Drosophila melanogaster* EcR ("DmEcR-CDEF"; SEQ ID NO: 31) were fused to a GAL4 DNA binding domain ("Gal4DNABD" or "Gal4DBD"; SEQ ID NO: 6) and placed under the control of an SV40e promoter (SEQ ID NO: 22). The E and F domains from locust *Locusta migratoria* ultraspiracle protein ("LmUSP-EF"; SEQ ID NO: 23) were fused to the transactivation domain from VP16 ("VP16AD"; SEQ ID NO: 12) and placed under the control of an SV40e promoter (SEQ ID NO: 22). Five consensus GAL4 response element binding sites ("5XGAL4RE"; comprising 5 copies of a GAL4RE comprising SEQ ID NO: 19) were fused to a synthetic E1b minimal promoter (SEQ ID NO: 24) and placed upstream of the luciferase gene (SEQ ID NO: 25).

1.9 - GAL4/mutantDmEcR-CDEF/VP16LmUSP-EF: This construct was prepared in the same way as in switch 1.8 above except wild-type DmEcR-CDEF was replaced with mutant DmEcR-CDEF comprising a ligand binding domain comprising a substitution mutation selected from Table 2 below.

Table 2. Substitution Mutants of *Drosophila melanogaster* Ecdysone Receptor ("DmEcR") Ligand Binding Domain (LBD).

DmEcR-CDEF LBD Mutation	Resulting "WT to Mutant" Amino Acid Substitution	Corresponding amino acid in full length DmEcR (SEQ ID NO: 32)
A107P	Alanine (A) to Proline (P)	522
G121R	Glycine (G) to Arginine (R)	536
G121L	Glycine (G) to Leucine (L)	536
N213A	Asparagine (N) to Alanine (A)	628
C217A	Cysteine (C) to Alanine (A)	632
C217S	Cysteine (C) to Serine (S)	632

30

1.10 - VP16/DmEcR-CDEF: This construct was prepared in the same way as switch 1.8 except the

GAL4 DNA binding domain was replaced with the transactivation domain from VP16 ("VP16AD"; SEQ ID NO: 12) and placed under the control of a baculovirus IE1 promoter (SEQ ID NO: 28). Six consensus ecdysone response element binding sites ("6XEERE"; comprising 6 copies of an ecdysone RE comprising SEQ ID NO: 18) were fused to a synthetic E1b minimal promoter (SEQ ID NO: 24) and placed upstream of the  $\beta$ -galactosidase gene (SEQ ID NO: 29). This construct uses endogenous ultraspiracle protein as a heterodimerization partner.

**1.11 - VP16/mutantDmEcR-CDEF:** This construct was prepared in the same way as in switch 1.10 above except wild-type DmEcR-CDEF was replaced with a mutant DmEcR-CDEF comprising a ligand binding domain comprising a substitution mutation selected from Table 2 above.

**1.12 - GAL4/AmaEcR-DEF/VP16/LmUSP-EF:** The wild-type D, E, and F domains from ixodid tick *Amblyomma americanum* EcR ("AmaEcR-DEF"; SEQ ID NO: 33) were fused to a GAL4 DNA binding domain ("Gal4DNABD" or "Gal4DBD"; SEQ ID NO: 6) and placed under the control of an SV40c promoter (SEQ ID NO: 22). The E and F domains from locust *Locusta migratoria* ultraspiracle protein ("LmUSP-EF"; SEQ ID NO: 23) were fused to the transactivation domain from VP16 ("VP16AD"; SEQ ID NO: 12) and placed under the control of an SV40c promoter (SEQ ID NO: 22). Five consensus GAL4 response element binding sites ("5XGAL4RE"; comprising 5 copies of a GAL4RE comprising SEQ ID NO: 19) were fused to a synthetic E1b minimal promoter (SEQ ID NO: 24) and placed upstream of the luciferase gene (SEQ ID NO: 25).

**1.13 - GAL4/mutantAmaEcR-DEF/VP16/LmUSP-EF:** This construct was prepared in the same way as in switch 1.12 above except wild-type AmaEcR-DEF was replaced with mutant AmaEcR-DEF comprising a ligand binding domain comprising a substitution mutation selected from Table 3 below.

**Table 3. Substitution Mutants of *Amblyomma americanum* Ecdysone Receptor ("AmaEcR") Ligand Binding Domain (LBD).**

AmaEcR-DEF LBD Mutation	Resulting "WT to Mutant" Amino Acid Substitution	Corresponding amino acid in full length AmaEcR (SEQ ID NO: 34)
G99A	Glycine (G) to Alanine (A)	417
A113P	Alanine (A) to Proline (P)	431

**Construction of Ecdysone Receptor Ligand Binding Domains Comprising a Substitution Mutation:**

In an effort to modify EcR ligand binding, residues within the EcR ligand binding domains that were predicted to be important for ligand binding based upon a molecular modeling analysis were mutated in EcRs from three different classes of organisms. Tables 1-3 indicate the amino acid residues within the ligand binding domain of CfEcR (Lepidopteran EcR), DmEcR (Dipteran EcR) and AmaEcR (Arthropod EcR), respectively that were mutated and examined for modification of steroid and non-steroid binding.

Each one of the amino acid substitution mutations listed in Tables 1-3 was constructed in an EcR cDNA by PCR mediated site-directed mutagenesis to alanine (or to proline or phenylalanine in the case

of a wild-type alanine residue, e.g. CfEcR residues A110 and A123, respectively). Amino acids T52, V96 and A110 of CfEcR were mutated to four different amino acids. Five different double point mutant CfEcRs were also made: one comprising both the R95A and A110P substitutions (R95A + A110P, "DM"), a second comprising both the M218A and C219A substitutions (M218A + C219A), a third 5 comprising both the V107I and R175E substitutions (V107I + R175E), a fourth comprising Y127E and R175E substitutions (Y127E + R175E), and a fifth comprising V107I and Y127E substitutions (V107I + Y127E). Six different triple point mutant CfEcRs were also made: one comprising both the V107I and R175E substitutions and a Y127E substitution (V107I + R175E + Y127E), a second comprising a T52V substitution and the V107I and R175E substitutions (T52V + V107I + R175E), a third comprising the 10 V96A, V107I, and R175E substitutions (V96A + V107I + R175E), a fourth comprising the T52A, V107I and R175E substitutions (T52A + V107I + R175E), a fifth comprising a V96T substitution and the V107I and R175E substitutions (V96T + V107I + R175E), and a sixth comprising the A110P, V107I, and R175E substitutions.

PCR site-directed mutagenesis was performed using the Quikchange site-directed mutagenesis 15 kit (Stratagene, La Jolla, CA) using the reaction conditions and cycling parameters as follows. PCR site-directed mutagenesis was performed using 1x reaction buffer (supplied by manufacturer), 50 ng of dsDNA template, 125ng of forward primer (FP), 125ng of reverse complementary primer (RCP), and 1 µl of dNTP mix (supplied by manufacturer) in a final reaction volume of 50 µL. The forward primer and reverse complementary primer used to produce each EcR mutant are presented in Tables 4-6. The 20 cycling parameters used consisted of one cycle of denaturing at 95°C for 30 seconds, followed by 16 cycles of denaturing at 95°C for 30 seconds, annealing at 55°C for 1 minute, and extending at 68°C for 22 minutes.

**Table 4: PCR Primers for Substitution Mutant CfEcR Ligand Binding Domain Construction**

MUTANT	PRIMER (SEQ ID NO:)	PRIMER NUCLEOTIDE SEQUENCE (5' TO 3')
E20A	FP (SEQ ID NO: 35)	gtaccaggacgggtacgcgcagccttctgatgaagattg
E20A	RCP (SEQ ID NO: 36)	caaatctcatcagaaggctgcgcgtacccgtcctgtac
Q21A	FP (SEQ ID NO: 37)	ccaggacgggtacgagcgccttctgatgaagattg
Q21A	RCP (SEQ ID NO: 38)	caaatctcatcagaaggcgcctcgtacccgtcctgg
F48A	FP (SEQ ID NO: 39)	gagtctgacactcccggccagatcacag
F48A	RCP (SEQ ID NO: 40)	ctgtgatctggcggcgggagtgacagctc
I51A	FP (SEQ ID NO: 41)	cactccctccgcccagccacagatgac
I51A	RCP (SEQ ID NO: 42)	gtcatctctgtggcctggcgggaaggagtg
T52A	FP	cactccctccgcccagatcgagatgac

	(SEQ ID NO: 43)	
T52A	RCP (SEQ ID NO: 44)	gtcatctctgcgatctggcggaaggagtg
T55A	FP (SEQ ID NO: 45)	cgccagatcacagagatggctatcctcacggtcc
T55A	RCP (SEQ ID NO: 46)	ggaccgtgaggatagccatctctgtgatctggcg
T58A	FP (SEQ ID NO: 47)	gagatgactatcctcgcggtccaacttatcgtg
T58A	RCP (SEQ ID NO: 48)	cacgataagttggaccgcgaggatgcatctc
V59A	FP (SEQ ID NO: 49)	gatgactatcctcacggccaacttatcgtgg
V59A	RCP (SEQ ID NO: 50)	ccacgataagttggccggtgaggatagtcac
L61A	FP (SEQ ID NO: 51)	ctatcctcacggtccaagctatcgtggagttcgcg
L61A	RCP (SEQ ID NO: 52)	cgcgaactccacgatagcttggaccgtgaggatag
I62A	FP (SEQ ID NO: 53)	ctatcctcacggtccaacttgcggtggagttcgcg
I62A	RCP (SEQ ID NO: 54)	cgcgaactccacggcaagttggaccgtgaggatag
M92A	FP (SEQ ID NO: 55)	gctcaagtgaggtagcgtatcctccgagtcgc
M92A	RCP (SEQ ID NO: 56)	gcgactcggagcatcgtacctcacttgagc
M93A	FP (SEQ ID NO: 57)	gctcaagtgaggtaatggcgtccgagtcgc
M93A	RCP (SEQ ID NO: 58)	gcgactcggagcgcattacctcacttgagc
V96A	FP (SEQ ID NO: 59)	gtaatgatgctccgagccgcggaagatac
V96A	RCP (SEQ ID NO: 60)	gtatcgtcgcgcgctcggagcatcattac
R95A	FP (SEQ ID NO: 61)	gtgaggtaatgatgctcgcagtcgcccagcagatac
R95A	RCP (SEQ ID NO: 62)	cgtatcgtcgcgactcgcgagcatcattacctcac
F108A	FP (SEQ ID NO: 63)	cagacagtgttctggccgcgaacaaccaagcg
F108A	RCP (SEQ ID NO: 64)	cgcttggttgtcgcggccagaacactgtctg
F109A	FP (SEQ ID NO: 65)	tcagacagtgttctggccgcgaacaaccaagcg
F109A	RCP (SEQ ID NO: 66)	cgcttggttgtcgcggccagaacactgtctga
A110P	FP (SEQ ID NO: 67)	cagacagtgttctgtcccgaacaaccaagcg
A110P	RCP (SEQ ID NO: 68)	cgcttggttgtcgggaacagaacactgtctg
Y120A	FP (SEQ ID NO: 69)	cactcgcgacaacgcccaaggctggcatg
Y120A	RCP	catgccagccttgcggcggttctcgcgagtg

	(SEQ ID NO: 70)	
A123F	FP (SEQ ID NO: 71)	cgacaactaccgcaagtttggcatggcctacgtc
A123F	RCP (SEQ ID NO: 72)	gacgtaggccatgccaaacttgcggtagtgtgctg
M125A	FP (SEQ ID NO: 73)	ctaccgcaaggctggcgcggcctacgtcctc
M125A	RCP (SEQ ID NO: 74)	gatgacgtaggccgcgccagccttgcggtag
L230A	FP (SEQ ID NO: 75)	gtcaagaacagaaaggcggcctttcctcg
L230A	RCP (SEQ ID NO: 76)	cgaggaaaaggcggcggcctttctgttctgagc
L223A	FP (SEQ ID NO: 77)	ctccaacatgtgcatctccgccaagctcaagaacag
L223A	RCP (SEQ ID NO: 78)	ctgttcttgagcttggcggagatgcacatgttgag
L234A	FP (SEQ ID NO: 79)	gaaagctgccgctttccggaggagatctg
L234A	RCP (SEQ ID NO: 80)	cagatctctcggcgaaaggcggcagcttctc
W238A	FP (SEQ ID NO: 81)	cttctctgaggagatcgggatgtggcagg
W238A	RCP (SEQ ID NO: 82)	cctgccacatccgcatctcctcgaggaaaag
A110n	RANDOM FP (SEQ ID NO: 83)	cagacagtgttctgttgncaacaaccaagcg
A110n	RANDOM RCP (SEQ ID NO: 84)	cgcttggtgttcgncaacagaacactgtctg
A110n	RANDOM2 FP (SEQ ID NO: 85)	cagacagtgttctgttgnngaacaaccaagcg
A110n	RANDOM2 RCP (SEQ ID NO: 86)	cgcttggtgttcnnaacagaacactgtctg
T52n	RANDOM FP (SEQ ID NO: 87)	cactccctccgccagatcnngagatgactatcctcag
T52n	RANDOM RCP (SEQ ID NO: 88)	cgtgaggatagtcctcnnngatctggcggaggaggat
V96n	RANDOM FP (SEQ ID NO: 89)	gtaatgatgctccgannngcgcgacgalacgatcggc
V96n	RANDOM RCP (SEQ ID NO: 90)	gccgcatcgtatcgtcgcgnntcggagcattac
V107I	FP (SEQ ID NO: 107)	gcggcctcagacagtattctgttcggaac
R175E	FP (SEQ ID NO: 108)	ggtggaagaaatccaggagtactacctgaatagctcc
Y127E	FP (SEQ ID NO: 109)	caaggctggcatggccgaggtcctcagg
T52V	FP (SEQ ID NO: 110)	cccttccgccagatcgtagagatgactatcctcag

V96T	FP (SEQ ID NO: 111)	ggtaatgatgclccgaaccgcgacgatacg
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Table 5: PCR Primers for Substitution Mutant DmEcR Ligand Binding Domain Construction

MUTANT	PRIMER (SEQ ID NO: )	PRIMER NUCLEOTIDE SEQUENCE (5' TO 3')
A107P	FP (SEQ ID NO: 91)	lccgactcaatattcttcccgaataatagaicatatc
A107P	RCP (SEQ ID NO: 92)	gtatatgatctattattcgggaagaatattgagtcgca
G121R	FP (SEQ ID NO: 93)	tcttcaaaatggcccgaatggctgataacattg
G121R	RCP (SEQ ID NO: 94)	caatggtatcagccattcgggccatttgtaaga
G121L	FP (SEQ ID NO: 95)	tcttcaaaatggccctaattggctgataacattg
G121L	RCP (SEQ ID NO: 96)	caatggtatcagccattagggccatttgtaaga
N213A	FP (SEQ ID NO: 97)	acgctgggcaaccaggccgccgagatgtgttc
N213A	RCP (SEQ ID NO: 98)	gaaacacatctcggcgccctggtgccagcgt
C217A	FP (SEQ ID NO: 99)	cagaacgccgagatggctttctcactaaagctc
C217A	RCP (SEQ ID NO: 100)	gagctttagtggaaagccatctcggcgttcg
C217S	FP (SEQ ID NO: 101)	cagaacgccgagatgtctttctcactaaagctc
C217S	RCP (SEQ ID NO: 102)	gagctttagtggaaagacatctcggcgttcg

5

Table 6: PCR Primers for Substitution Mutant AmaEcR Ligand Binding Domain Construction

MUTANT	PRIMER (SEQ ID NO: )	PRIMER NUCLEOTIDE SEQUENCE (5' TO 3')
G91A	FP (SEQ ID NO: 103)	gtgatgatgctgagagctgccggaaatgatg
G91A	RCP (SEQ ID NO: 104)	catcatattccggcagctctcagcatcatcac
A105P	FP (SEQ ID NO: 105)	acagattctatagtgttccaataaccagccgtacac
A105P	RCP (SEQ ID NO: 106)	gtgtacggctggttattgggaacactatagaatctgt

The resulting PCR nucleic acid products encoding the mutant EcR ligand binding domains were then each fused to a GAL4 DNA binding domain as described in Examples 1.2, 1.4, 1.9 and 1.13 above. The GAL4/mutant EcR receptor constructs were tested for activity by transfecting them into NIH3T3

cells along with VP16/LmUSP-EF and pFRLuc in the presence of steroid or non-steroid ligand.

The resulting nucleic acids encoding the mutant EcR ligand binding domains were also each fused to a VP16 transactivation domain as described in Examples 1.6 and 1.11 above. The VP16/mutant CfEcR-DEF and VP16/mutant DmEcR-CDEF receptor constructs were tested for activity by transfecting  
5 them into L57 insect cells along with a 6XEcRE/ $\beta$ -galactosidase reporter gene in the presence of 20-hydroxyecdysone (20E).

**Ligands:** The steroidal ligands muristerone A, ponasterone A,  $\alpha$ -ecdysone, and 20-hydroxyecdysone were purchased from Sigma Chemical Company and Invitrogen. The non-steroidal ligands: N-(2-ethyl-3-methoxybenzoyl)-N'-(3,5-dimethylbenzoyl)-N'-tert-butylhydrazine (GS<sup>TM</sup>-E non-steroidal ligand); N'-  
10 tert-butyl-N'-(3,5-dimethylbenzoyl)-3-methoxy-2-methylbenzohydrazide (RH-2485); N-tert-butyl-N'-(4-ethylbenzoyl)-3,5-dimethylbenzohydrazide (RH-5992), and N'-tert-butyl-N'-(3,5-dimethylbenzoyl)-3,4-(1,2-ethylenedioxy)-2-methylbenzohydrazide (RH-125020) are synthetic stable ecdysteroid ligands synthesized at Rohm and Haas Company. All ligands were dissolved in DMSO and the final concentration of DMSO was maintained at 0.1% in both controls and treatments. <sup>3</sup>H-PonA and <sup>3</sup>H- $\alpha$ -  
15 ecdysone were purchased from New England Nuclear. <sup>3</sup>H-RH2485 was synthesized at Rohm and Haas Company.

**Transfections:** DNAs corresponding to the various switch constructs outlined in Example 1, specifically switches 1.1-1.13, were transfected into mouse NIH3T3 cells (ATCC) or L57 cells (Dr. Peter Cherbas; Indiana University) as follows. Standard methods for culture and maintenance of the cells were  
20 followed. Cells were harvested when they reached 50% confluency and plated in 6-, 12- or 24- well plates at 125,000, 50,000, or 25,000 cells, respectively, in 2.5, 1.0, or 0.5 ml of growth medium containing 10% fetal bovine serum (FBS), respectively. The next day, the cells were rinsed with growth medium and transfected for four hours. Superfect<sup>TM</sup> (Qiagen Inc.) was used for 3T3 cells and Lipofectamine<sup>TM</sup> (Life Technologies) was used for L57 cells as the transfection reagents. For 12- well  
25 plates, 4  $\mu$ l of Superfect<sup>TM</sup> or Lipofectamine<sup>TM</sup> was mixed with 100  $\mu$ l of growth medium. One  $\mu$ g of reporter construct and 0.25  $\mu$ g of each receptor construct of the receptor pair to be analyzed were added to the transfection mix. A second reporter construct was added [pTKRL (Promega), 0.1  $\mu$ g/transfection mix] that comprises a *Renilla* luciferase gene operably linked and placed under the control of a thymidine kinase (TK) constitutive promoter and was used for normalization. The contents of the  
30 transfection mix were mixed in a vortex mixer and let stand at room temperature for 30 minutes. At the end of incubation, the transfection mix was added to the cells maintained in 400  $\mu$ l growth medium. The cells were maintained at 37°C and 5% CO<sub>2</sub> for four hours. At the end of incubation, 500  $\mu$ l of growth medium containing 20% FBS and either dimethylsulfoxide (DMSO; control) or a DMSO solution of steroidal or non-steroidal ligand was added and the cells were maintained at 37°C and 5% CO<sub>2</sub> for 48  
35 hours. The cells were harvested and reporter activity was assayed. The same procedure was followed for 6 and 24 well plates as well except all the reagents were doubled for 6 well plates and reduced to half for 24-well plates.

**Reporter Assays:** Cells were harvested 40 hours after adding ligands. 125  $\mu$ l of passive lysis buffer (part of Dual-luciferase™ reporter assay system from Promega Corporation) were added to each well of the 24-well plate. The plates were placed on a rotary shaker for 15 minutes. Twenty  $\mu$ l of lysate were assayed. Luciferase activity was measured using Dual-luciferase™ reporter assay system from Promega Corporation following the manufacturer's instructions.  $\beta$ -Galactosidase was measured using Galacto-Star™ assay kit from TROPIX following the manufacturer's instructions. All luciferase and  $\beta$ -galactosidase activities were normalized using *Renilla* luciferase as a standard. Fold activities were calculated by dividing normalized relative light units ("RLU") in ligand treated cells with normalized RLU in DMSO treated cells (untreated control).

10

## EXAMPLE 2

This Example describes the identification of improved non-steroid responsive CfEcR ligand binding domain substitution mutants that exhibit increased activity in response to non-steroidal ligand and decreased activity in response to steroidal ligand. Briefly, Applicants mutated amino acid residues predicted to be critical for ecdysteroid binding into alanine and created GAL4/mutantCfEcR-DEF cDNA gene expression cassettes as described in Example 1 above using the Quikchange PCR-mediated site-directed mutagenesis kit (Stratagene, La Jolla, CA). The mutated and the WT cDNAs were tested in GAL4-driven luciferase reporter assays.

20 **Transfections:** DNAs corresponding to the various switch constructs outlined in Example 1, specifically switches 1.1-1.2, were transfected into mouse NIH3T3 cells (ATCC) as follows. Cells were harvested when they reached 50% confluency and plated in 24 well plates at 12,500 cells/well in 0.5 ml of growth medium containing 10% fetal bovine serum (FBS). The next day, the cells were rinsed with growth medium and transfected for four hours. Superfect™ (Qiagen Inc.) was found to be the best transfection reagent for 3T3 cells. Two  $\mu$ l of Superfect™ was mixed with 100  $\mu$ l of growth medium and 50 ng of either GAL4/wild-type EcR or Gal4/mutant EcR cassette, 50 ng of VP16/LmUSP-EF and 200 ng of pFRLuc were added to the transfection mix. A second reporter construct was added [pTKRL (Promega), 0.05  $\mu$ g/transfection mix] that comprises a *Renilla* luciferase gene operably linked and placed under the control of a thymidine kinase (TK) constitutive promoter and was used for normalization. The contents of the transfection mix were mixed in a vortex mixer and let stand at room temperature for 30 min. At the end of incubation, the transfection mix was added to the cells maintained in 200  $\mu$ l growth medium. The cells were maintained at 37°C and 5% CO<sub>2</sub> for four hours. At the end of incubation, 250  $\mu$ l of growth medium containing 20% FBS and either dimethylsulfoxide (DMSO; control) or a DMSO solution of 10 nM or 2.5  $\mu$ M PonA steroidal ligand or GS™-E [N-(2-ethyl-3-methoxybenzoyl)-N'-(3,5-dimethylbenzoyl)-N'-tert-butylhydrazine] non-steroidal ligand was added and the cells were maintained at 37 °C and 5% CO<sub>2</sub> for 40 hours. The cells were harvested and reporter activity was assayed as described above. Fold activities were calculated by dividing normalized relative light units ("RLU") in

ligand treated cells with normalized RLU in DMSO treated cells (untreated control).

Two amino acid residues were identified that, when substituted, yield a mutant ecdysone receptor that exhibits increased activity in response to a non-steroid ligand and decreased activity in response to a steroid ligand. The effect of alanine substitution at amino acid residue 52 or 55 of SEQ ID NO: 1 on the activity of the mutated CfEcR-DEF receptor is presented in Table 7 as a fold increase over Gal4/wild-type CfEcR-DEF (WT) switch activity.

Table 7. CfEcR-DEF Mutants that show increased non-steroid activity and decreased steroid activity

Fold increase over WT		
MUTANTS	2.5 $\mu$ M GST <sup>TM</sup> -E	2.5 $\mu$ M PonA
T52A	1.5	0.5
T55A	1.7	0.13

10

### EXAMPLE 3

This Example describes the identification of steroid responsive CfEcR ligand binding domain substitution mutants that exhibit increased activity in response to steroidal ligand and significantly decreased activity in response to non-steroidal ligand. In an effort to identify substitution mutations in the CfEcR that increase steroidal ligand activity, but decrease non-steroidal ligand activity, Applicants mutated amino acid residues predicted to be critical for ecdysteroid binding and created GAL4/mutantCfEcR-DEF cDNA gene expression cassettes as described in Example 1 above using PCR-mediated site-directed mutagenesis kit. The mutated and the WT cDNAs corresponding to the various switch constructs outlined above in Examples 1.1 and 1.2 were made and tested in GAL4-driven luciferase reporter assays as described in Example 2 above. Fold activity was calculated by dividing RLU's in the presence of ligand with RLU's in the absence of the ligand.

Specific amino acid residues were identified that, when substituted, yield a mutant ecdysone receptor that exhibits increased activity in response to a steroid ligand and decreased activity in response to a non-steroid ligand. The effect of an amino acid substitution at amino acid residue 52 or 96 of SEQ ID NO: 1 and amino acid substitution at amino acid residues 96, 107 and 175 of SEQ ID NO: 1 on the activity of the mutated CfEcR-DEF receptor is presented in Table 8 as a fold increase over Gal4/wild-type CfEcR-DEF (WT) switch activity.

20

Table 8. Mutants that show increased steroid and decreased non-steroid activity

Fold increase over WT				
MUTANTS	2.5 $\mu$ M GST <sup>TM</sup> E	2.5 $\mu$ M PonA	10 nM GST <sup>TM</sup> E	10 nM PonA
T52L	0.26	3.4		
V96A	0.35	408		
V96T	0.018	45		
V96T/V107I/R175E			0.4	485.7

#### EXAMPLE 4

This Example describes the identification of improved steroid and non-steroid responsive CfEcR ligand binding domain substitution mutants that exhibit increased activity in response to both a steroidal ligand and a non-steroidal ligand. In an effort to identify substitution mutations in the CfEcR that increase both steroidal and non-steroidal ligand activity, Applicants mutated amino acid residues predicted to be critical for steroid binding and created GAL4/mutantCfEcR-DEF cDNA gene expression cassettes as described in Example 1 above using PCR-mediated site-directed mutagenesis. The mutated and the WT cDNAs corresponding to the various switch constructs outlined above in Examples 1.1 and 1.2 were made and tested in GAL4-driven luciferase reporter assays as described in Example 2 above. Fold activity was calculated by dividing RLU's in the presence of ligand with RLU's in the absence of the ligand.

Specific amino acid residues were identified that, when substituted, yield a mutant ecdysone receptor that exhibits increased activity in response to both non-steroid and steroid ligands. The effect of an amino acid substitution at amino acid residue 52, 96, 107 or 175 of SEQ ID NO: 1, amino acid substitution at amino acid residues 107 and 175 of SEQ ID NO: 1, amino acid substitution at amino acid residues 127 and 175 of SEQ ID NO: 1, amino acid substitution at amino acid residues 107 and 127 of SEQ ID NO: 1, amino acid substitution at amino acid residues 107, 127 and 175 of SEQ ID NO: 1, amino acid substitution at amino acid residues 52, 107 and 175 of SEQ ID NO: 1 or amino acid substitution at amino acid residues 96, 107 and 175 of SEQ ID NO: 1 on the activity of the mutated CfEcR-DEF receptor is presented in Table 9 as a fold increase over Gal4/wild-type CfEcR-DEF (WT) switch activity.

Table 9. Mutants that show increased steroid and non-steroid activity

Fold increase over WT				
MUTANTS	2.5 $\mu$ M GST <sup>ME</sup>	2.5 $\mu$ M PonA	10 nM GST <sup>ME</sup>	10 nM PonA
T52V	17.3	35.7		
T52I	8	8		
V96D	3.07	3.1		
V96M	122	3.37		
✓ V107I			12.4	26.6
✓ R175E			22.0	11.3
✓ V107I/R175E			386.4	1194.4
✓ Y127E/R175E			622.8	42.2
✓ V107I/Y127E			314.6	35.8
V107I/Y127E/R175E			124.3	122.3
T52V/V107I/R175E			62.8	136.6
V96A/V107I/R175E			21.1	1005.1
T52A/V107I/R175E			2.3	20.3

25

#### EXAMPLE 5

This Example describes the identification of non-steroid responsive CfEcR ligand binding domain substitution mutants that exhibit significantly decreased activity in response to steroidal ligand but do not affect activity in response to non-steroidal ligand. In an effort to identify substitution mutations in the CfEcR that decrease steroidal ligand activity, but do not affect non-steroidal ligand activity, Applicants mutated amino acid residues predicted to be critical for ecdysteroid binding and created GAL4/mutantCfEcR-DEF cDNA gene expression cassettes as described in Example 1 above using PCR-mediated site-directed mutagenesis. The mutated and the WT cDNAs corresponding to the various switch constructs outlined above in Examples 1.1 and 1.2 were made and tested in GAL4-driven luciferase reporter assays as described in Example 2 above. Fold activity was calculated by dividing RLU in the presence of ligand with RLU in the absence of the ligand.

Four amino acid residues were identified that, when substituted, yield mutant ecdysone receptor that exhibit decreased activity in response to a steroid ligand and minimal effect on activity in response to a non-steroid ligand. The effect of an amino acid substitution at amino acid residue 20, 58, 92, or 110 of SEQ ID NO: 1 on the activity of the mutated CfEcR-DEF receptor is presented in Table 10 as a fold increase over Gal4/wild-type CfEcR-DEF (WT) switch activity.

Table 10. Mutants that show decreased steroid activity, but non-steroid activity is unaffected

Fold increase over WT

MUTANTS	2.5 $\mu$ M GST <sup>ME</sup>	2.5 $\mu$ M PonA
E20A	0.9	0.35
T58A	0.8	0.008
M92A	0.7	0.39
A110P	0.8	0.005

As described in Table 10, Applicants have identified point mutations in the ligand binding domain of CfEcR that significantly reduce steroid binding activity. CfEcR point mutants T58A and A110P essentially eliminated steroid binding activity. Interestingly, the non-steroid activity of these point mutants was not significantly affected.

#### 25 EXAMPLE 6

Applicants have further characterized the non-steroid A110P CfEcR receptor identified in Example 5 above. This Example demonstrates that the mutation of a critical alanine residue (A110) leads to the disruption of steroid binding and hence transactivation by the EcR in the presence of steroids. However, the binding as well as transactivation by non-steroids is not impaired.

#### Ligand Binding Assay

Applicants tested the A110P mutant CfEcR receptor in a steroid and non-steroid ligand binding assay to confirm that steroid binding was eliminated. Briefly, PonA binding activity was determined

using an *in vitro* ligand binding assay (LBA). Steroid ligand binding assay (LBA) was performed using <sup>3</sup>H-PonA (200 Ci/mmol). *In vitro* translated Gal4/wild-type or A110P mutant CfEcR-DEF and bacterial expressed GST-CfUSP-A/BCDEF were used in the assay. The assay was performed with 8 μL of Gal4/wild-type or A110P mutant CfEcR-DEF, 2.5 μL of GST-CfUSP-A/BCDEF, 1 μL of <sup>3</sup>H-PonA, and 2 μL of unlabeled (“cold”) PonA as competitor in the presence of T buffer [90 mM Tris pH 8.0, 10 μM DTT comprising Complete™ protease inhibitor cocktail used according to the manufacturer’s instructions (Boehringer Mannheim)]. The reaction was carried out at room temperature for 1 hour followed by the addition of dextran-coated charcoal (Sigma). The mixture was centrifuged at 7000xg for 10 minutes the amount of <sup>3</sup>H-PonA in the supernatant was measured. The reactions were done in triplicate. The full-length WT EcR or its A110P mutant were also *in vitro* translated and transcribed using the TNT system (Promega) according to the manufacturer’s instructions and tested in *in vitro* ligand binding assays using <sup>3</sup>H-RH2485, with cold 20E or non-steroids (RH2485 and GS™-E) as competitors. In addition, 5 μL of the *in vitro* translations were assayed for translation efficiency using SDS-PAGE following standard methods (Maniatis, 1989). The ligand binding results for both the wild-type and A110P mutant CfEcR-DEF receptors were calculated and are shown in Figure 1.

The two non-steroid ligands, RH2485 and GS™-E, and the steroid ligand 20E tested were able to effectively compete with bound <sup>3</sup>H-RH2485 suggesting that they are able to bind the WT full-length EcR efficiently (see Figure 1). However, when the binding of the same ligands by the A110P mutant was examined, binding of the steroid 20E was completely disrupted but the binding of the non-steroids was unaffected (see Figure 1). These results indicate that the lack of steroid binding in the case of the GAL4CfEcR fusion protein is not an artifact of the truncation or fusion and demonstrates that the A110P mutant CfEcR is a selective non-steroid receptor.

**Ligand Affinities of mutant A110P CfEcR to various steroid and non-steroid ligands :** The ligand binding affinities of the A110P GAL4/CfEcR mutant were measured by binding <sup>3</sup>H-RH2485 and competing it with different concentrations of cold steroids or non-steroids. Briefly, <sup>3</sup>H-RH2485 was bound to *in vitro* translated full-length CfEcR and bacterially expressed CfUSP and competed with increasing concentrations of cold steroidal or non-steroidal ligands. The reaction was carried out at room temperature for 1 hour followed by addition of activated dextran coated charcoal and centrifugation at 7000xg for 10 minutes at 4°C. The residual <sup>3</sup>H-RH2485 in the supernatant after centrifugation was measured using a scintillation counter. The fraction bound (f bound) values were determined and plotted against the concentration of ligand (in mM). The IC50 values were determined for each of the steroid PonA and MurA and non-steroid N-(2-ethyl-3-methoxybenzoyl)-N’-(3,5-dimethylbenzoyl)-N’-tert-butylhydrazine (GS™-E non-steroidal ligand); N’-tert-butyl-N’-(3,5-dimethylbenzoyl)-3-methoxy-2-methylbenzohydrazide (RH-2485); N-tert-butyl-N’-(4-ethylbenzoyl)-3,5-dimethylbenzohydrazide (RH-5992), and N’-tert-butyl-N’-(3,5-dimethylbenzoyl)-3,4-(1,2-ethylenedioxy)-2-methylbenzohydrazide (RH-125020) ligands for the WT and the mutant was determined by plotting the fraction bound against the concentration of each ligand.

As shown in Table 11, the IC50 values for steroids PonA and MurA were increased (more than 1 mM) in the case of the A110P mutant compared to the observed nanomolar values for the WT receptor, suggesting that the binding of steroids was impaired in the A110P mutant CfEcR. On the other hand, non-steroid IC50 values were similar for both the A110P mutant and WT receptors (see Table 11).

- 5 These results confirm Applicants' findings presented in Example 5 above that the A110P substitution mutation results in a non-steroid ecdysone receptor ligand binding domain that has lost the ability to bind steroid ligand.

**Table 11.** IC50 values determined for wild-type and A110P mutant CfEcR-A/BCDEF using several  
10 steroidal and non-steroidal ligands.

	Wild-type IC50 (nM)	A110P mutant IC50 (nM)
<b>Steroids:</b>		
Ponasterone A	345.95	> 1mM
Muristerone A	423.99	> 1mM
<b>Non-Steroids:</b>		
GST <sup>TM</sup> -E	85.26	12.88
RH-5992	132.81	322.34
RH-2485	1.80 x 10 <sup>3</sup>	350.42
RH-125020	10.11	25.71

**A110P in Truncated CfEcR or Full Length CfEcR Background**

To eliminate the possibility that the loss of steroid activity may be due to the truncated CfEcR-DEF receptor or an artifact of the GAL4 fusion protein, Applicants introduced the A110P mutation into  
15 the full length (FL) CfEcR (CfEcR-A/BCDEF), fused it to the GAL4 DNA binding domain as described in Example 1.4, and comparatively assayed it in NIH3T3 cells in 24-well plates as described in Example 2 above with full length wild type CfEcR (Example 1.3) in combination with VP16/LmUSP-EF and pFREcRE Luc that comprised the luciferase reporter gene operatively linked to six copies of the ecdysone response element (6X EcRE) and a synthetic TATAA. The transfected cells were grown in the  
20 presence of 0.25 or 10 μM PonA or GST<sup>TM</sup>-E and the reporter activity was measured at 40 hours after adding ligand. The cells were harvested and the extracts were assayed for luciferase activity. The results are presented in Figure 2. The numbers on top of the bars indicate fold increase over DMSO levels.

As shown in Figure 2, the A110P mutation had a similar effect when introduced into the full-length ecdysone receptor in the context of an EcRE-driven reporter gene. Specifically, PonA activity  
25 was completely lost for the full length A110P CfEcR mutant. However, there was no significant difference in non-steroid activity between the full length WT CfEcR and the full-length A110P mutant CfEcR in the presence of GST<sup>TM</sup>-E. These results indicate that the non-responsiveness of the A110P mutant to steroids observed with the GAL4-fusion CfEcR in Example 5 was not an artifact of the GAL4-fusion or truncation of EcR. Thus, Applicants have determined that the A110 amino acid residue is  
30 critical for steroidal activity in the full-length ecdysone receptor.

**A110 residue is critical for steroidal activity in insect cells**

In mammalian cells, the natural ligand of EcR, 20-hydroxyecdysone (20E) does not induce transactivation through a CfEcR-based gene expression system. To determine whether the A110P mutant can respond to 20E, Applicants tested this A110P mutant-based gene expression system in an EcRE-driven reporter assay in insect L57 cells (a *Drosophila melanogaster* cell line that lacks EcR isoform B, the *Drosophila melanogaster* EcR isoform homolog of CfEcR isoform B from which the A110P mutant is derived, however L57 cells still contain EcR isoform A). The mutation was introduced into the VP16/CfEcR-CDEF fusion protein and operably linked to an baculovirus IE1 promoter and L57 cells were transfected with IE1VP16CfEcRCDEF (Example 1.5) or its A110P mutant version DNA (Example 1.6) along with a pMK43.2  $\beta$ -galactosidase reporter gene under the control of 6X ecdysone response elements ("6XEcRE"; the pMK43.2 construct was obtained from Michael Koelle at Stanford University) in 24-well plates. Reporter activity for A110P mutant-based gene expression system transactivation was measured after 40 hours of treatment of the transfected cells with 0, 1, 10, 100, or 1000 nM 20E or GS<sup>TM</sup>-E. The cells were harvested and the extracts were assayed for  $\beta$ -galactosidase ( $\beta$ -gal) and luciferase activity.  $\beta$ -Galactosidase was measured using Galacto-Star<sup>TM</sup> assay kit from TROPIX following the manufacturer's instructions. The numbers on top of the bars indicate fold increase over DMSO levels. The results are presented in Figure 3.

In insect cells, the wild-type CfEcR-based gene expression system induced  $\beta$ -gal activity in a dose dependent manner in response to both 20E and GS<sup>TM</sup>-E, whereas the A110P mutant-based gene expression system transactivated reporter gene expression in the presence of GS<sup>TM</sup>-E, however, the L57 cells transfected with the A110P mutant showed slightly increased reporter gene activity in the presence of 20E (see Figure 3). This low level activity in the presence of 20E is most likely due to endogenous activity of the EcR isoform A within the L57 cells since Applicants have demonstrated that the A110P mutant derived from CfEcR isoform B does not 20E (data not shown).

The A110P mutation had a similar effect when introduced into the full-length receptor in the context of an EcRE-driven reporter gene in the L57 cells indicating that the mutation has an analogous effect in insect cells, presumably in the presence of insect transcriptional co-factors (data not shown). These data confirm Applicants' results from mammalian cells and establish that the A110P mutation results in a drastic effect on the steroidal responsiveness of CfEcR but does not affect the non-steroid responsiveness of CfEcR.

30

#### EXAMPLE 7

Applicants' results presented above in Examples 5 and 6 describe the identification of an alanine residue at position 110 that is a critical residue for steroid but not for non-steroid activity of the CfEcR ligand binding domain. To further characterize the role of residue A110 in CfEcR steroid and non-steroid transactivation of reporter genes, a mini library of CfEcR-DEF receptors was prepared by mutating A110 using degenerate primers. These degenerate PCR primers (A110P random primer pairs

comprising either SEQ ID NO: 83 and SEQ ID NO: 84 or SEQ ID NO: 85 and SEQ ID NO: 86; see Table 4) were designed to replace A110 with various amino acid residues. The PCR mutagenesis conditions used were as described above in Example 1. The resulting clones were sequenced to identify the mutants.

#### 5 Reporter Gene Transactivation of A110 Mutants

Four mutations: A110S, A110P, A110L, and A110M were obtained. These four mutant and wild-type receptors were assayed in NIH3T3 cells. GAL4 fusions of each of the four mutants or wild-type CfEcR-DEF receptor, VP16LmUSP-EF and pFRLUC were transfected into NIH3T3 cells, the cells were grown in the presence of 0, 0.04, 0.2, 1, 5, or 25  $\mu$ M PonA, MurA, N-(2-ethyl-3-methoxybenzoyl)-N'-(3,5-dimethylbenzoyl)-N'-tert-butylhydrazine (GS<sup>TM</sup>-E non-steroidal ligand), or N'-tert-butyl-N'-(3,5-dimethylbenzoyl)-3,4-(1,2-ethylenedioxy)-2-methylbenzohydrazide (RH-125020) for 48 hours and the reporter activity was measured. As shown in Figure 4, the wild-type ecdysone receptor showed reporter activity in the presence of both steroids and non-steroids. However, all mutant receptors showed reporter activity only in the presence of non-steroid ligands but not in the presence of steroid ligands. The A110P mutant exhibited similar non-steroid activity compared to wild-type receptor, however the A110S, A110L and A110M mutants demonstrated lower sensitivity and no detectable transactivation at the two lowest concentrations. These results confirm that an A110 substitution mutant EcR ligand binding domain is characterized by a significantly reduced response to steroids but remains responsive to non-steroids.

**20 Ligand binding by the A110 mutants:** Applicants have performed ligand binding assays using <sup>3</sup>H-PonA or <sup>3</sup>H-RH2485 (N'-tert-butyl-N'-(3,5-dimethylbenzoyl)-3-methoxy-2-methylbenzohydrazide) radioactively-labeled ligands to determine if the differences in ligand response of substitution mutant and wild-type ecdysone receptors are due to differences at the level of ligand binding. The CfEcR wild-type and mutant receptors were *in vitro* transcribed and translated and assayed in the presence of bacterially expressed GST-CfUSP-A/BCDEF (full length) PonA binding to A110P mutant was undetectable while other A110 substitution mutants showed 5-10% of wild-type receptor binding (see Figure 5). Wild-type EcR and all mutants tested showed similar binding to RH-2485, a close analog of GS<sup>TM</sup>-E (see Figure 6). It may be that the inflexible proline residue of the A110P mutant hinders binding of steroidal but not non-steroidal ligands.

**30** The *in vitro* translated proteins were analyzed by SDS-PAGE and were found to be translated similar to the WT receptor, indicating that the differences in binding observed between the mutants and wild-type receptor are not due to variation in the amount of proteins present in assay (data not shown). The ligand binding activity correlates with the reporter gene activity in most cases, providing further evidence of Applicants' discovery that the A110 residue plays a critical role in the binding of **35** ecdysteroids, but not non-steroids.

All of the A110 substitution mutants were impaired in steroid binding as well as in their ability to transactivate reporter genes in the presence of steroids in mammalian and insect cells. These mutants

maintained wild-type levels of non-steroid binding and reporter gene transactivation in the presence of non-steroids.

The A110 residue, found adjoining the predicted  $\beta$ -sheet between helix 5 and 6, is highly conserved in EcRs from various species of insects, and in RXR, progesterone receptor (PR) and estrogen receptor (ER) further underlining that this residue is critical for ligand binding and thus transactivation. In addition, residue A110 is flanked by other highly conserved residues, some of which may be also critical for ligand binding and/or transactivation. Close comparison of the three-dimensional structures of nuclear receptors show that there are major structural changes even in the conserved LBD among different nuclear receptors. Important changes are observed not only between different nuclear receptor structures, but also complexes of the same receptor when bound to natural and synthetic ligands as in the case of ER. The binding of steroid and non-steroids may reflect a similar situation. The homology models generated suggest that the binding of the two ligands is different, in terms of the helices involved and contact residues. Close examination of the transactivation assay results suggests that the dose responses are slightly different in the two situations. The steroids are less active at lower concentrations while the non-steroids induced activity is several fold higher. However, at higher doses the steroidal and non-steroidal activities are similar. The higher activity of non-steroids at lower concentrations may reflect higher affinity of the non-steroids to the EcR. It has been suggested that the presence of the tert-butyl group allows some non-steroids to form extensive van der Waals contacts with the EcR LBD and thus fits in a groove that is not occupied by ecdysteroids. This may explain to some extent the differences seen in the activities of the steroids and the non-steroids in reporter gene assays at low ligand concentrations. The mechanism by which binding affects conformational changes and thus transactivation potential is yet unknown. However, in the case of the ER, the binding of agonists and antagonists have been shown to induce different conformational changes resulting in displacement of the helix 12. Helix 12 plays an active role in the recruitment and interaction of coactivators to the receptor. In the case of agonists like diethylstilbestrol (DES), coactivator GRIP1 binds to a hydrophobic groove on the surface of the LBD formed by helices 3, 4, 5, and 12 and the turn between helices 3 and 4. On the other hand, in the presence a partial antagonist, 4-hydroxytamoxifen (OHT), helix 12 blocks the coactivator recognition groove by mimicking the interactions of GRIP NR box with the LBD. The binding of steroid and the non-steroids could also induce subtle conformational changes which affects coactivator recruitment and thus transactivation.

The A110 residue appears to interact with the side chain of the steroid ligand. The introduction of bulkier or inflexible residues in this position would potentially disrupt these interactions and thus docking of the ligand to the LBD. This in turn results in non-activation of the EcR. The identification of a mutant that results in disruption of ecdysteroid binding without affecting non-ecdysteroid binding and activation provides a means for systematic evolution of the EcR to develop an ecdysone inducible system that can be precisely regulated for use in mammalian systems.

### EXAMPLE 8

This Example describes the identification of CfEcR ligand binding domain substitution mutants that exhibit decreased activity in response to both a steroidal ligand and a non-steroidal ligand. These substitution mutants are useful in ligand screening assays for orthogonal ligand identification. In an effort to identify substitution mutations in the CfEcR that decrease both steroidal and non-steroidal ligand activity, Applicants mutated amino acid residues predicted to be critical for ecdysteroid binding and created GAL4/mutantCfEcR-DEF cDNA gene expression cassettes as described in Example 1 above using PCR-mediated site-directed mutagenesis. The mutated and the WT cDNAs corresponding to the various switch constructs outlined above in Examples 1.1 and 1.2 were made and tested in GAL4-driven luciferase reporter assays as described in Example 2 above. Fold activity was calculated by dividing RLU<sub>s</sub> in the presence of ligand with RLU<sub>s</sub> in the absence of the ligand.

Seventeen amino acid residues were identified that, when substituted, yield a mutant ecdysone receptor that exhibits decreased activity in response to both non-steroid and steroid ligands. The effect of an amino acid substitution at amino acid residue 21, 48, 51, 59, 62, 93, 95, 109, 120, 123, 125, 218, 219, 223, 230, 234, or 238 of SEQ ID NO: 1 on the activity of the mutated CfEcR-DEF receptor is presented in Table 12 as a fold increase over Gal4/wild-type CfEcR-DEF (WT) switch activity. In addition, two double mutants (R95A/A110P and M218A/C219A) and one triple mutant (V107I/A110P/R175E) were made and were also identified as mutated CfEcR-DEF receptors that exhibit decreased activity in response to both non-steroid and steroid ligands (see Table 12).

**Table 12.** Mutants that show decreased steroid and non-steroid activity  
Fold increase over WT

MUTANTS	2.5 $\mu$ M GST <sup>TM</sup> -E	2.5 $\mu$ M PonA	10 nM GST <sup>TM</sup> -E	10nM PonA
Q21A	0.32	0.37		
F48A	0.007	0.007		
I51A	0.003	0.004		
V59A	0.47	0.002		
I62A	0.12	0.004		
M93A	0.46	0.07		
R95A	0.4	0.006		
F109A	0.22	0.005		
Y120A	0.001	0.006		
A123F	0.09	0.005		
M125A	0.005	0.007		
M218A	0.001	0.001		
C219A	0.001	0.001		
L223A	0.118	0.007		
L230A	0.001	0.006		
L234A	0.001	0.006		
W238A	0.002	0.013		
R95A/A110P	0.4	0.007		
M218A/C219A	0.001	0.001		
V107I/A110P/R175E			0.345	nd*

\* Not detectable

### EXAMPLE 9

5 This Example describes the introduction of substitution mutations within the *Drosophila melanogaster* EcR (DmEcR) at amino acid residues within the DmEcR ligand binding domain that are analogous to the CfEcR ligand binding domain substitution mutants identified above. Specifically, substitution mutations were introduced at DmEcR amino acid residues 107, 121, 213, and 217 of SEQ ID NO: 2, corresponding to CfEcR amino acid residues 110, 124, 211, and 219 of SEQ ID NO: 1,  
10 respectively.

Applicants mutated amino acid residues predicted to be critical for ecdysteroid binding and created GAL4/mutantDmEcR-CDEF cDNA gene expression cassettes as described in Example 1 above using PCR-mediated site-directed mutagenesis. The mutated and the WT cDNAs corresponding to the various switch constructs outlined above in Examples 1.8 and 1.9 were made and tested in reporter  
15 assays in NIH3T3 cells as described in Example 2. Each GAL4/DmEcR-CDEF construct, VP16/LmUSP-EF, and pFRLUC were transfected into NIH3T3 cells and the transfected cells were treated with 2.5  $\mu$ M GS<sup>TM</sup>-E or Ponasterone A. The cells were harvested and the reporter activity was measured at 48 hours after addition of ligand. The fold induction was calculated by dividing reporter activity in the presence of ligand with the reporter activity in the absence of ligand. From the fold  
20 induction, percent wild-type activity was calculated for each mutant. The results are presented in Table 13.

Table 13. GAL4/DmEcR-CDEF wild-type and Substitution Mutants G121R, G121L, G217A, and C217S tested for transactivation in NIH3T3 cells.

25 Fold increase over WT:

DmEcR-CDEF Mutant	2.5 $\mu$ M Ponasterone A	2.5 $\mu$ M GS <sup>TM</sup> -E
G121R	0.05	0.0075
G121L	0.001	0.008
C217A	0.022	0.008
C217S	0.0064	0.014

As seen in Table 13, both non-steroid and steroid activities were decreased significantly when the DmEcR ligand binding domain was mutated at amino acid residues 121 or 217, indicating that these residues are important residues in the ligand binding pocket of DmEcR.

30 The wild-type and mutant DmEcR-CDEF receptors were also used to make VP16/wild-type or mutantDmEcR-CDEF constructs as described in Example 1.10 and 1.11. VP16DmEcR-CDEF and a 6XE $\beta$ -gal reporter were transfected into L57 cells and the transfected cells were treated with 1  $\mu$ M 20-hydroxyecdysone (20E) or GS<sup>TM</sup>-E. The cells were harvested, lysed and the reporter activity was measured as described above in Example 6. The fold induction was calculated by dividing reporter

activity in the presence of ligand with the reporter activity in the absence of ligand. From the fold induction, percent wild-type activity was calculated for each mutant. The results are presented in Table 14.

5 Table 14. VP16/DmEcR-CDEF wild-type and Substitution Mutants A107P, G121R, G121L, N213A, G217A, and C217S tested for transactivation in insect L57 cells.

Fold increase over WT:

DmEcR-CDEF Mutant	1 $\mu$ M 20-hydroxycodysone	1 $\mu$ M GS <sup>TM</sup> -E
A107P	0.09	0.9
G121R	0.5	0.92
G121L	0.09	0.15
N213A	0.01	0.08
C217A	0.48	0.70
C217S	0.39	0.92

The A107P mutation of DmEcR caused the loss of most steroid activity but had very little effect  
 10 on non-steroid activity. The G121R and C217S mutations of DmEcR resulted in 50% and 61%  
 reductions respectively in steroid activity but minimal effect on non-steroid activity. The C217A  
 mutation of DmEcR resulted in reduced non-steroid and steroid activities, and the DmEcR mutants  
 G121L and N213A lost sensitivity to both steroids and non-steroids, indicating that these residues are  
 involved in binding to both steroids and non-steroids.

15

#### EXAMPLE 10

This Example describes the introduction of substitution mutations within the *Amblyomma*  
*americanum* EcR (AmaEcR) at amino acid residues within the AmaEcR ligand binding domain that are  
 20 analogous to the CfEcR ligand binding domain substitution mutants identified above. Specifically,  
 substitution mutations were introduced at AmaEcR amino acid residues 99 and 113 of SEQ ID NO: 3,  
 corresponding to CfEcR amino acid residues 96 and 110 of SEQ ID NO: 1, respectively.

Applicants mutated amino acid residues predicted to be critical for ecdysteroid binding and  
 created GAL4/mutantAmaEcR-DEF cDNA gene expression cassettes as described in Example 1 above  
 25 using PCR-mediated site-directed mutagenesis. The mutated and the WT cDNAs corresponding to the  
 various switch constructs outlined above in Examples 1.12 and 1.13 were tested in GAL4-driven  
 luciferase reporter assays in NIH3T3 cells as described in Example 2. GAL4/AmaEcR-DEF,  
 VP16LmUSP-EF and pRLUC were transfected into NIH3T3 cells and the transfected cells were treated  
 30 with either 0.2  $\mu$ M Ponasterone A steroid ligand or 1  $\mu$ M GS<sup>TM</sup>-E non-steroid ligand. The cells were  
 harvested and the reporter activity was measured at 48 hours after addition of ligand. The fold induction  
 was calculated by dividing reporter activity in the presence of ligand with the reporter activity in the  
 absence of ligand. From the fold induction, percent wild-type activity was calculated for each mutant.  
 The results are presented in Table 15.

Table 15. AmaxEcR-DEF Substitution Mutants at G99 and A113 in NIH3T3 cells.

Fold increase over WT:

AmaxEcR-DEF Mutant	0.2 $\mu$ M Ponasterone A	1 $\mu$ M GS <sup>TM</sup> -E
G99A	1.29	1.22
A113P	0.11	0.01

- 5 The G99A mutation of AmaxEcR at the homologous amino acid residue position of V96 in CBEcR resulted in increased steroid and non-steroid activities. The A113P mutation of AmaxEcR at the homologous amino acid residue position of A110 of CBEcR caused the loss of most steroid activity and essentially eliminated non-steroid activity.

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It is further to be understood that all base sizes or amino acid sizes, and all molecular weight or molecular mass values, given for nucleic acids or polypeptides are approximate, and are provided for  
15 description.

CLAIMS:

1. A gene expression modulation system comprising:
  - a) a first gene expression cassette that is capable of being expressed in a host cell comprising a polynucleotide that encodes a first polypeptide comprising:
    - i) a DNA-binding domain that recognizes a response element associated with a gene whose expression is to be modulated; and
    - ii) a nuclear receptor ligand binding domain; and
  - b) a second gene expression cassette that is capable of being expressed in the host cell comprising a polynucleotide that encodes a second polypeptide comprising:
    - i) a transactivation domain; and
    - ii) a nuclear receptor ligand binding domain

wherein one of the nuclear receptor ligand binding domains is an ecdysone receptor ligand binding domain comprising a substitution mutation,

wherein the ecdysone receptor ligand binding domain is encoded by a polynucleotide comprising a codon mutation that results in a substitution of an amino acid residue, wherein the amino acid residue is at position 99 or 113 of SEQ ID NO: 3.

2. The gene expression modulation system according to claim 1, wherein one of the the nuclear receptor ligand binding domains is selected from the group consisting of a vertebrate retinoid X receptor ligand binding domain, an invertebrate retinoid X receptor ligand binding domain, an ultraspiracle protein ligand binding domain, and a chimeric ligand binding domain comprising two polypeptide fragments, wherein the first polypeptide fragment is from a vertebrate retinoid X receptor ligand binding domain, an invertebrate retinoid X receptor ligand binding domain, or an ultraspiracle protein ligand binding domain, and the second polypeptide fragment is from a different vertebrate retinoid X receptor ligand binding domain, invertebrate retinoid X receptor ligand binding domain, or ultraspiracle protein ligand binding domain.

3. The gene expression modulation system according to claim 1 or 2, wherein the substitution mutation is G99A or A113P of SEQ ID NO: 3.

4. The gene expression modulation system according to any one of claims 1 to 3, wherein the DNA-binding domain is selected from the group consisting of an ecdysone receptor DNA-binding domain, a GAL4 DNA-binding domain, and a LexA DNA-binding domain.

5. The gene expression modulation system according to any one of claims 1 to 4, wherein the transactivation domain is selected from the group consisting of an ecdysone receptor transactivation domain, a VP16 transactivation domain, a B42 acidic activator transactivation domain, and a p65 transactivation domain.

6. A gene expression cassette comprising a polynucleotide that encodes a polypeptide selected from the group consisting of:

a) a polypeptide comprising a transactivation domain, a DNA-binding domain, and an ecdysone receptor ligand binding domain comprising a substitution mutation,

b) a polypeptide comprising a DNA-binding domain and an ecdysone receptor ligand binding domain comprising a substitution mutation, and

c) a polypeptide comprising a transactivation domain and an ecdysone receptor ligand binding domain comprising a substitution mutation,

wherein the ecdysone receptor ligand binding domain is encoded by a polynucleotide comprising a codon mutation that results in a substitution of an amino acid residue, wherein the amino acid residue is at position 99 or 113 of SEQ ID NO: 3.

7. An isolated polynucleotide encoding an ecdysone receptor ligand binding domain comprising a substitution mutation, wherein the isolated polynucleotide comprises a codon mutation that results in a substitution of an amino acid residue at position 99 or 113 of SEQ ID NO: 3.

8. The isolated polynucleotide according to claim 7, wherein the codon mutation results in substitution G99A or A113P of SEQ ID NO: 3.

9. The isolated polynucleotide according to claim 7, wherein the ecdysone receptor ligand binding domain lacks ecdysone binding activity and the substitution mutation is at amino acid residue 113 of SEQ ID NO: 3.

10. The isolated polynucleotide according to claim 9, wherein the substitution mutation is A113P of SEQ ID NO: 3.

11. An expression vector comprising the isolated polynucleotide of claim 7 operatively linked to a transcription regulatory element.

12. An isolated polypeptide encoded by the isolated polynucleotide according to claim 7.

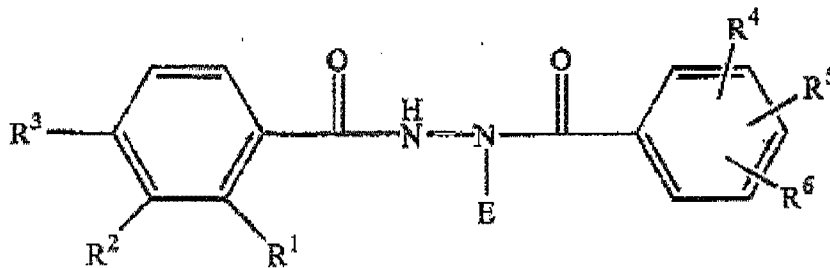
13. The isolated polypeptide according to claim 12, wherein the substitution mutation is G99A or A113P of SEQ ID NO: 3.

14. Use of the gene expression modulation system according to any one of claims 1 to 5 in modulating the expression of a gene in a host cell in combination with a ligand, wherein the gene to be modulated is a component of a gene expression cassette comprising:

- i) a response element recognized by the DNA binding domain;
- ii) a promoter that is activated by the transactivation domain; and
- iii) a gene whose expression is to be modulated.

15. The use according to claim 14, wherein the ligand is

a) a compound of the formula:



wherein:

E is a (C<sub>4</sub>-C<sub>6</sub>)alkyl containing a tertiary carbon or a cyano(C<sub>3</sub>-C<sub>3</sub>)alkyl containing a tertiary carbon;

R<sup>1</sup> is H, Me, Et, i-Pr, F, formyl, CF<sub>3</sub>, CHF<sub>2</sub>, CHCl<sub>2</sub>, CH<sub>2</sub>F, CH<sub>2</sub>Cl, CH<sub>2</sub>OH, CH<sub>2</sub>OMe, CH<sub>2</sub>CN, CN, C≡CH, 1-propynyl, 2-propynyl, vinyl, OH, OMe, OEt, cyclopropyl, CF<sub>2</sub>CF<sub>3</sub>, CH=CHCN, allyl, azido, SCN, or SCHF<sub>2</sub>;

R<sup>2</sup> is H, Me, Et, n-Pr, i-Pr, formyl, CF<sub>3</sub>, CHF<sub>2</sub>, CHCl<sub>2</sub>, CH<sub>2</sub>F, CH<sub>2</sub>Cl, CH<sub>2</sub>OH, CH<sub>2</sub>OMe, CH<sub>2</sub>CN, CN, C≡CH, 1-propynyl, 2-propynyl, vinyl, Ac, F, Cl, OH, OMe, OEt, O-n-Pr, OAc, NMe<sub>2</sub>, NEt<sub>2</sub>, SMe, SEt, SOCF<sub>3</sub>, OCF<sub>2</sub>CF<sub>2</sub>H, COEt, cyclopropyl, CF<sub>2</sub>CF<sub>3</sub>, CH=CHCN, allyl, azido, OCF<sub>3</sub>, OCHF<sub>2</sub>, O-i-Pr, SCN, SCHF<sub>2</sub>, SOMe, NH-CN, or joined with R<sup>3</sup> and the phenyl carbons to which R<sup>2</sup> and R<sup>3</sup> are attached to form an ethylenedioxy, a dihydrofuryl ring with the oxygen adjacent to a phenyl carbon, or a dihydropyryl ring with the oxygen adjacent to a phenyl carbon;

R<sup>3</sup> is H, Et, or joined with R<sup>2</sup> and the phenyl carbons to which R<sup>2</sup> and R<sup>3</sup> are attached to form an ethylenedioxy, a dihydrofuryl ring with the oxygen adjacent to a phenyl carbon, or a dihydropyryl ring with the oxygen adjacent to a phenyl carbon;

R<sup>4</sup>, R<sup>5</sup>, and R<sup>6</sup> are independently H, Me, Et, F, Cl, Br, formyl, CF<sub>3</sub>, CHF<sub>2</sub>, CHCl<sub>2</sub>, CH<sub>2</sub>F, CH<sub>2</sub>Cl, CH<sub>2</sub>OH, CN, C≡CH, 1-propynyl, 2-propynyl, vinyl, OMe, OEt, SMe, or SEt; or

b) an ecdysone, 20-hydroxyecdysone, ponasterone A, muristerone A, an oxysterol, a 22(R)hydroxycholesterol, 24(S)hydroxycholesterol, 25-epoxycholesterol, T0901317, 5-alpha-6-alpha-epoxycholesterol-3-sulfate, 7-ketocholesterol-3-sulfate, farnesol, a bile acid, a 1,1-biphosphonate ester, or a Juvenile hormone III.

16. The use according to claim 14, wherein 9-cis-retinoic acid or a synthetic analog of a retinoic acid is used in combination with the ligand.

17. An isolated host cell comprising the gene expression modulation system according to any one of claims 1 to 5.

18. The gene expression cassette of claim 6, wherein the codon mutation results in substitution mutation G99A or A113P of SEQ ID NO: 3.

19. The gene expression cassette of claim 6, wherein the ecdysone receptor ligand binding domain lacks ecdysone binding activity and the substitution mutation is at amino acid position 113 of SEQ ID NO: 3.

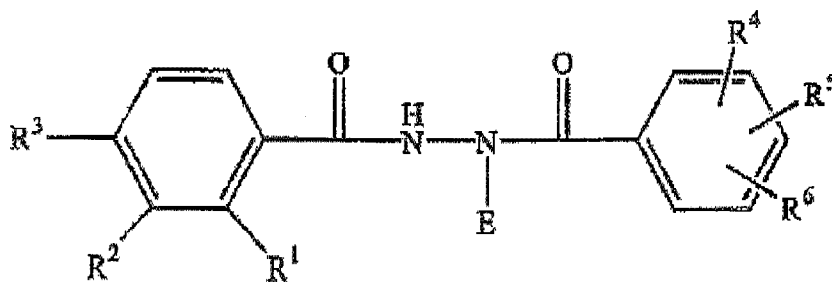
20. The gene expression cassette of claim 19, wherein the substitution mutation is A113P of SEQ ID NO: 3.

21. An expression vector comprising the gene expression cassette of claim 6 operatively linked to a transcription regulatory element.

22. Use of the gene expression cassette according to claim 6 in modulating the expression of a gene in a host cell in combination with a ligand, wherein the gene to be modulated is a component of a gene expression cassette comprising:

- i) a response element recognized by the DNA binding domain;
- ii) a promoter that is activated by the transactivation domain; and
- iii) a gene whose expression is to be modulated.

23. The use according to claim 22, wherein the ligand is  
a) a compound of the formula:



wherein:

E is a (C<sub>4</sub>-C<sub>6</sub>)alkyl containing a tertiary carbon or a cyano(C<sub>3</sub>-C<sub>5</sub>)alkyl containing a tertiary carbon;

R<sup>1</sup> is H, Me, Et, i-Pr, F, formyl, CF<sub>3</sub>, CHF<sub>2</sub>, CHCl<sub>2</sub>, CH<sub>2</sub>F, CH<sub>2</sub>Cl, CH<sub>2</sub>OH, CH<sub>2</sub>OMe, CH<sub>2</sub>CN, CN, C≡CH, 1-propynyl, 2-propynyl, vinyl, OH, OMe, OEt, cyclopropyl, CF<sub>2</sub>CF<sub>3</sub>, CH=CHCN, allyl, azido, SCN, or SCHF<sub>2</sub>;

R<sup>2</sup> is H, Me, Et, n-Pr, i-Pr, formyl, CF<sub>3</sub>, CHF<sub>2</sub>, CHCl<sub>2</sub>, CH<sub>2</sub>F, CH<sub>2</sub>Cl, CH<sub>2</sub>OH, CH<sub>2</sub>OMe, CH<sub>2</sub>CN, CN, C≡CH, 1-propynyl, 2-propynyl, vinyl, Ac, F, Cl, OH, OMe, OEt, O-n-Pr, OAc, NMe<sub>2</sub>, NEt<sub>2</sub>, SMe, SEt, SOCF<sub>3</sub>, CF<sub>2</sub>CF<sub>2</sub>H, COEt, cyclopropyl, CF<sub>2</sub>CF<sub>3</sub>, CH=CHCN, allyl, azido, OCF<sub>3</sub>, OCHF<sub>2</sub>, O-i-Pr, SCN, SCHF<sub>2</sub>, SMe, NH-CN, or joined with R<sup>3</sup> and the phenyl carbons to which R<sup>2</sup> and R<sup>3</sup> are attached to form an ethylenedioxy, a dihydrofuryl ring with the oxygen adjacent to a phenyl carbon, or a dihydropyryl ring with the oxygen adjacent to a phenyl carbon;

R<sup>3</sup> is H, Et, or joined with R<sup>2</sup> and the phenyl carbons to which R<sup>2</sup> and R<sup>3</sup> are attached to form an ethylenedioxy, a dihydrofuryl ring with the oxygen adjacent to a phenyl carbon, or a dihydropyryl ring with the oxygen adjacent to a phenyl carbon;

R<sup>4</sup>, R<sup>5</sup>, and R<sup>6</sup> are independently H, Me, Et, F, Cl, Br, formyl, CF<sub>3</sub>, CHF<sub>2</sub>, CHCl<sub>2</sub>, CH<sub>2</sub>F, CH<sub>2</sub>Cl, CH<sub>2</sub>OH, CN, C≡CH, 1-propynyl, 2-propynyl, vinyl, OMe, OEt, SMe, or SEt; or

b) an ecdysone, 20-hydroxyecdysone, ponasterone A, muristerone A, an oxysterol, a 22(R)hydroxycholesterol, 24(S)hydroxycholesterol, 25-epoxycholesterol, T0901317, 5-alpha-6-alpha-epoxycholesterol-3-sulfate, 7-ketocholesterol-3-sulfate, farnesol, a bile acid, a 1,1-biphosphonate ester, or a Juvenile hormone III.

24. The use according to claim 22, wherein 9-cis-retinoic acid or a synthetic analog of a retinoic acid is used in combination with the ligand.

25. An isolated host cell comprising the gene expression cassette according to claim 6.

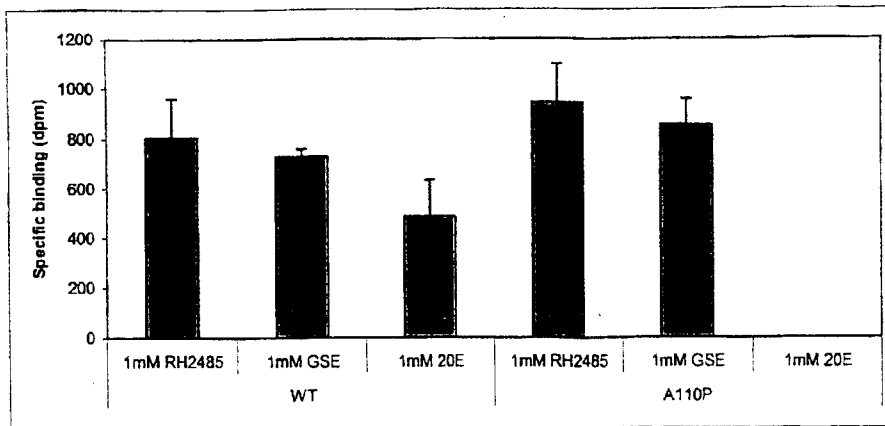


Figure 1

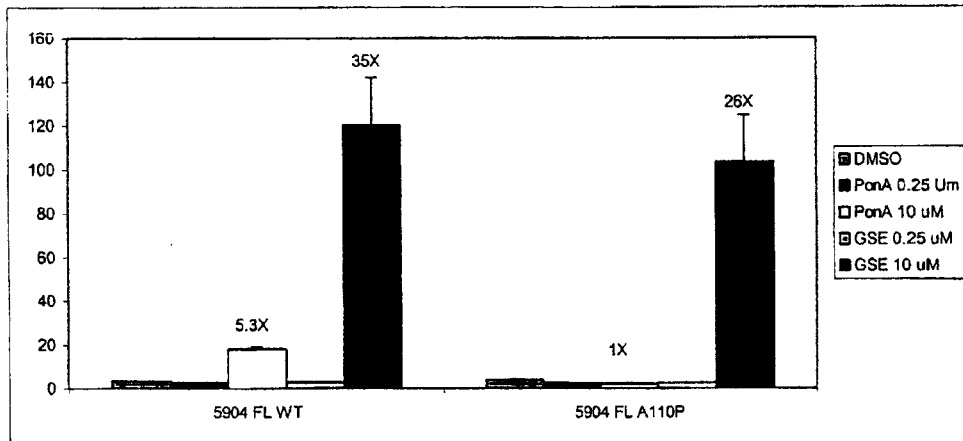


Figure 2

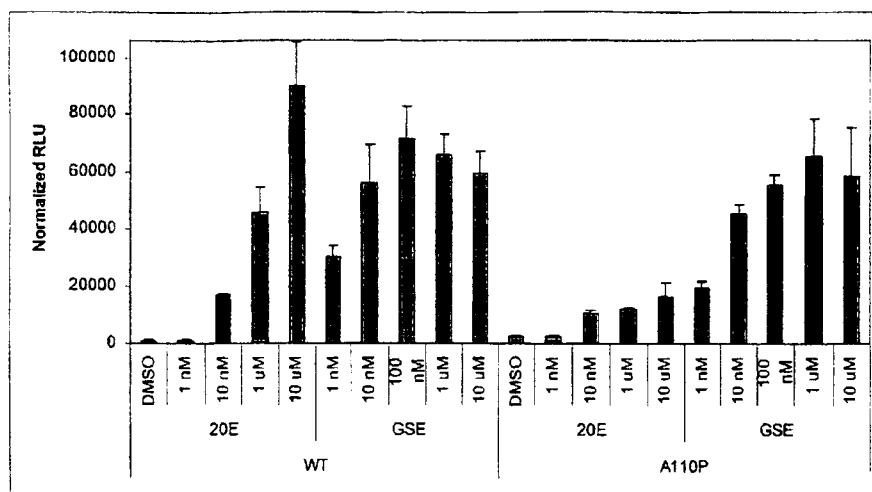


Figure 3

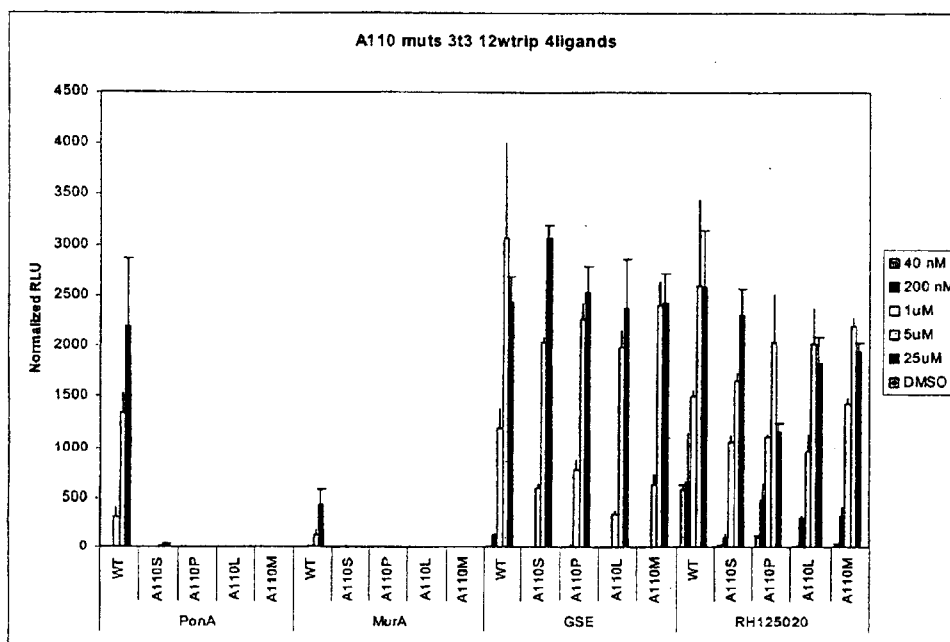


Figure 4

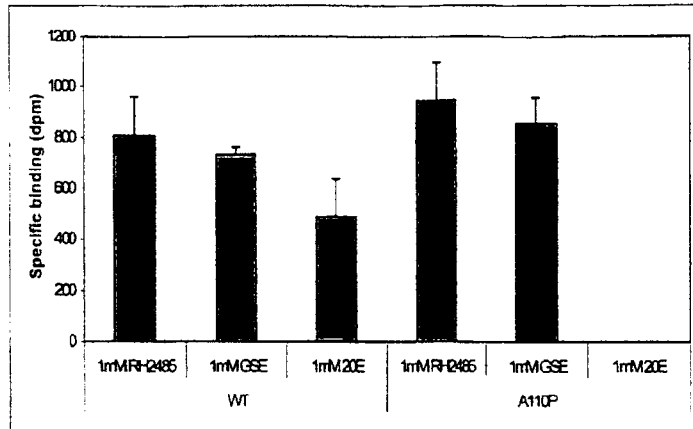


Figure 5

**Non-steroid (RH2485) binding by A110 mutants**

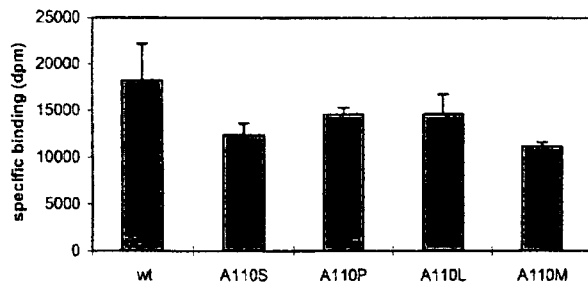


Figure 6